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An approach to salmon farming in Norway

A future for land based salmon farming?

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Abstract

The aim of this thesis is to give an overview over the salmon farming industry in Norway. It presents some theory around production- and investment costs associated with land based- and sea based fish farming, as well as challenges around environmental issues, technology, fish feed etc. Several production concepts such as open cages in the sea, cages offshore, closed operations in the sea, both exposed and protected and land based production sites are available today, and the characteristics and issues associated with them are discussed. Important is also the production process – from birth to slaughtering. Especially the field of slaughtering is of noticeable importance since there are in general a widespread usage of inhumane slaughter methods. A vast amount of salmon produced throughout the world are killed with little or no consideration for their welfare. In a daily operation of a production site a necessary component is fish feed. It does not only help the salmon to grow, but also adds omega-3 and other important ingredients beneficial to consumers. As any other field within fish farming it is dynamic and constantly changing to meet requirements. Crucial ingredients that made up a huge proportion of the feed a few years ago have to yield for other substitutes.

In the analysis of how Norway's position as a leading country within aquaculture could be challenged a three – step model can be applied. In the first step the current production concepts' possibilities will be evaluated along the possibility of technological success and what circumstances in society that can influence these concepts. In the second step the economic side of the concepts is evaluated. In the last step, the possibility of success based on previous factors will be summed up, and how this will inflict the Norwegian fish farming industry and whether the new technology can threaten the position and competitiveness of Norway's industry.

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Contents

1. Introduction and motivation

Aquaculture of salmon started back in the 19th century in the UK. Then it was more as a support for the anglers where parr (juvenile salmon) was set out in order to increase the salmon stock. The fish farming industry began in Norway in the 1960s. It quickly became a success, and more countries followed suit such as Scotland, Ireland, Canada and Chile. Much of Norway's success is due to deep sheltered sites, stable temperatures, a salmon stock that matures late, governmental support and investment. In Ireland fish farming has been limited due to local opposition and shallow waters. A major producer, besides Norway, is Chile. They are able to compete with Norway because of low production costs and great supply of fishmeal and fish oil (Food and Agriculture Organization of the United Nations, 2016).

Since the birth of industrialized fishing global demand for fish has rapidly increased and will continue to increase. The traditional way of fishing through capture fisheries has more or less flattened out. This is due to the sustainability of the wild fish stock. This is underlined by these facts: Of the marine fish stocks 3 % are underexploited, 20 % are moderately exploited, 52 % are fully exploited, 17 % are overexploited, 7 % are depleted and 1 % are recovering from depletion (United Nations Food and Agriculture Organization). So, in order to keep the stock on a sustainable level capture fisheries can only provide 80 – 100 million tons per year (Canadian Aquaculture Industry Alliance, 2016).

Aquaculture production, i.e. fish farming, has grown steadily over the last 45 years. The annual growth rate has been as high as 9 %, meaning it is the fastest growing food producing system (Canadian Aquaculture Industry Alliance, 2016). This is needed in order to cope with world population growth and higher fish consumption per capita. The fish consumption per capita in the world is more or less doubled from 9,9 kg in the 1960s to 19,2 kg in 2012. Important reasons for this are e.g. the combination of population growth with rising incomes and urbanization (Food and Agriculture Organization of the United Nations, 2016). Two illustrations are given below to display both the farmed and wild caught of fish in general and salmon, respectively.

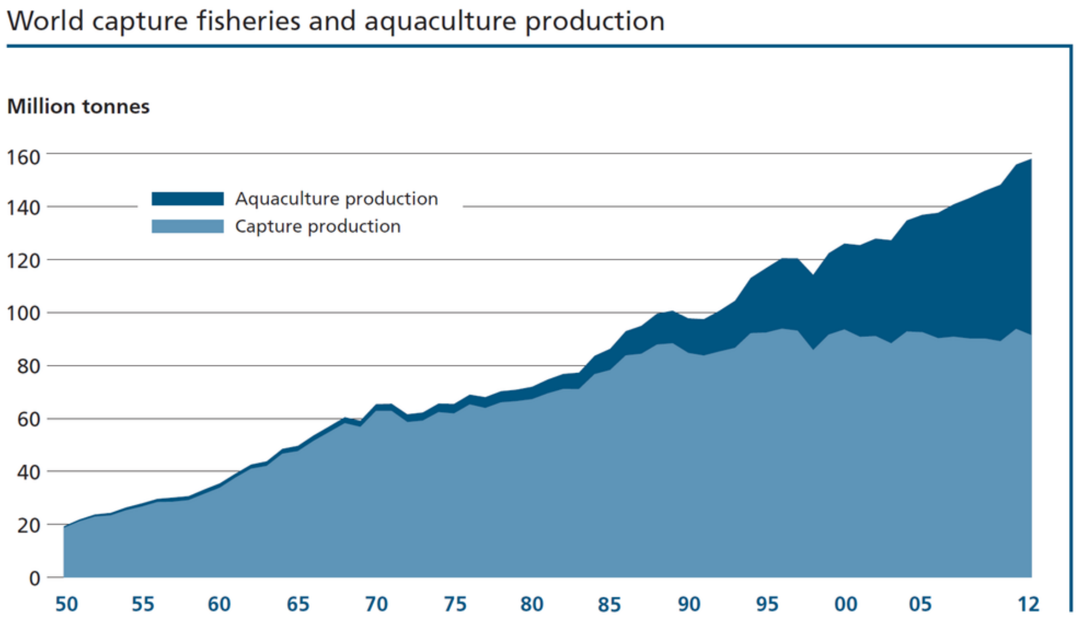

Figure 1: World capture fisheries and aquaculture production. Retrieved from (Amy's Island Seafood, 2014).

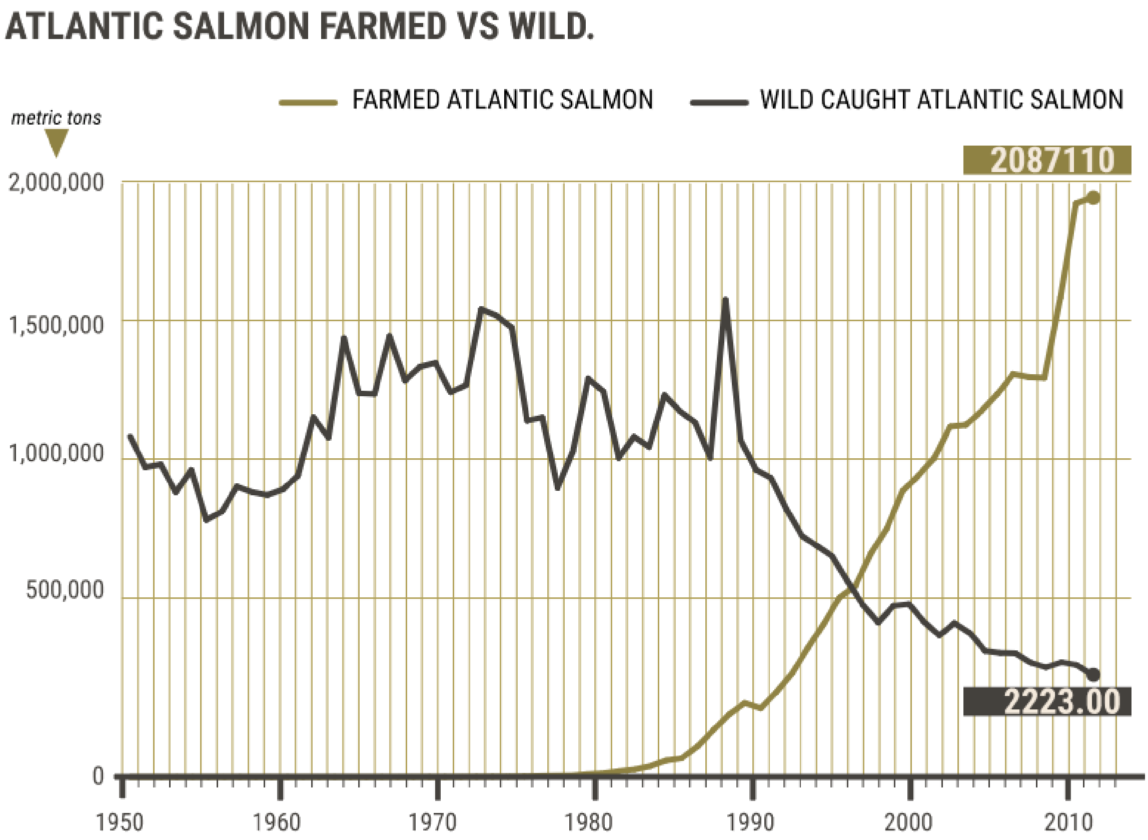

Figure 2: Atlantic salmon vs wild. Retrieved from (What are the fish telling us, 2012).

As seen from the illustrations fish farming is increasing, and especially salmon farming has shown an impressive development. The capture production is fairly steady, and for salmon it is even decreasing.

One major contributor to the increased supply of farmed fish is China. The per capita consumption in China surged up to about 35,1 kg in 2010. In general, the per capita consumption in developed regions is higher than in developing regions, but the difference has become smaller as time has progressed. A trend in the developed part of the world is continuously lower domestic production of fish combined with steady demand. This gap must therefore be compensated with increased imports.

2. Problem statement

This thesis presents some theory around production- and investment costs associated with land based fish farming, as well as challenges around environmental issues, technology, fish feed etc. In the last section, a series of questions are asked to several companies within the Norwegian fish farming industry. The goal is to establish whether there is some discrepancy between theory and what the industry itself has experienced, and how they view the future of land based fish farming in Norway.

3. Salmon – from birth to slaughtering

3.1. The production process

A salmon is a type of an anadromous fish meaning it is born in freshwater. The only time it goes back to freshwater is to lay eggs. Rest of its life it spends in the sea. The production process consists of two stages: The first one in freshwater hatchery and the second in seawater (Food and Agriculture Organization of the United Nations, 2016).

First the mature fish ready to breed, also called broodstock/broodfish, are selected from sea cages. A sea cage is the net used to encompass the fish in order to keep them confined in a sealed-off space. They are moved into freshwater tanks. The next step is to strip the eggs out of the salmon. This is done about two months after the broodstock is placed in freshwater tanks. Then a meticulous process of handling the eggs follow. They are cleaned and fertilized with milt. After fertilization the eggs start to swell. When the eggs are fully swelled they have hardened and are disinfected. Hopefully, a great amount of the eggs is now fertilized. The unfertilized eggs are removed by pouring the eggs in trays or through silo systems (Food and Agriculture Organization of the United Nations, 2016).

The fertilized eggs are moved to hatchery trays or tanks which are kept in a dark environment. The optimal condition for the incubation process and the newly hatched alevins is a temperature of below 10°C. An alevin is another word for a newly hatched salmon with the characteristic yolk sac still attached to it. This yolk sac containing important nutrients is then consumed by the alevin. Now the alevins will swim from the bottom up towards the water surface and this signals readiness for the first regular feeding. The first feeding is either done in the hatchery trays or in tanks which are inhabited by late alevins. The feeding process continues until the alevins weigh about six grams. At this stage they are referred to as parr. Again the fish product is moved into larger tanks or even to sea cages. They continue to gain weight until they reach a weight of about 60 – 80 grams. Now they have reached a stage where they are classified as smolt. In this process, the smoltification process, they have been through a physiological change which enables them to survive in seawater. They now enter the second step in the production process which is living in seawater in net pens. The smolt is transferred to the net pens in tanks specifically designed for this task i.e. by helicopter, road or boat. These net pens are anchored to the seabed and forms a cage which may have different designs and sizes. The cages again form a sea site if they are grouped together. A critical point is to choose the appropriate sea site. Several factors have to be brought into consideration such as water temperature, salinity, flow and exchange rates, farms and wild fisheries nearby and local regulations. The salmon is kept in the cages for 1 to 2 years depending on desired size. The lower limit of harvesting is about 2 kg, but the market weight is considered to be 4,5 to 5,5 kg. Usually the sea sites are based on breeding of one generation at a time. Normally the sea sites are left unused for about 6 weeks before the next generation of smolt is introduced (Food and Agriculture Organization of the United Nations, 2016).

When the salmon are ready to be harvested, they are usually starved for a couple of days in advance. It is important that the harvesting process is as stress-free as possible, because a high stress level could damage the quality of the flesh. The fish ready to be slaughtered are typically pumped from the holding pen to a well boat. The well boat brings the fish from the holding pen alive to the slaughter plant (Food and Agriculture Organization of the United Nations, 2016).

3.2. Fish feed

A crucial part of the whole production process is the feeding of the salmon. Two of the most important ingredients in salmon feeds are fishmeal and fish oil which are produced from small, pelagic fish such as herring, anchovies, sardines, capelin, mackerel etc., and they make up about 75 % of fishmeal and fish oil. An important reason that pelagic fish is such a substantial ingredient are their capability of fast reproduction and stock replenishment. The last 25 % are waste and scraps from fish processed for human consumption. Fishmeal and fish oil mostly come from industrial fisheries, also known as reduction fisheries, in South America. The term reduction fisheries is due to the stepwise processing of pelagic fish into fishmeal and fish oil. Chile and Peru alone make up 40 % of the global production of fishmeal and fish oil. The US is also a producer of fishmeal and fish oil, but they are a small net producer compared with Chile and Peru (NOOA Fisheries, 2014).

Fishmeal and fish oil have a prominent position in the diet for farmed salmon due to the about 40 essential nutrients that make up a healthy diet. This is not exclusively for fish, but for all animals. Usually fishmeal and fish oil were important ingredients in the diet of swine and poultry, but as fish farming is becoming increasingly more important a larger share of fishmeal and fish oil is used in aquatic feeds. With essential nutrients we divide into vitamins, essential fatty acids, minerals and essential amino acids. Fishmeal is an important source of high – quality protein. Fish oil contains omega-3 fatty acids such as eicosapentaenoic (EPA) and docosahexaenoic (DHA) which are not produced by the fish themselves, but are synthesized by plankton (marine algae and microbes). Smaller fish then consume plankton. In the future we might be able to produce the omega-3 acids with help from microalgae production (Naylor et al., 2009, p.15, 107). Since fishmeal and fish oil are highly beneficial in the fish farming industry there is a high willingness to pay amongst the producers. It is still possible to achieve the effects from the essential nutrients with other replacement ingredients. As mentioned later ingredients can be substituted for different reasons (NOOA Fisheries, 2014).

The position of fishmeal and fish oil may not be so prominent in the future as there is an increasing pressure of substituting the conventional supplies with vegetable protein and other oil sources. The fact is, in e.g. Norway, there has been a change. About 70 % of a pellet consist of vegetable ingredients and about 30 % of marine resources such as fishmeal and fish oil (Laksefakta, 2016). In addition, it is also a question of social matter regarding the fish feed. Since parts of the pellets used to feed the salmon are made from small, pelagic fish this could just as easily been used for human consumption instead. Especially in third world countries this a big issue. Instead of using it as a mean of enhancing value of farmed salmon it could be a cheap alternative for poor people. It is also pressure on already existing fish stocks which can increase if the growing fish farming industry does not take appropriate actions. The removal of small, pelagic fish in great quantities can also destroy or make the food chain in the ocean more vulnerable. Another factor that push the fish farming industry in substituting fishmeal and fish oil is purchase price. The reduction fisheries sector is highly regulated through management where quotas and catch limits are two of the most important instruments. Consequently, supply is rather constant or more or less declining and combined with increased demand and the growth of the aquaculture industry prices will be pushed upwards (Food and Agriculture Organization of the United Nations, 2016) (NOOA Fisheries, 2014). According to the bank Rabobank fishmeal will not be a commodity in the long run, because of the demand and supply effects making it a "high-price" strategic marine protein. This is pushing fishmeal to become a strategic ingredient in the sense when no other protein substitutes can be used. This is already become apparent in fish oil. Supply of fishmeal can also suffer quite a lot in the short run. An example of this is a phenomenon called El Nino. A part of the Peruvian fishing season was cancelled because of El Nino leading to a shortage of fishmeal in 2014/15 (Villegas, 2015). The Peruvian fisheries authority, Produce, stated "The Ministry of Production maintains the closure of the fishery Stock Norte-Center anchoveta until environmental conditions have returned to normal and the anchovy evidences a strong recovery" (Undercurrent News, 2014). Since then the conditions are back to normal. It is expected that the underlying long term trend in the fishmeal price will increase, and show peaks caused by short term events like El Nino. The declining supply of fishmeal observed is an effect of lower catch of small, pelagic fish used to produce fishmeal, and the fact that more is ending up as direct human consumption. The fish types experiencing a decline are for instance anchovies in Peru, sardines in Chile and blue whiting and capelin in Europe. Some pelagic fish stocks have been overexploited and time is needed to fully recover. The harvest levels in the 1990s and early 2000s will probably not be reached again.

Figure 3: Declining global fishmeal production, 1997-2015. Retrieved from (Rabobank, Kontali, IFFO, 2015).

The fact that direct human consumption is becoming more important is underlined by producers in Chile, Peru and Europe investing in production facilities and infrastructure. The markets for pelagic fish are found in Africa, Latin America and Asia. These sources of protein are sought after, because of their low acquisition cost. In fact, protein from pelagics is the cheapest in the world amongst all animal protein. Further increase in the pelagics demand is expected considering population growth and increased price on competing protein sources. It is also possible to produce omega-3 capsules and similar products using pelagic fish as main ingredient. This could be an alternative to utilizing pelagics as a mean of enhancing the value of farmed salmon (Villegas, 2015).

The market for fish oil is also an interesting market undergoing changes. Fish oil is a highly valuable ingredient in fish feed, because it contributes largely with omega-3 unsaturated fatty acids. Fish oil is of great importance in the aquaculture industry, and their demand makes up a total of 74 % of available fish oil supply. Most of the acquired fish oil is used in salmon feed, and the salmons' diet consists of 7 – 9 % fish oil. The critical limit without compromising the nutritious quality of the fish feed is around 5 – 6 %. Again, this could impact health effects of eating salmon since fish oil is an important source of omega-3 unsaturated fatty acids. As mentioned earlier the direct human consumption market is important. The profitability of using fish oil toward this market is higher than using it as fish feed. This is proven by the figures showing that fish oil directed for human consumption yields 400 – 600 UDS/tons in premium in comparison with fish oil graded for fish feed. Since the competition for fish oil is tough in the aquaculture industry different substitutes in great supplies are gaining importance such as soybean and rapeseed. This diagram shows the price dynamics of fish oil and soy oil. Up until 2012 the prices were correlated, but dynamics changed. Factors such as hardened competition and stock size have played a key role.

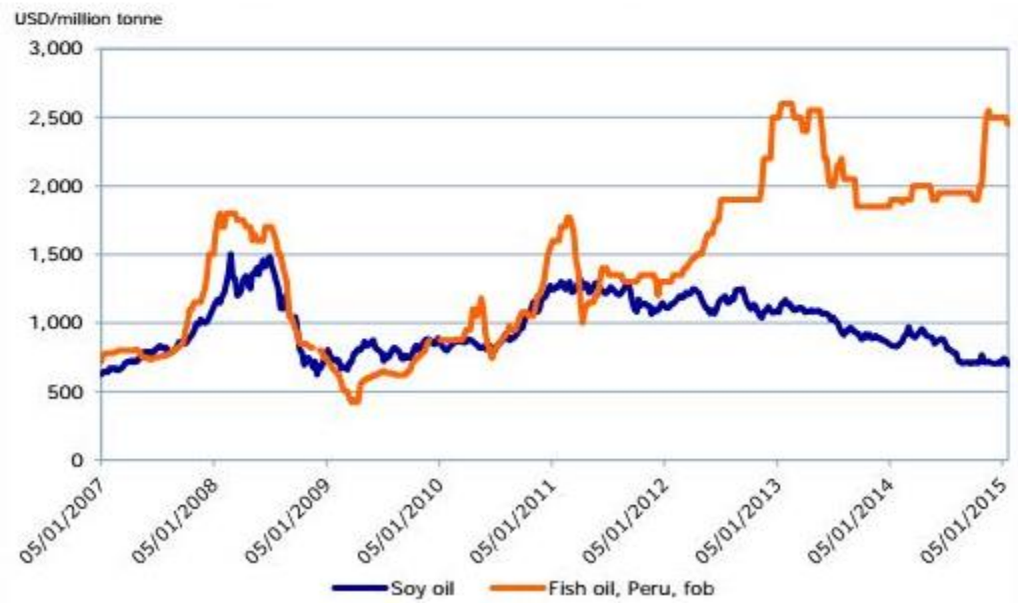

Figure 4: Fish oil and soy oil prices are no longer correlated, 2007-2015. Retrieved from (Oilworld, Bloomberg, 2015).

Referring back to the fishmeal market the same trend is becoming apparent. The same supply dynamics is present in this market as in the fish oil market.

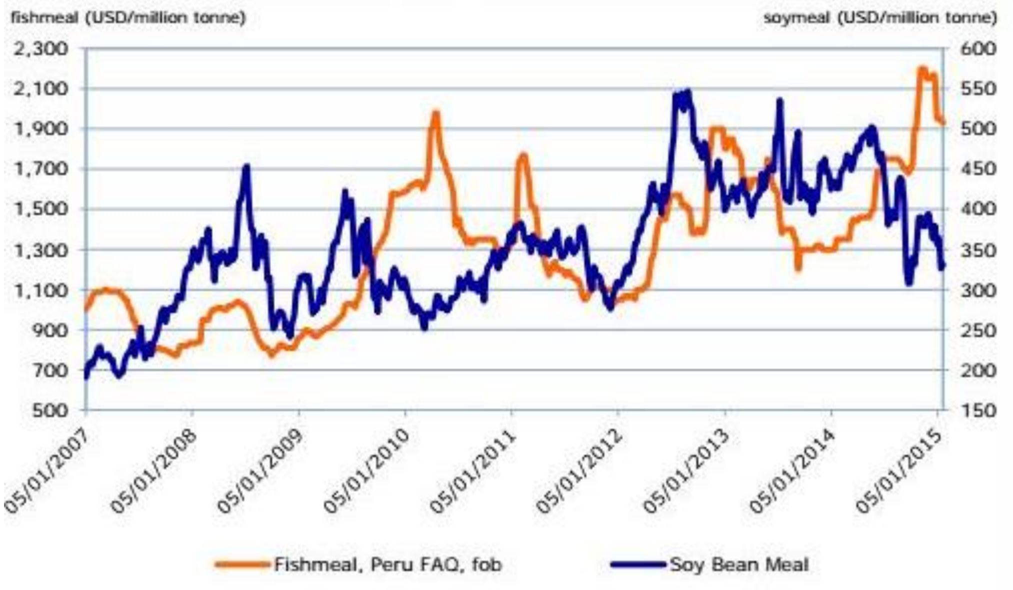

Figure 5: Fishmeal and soymeal prices, 2007-2015. Retrieved from (Oilworld, Bloomberg, 2015).

As earlier stated, the pellets used as feed contains wild fish, but also animal and plant protein. The two most important ingredients, fishmeal and fish oil, can be replaced by a number of substitutes. Fish oil can be replaced with linseed, sunflower, rapeseed, soybean, olive and palm oils. Regarding fishmeal, it can be replaced with foodstuff from land based animals such as meat and bone meal, blood meal and byproducts from poultry (Fry et al, 2016). However, it is important that the substitution of ingredients does not compromise the final product. A consequence might be a change in the omega-3 content or overall content. This might be a non – optimal solution for the consumers. The way salmon are being fed is also changing. Methods of feeding and technology have advanced over the years. Many companies within the fish farming industry use computers to automate feeding systems. The computers are also able to detect when the fish have had enough food. This system makes sure that there is no feed wastage and that the salmon is not overfed. The pellets are not just for the purpose of gaining weight. They also have to contain carotenoid pigments in order for the salmon to get the right flesh color demanded by the market (Food and Agriculture Organization of the United Nations, 2016).

3.3. The feed conversion ratio

Some interesting measurements are related to how we utilize fish feed and how much wild fish is needed to produce farmed fish. It is also of importance how the efficiency looks compared with e.g. cows and poultry.

The feed conversion ratio (FCR) is a tool to describe the efficiency of how much input (feed) is needed to produce 1 kg of fish. The amount of feed necessary to produce 1 kg of output varies across fish species and animals in general. The FCR for different animals shows that there is a great variance in efficiency. Salmon has a quite high efficiency with a FCR of 1,2 which means in order to produce 1 kg of farmed salmon 1,2 kg of fish feed is required. Compared with poultry, pig, sheep and cattle the FCR is around 2, 3, 8 and 8, respectively. Although this is a fact with modifications since the different feeds for different animals have various qualities due to energy density and composition. There are several factors contributing to the low FCR for farmed salmon. The first one is that salmon feed delivers on high energy content. Second is that salmon in fact are able to utilize the protein in the feed much better than other animals. For salmon the utilization rate could go up to 45 %, whereas for poultry and pig the numbers are 18 % and 13 %, respectively. This means that salmon is better able to transform protein in the fish feed to meat. At last, salmon have an advantage over land animals referring to energy usage. They use little energy to support themselves as they are floating about in the water, and to keep their bodily functions at a stable level. This is mostly a consequence of their body temperature being close to the ambient temperature (6 – 16 °C) meaning the temperature of the surroundings. Salmon will therefore experience less heat loss than land animals since they already are cold-blooded (5m Publishing, 2011). Further, it is possible to divide FCR in an economical and biological part. According to (Aquamedia, 2006) "biological FCR is the net amount of feed used to produce one kg of fish, while the economic FCR takes into account all the feed used, meaning that the effects of feed losses and mortalities, for example, are included".

The second interesting measurement is the fish in-fish out ratio, just shortened to FIFO. The FIFO ratio indicates how many tons of wild fish needed to produce a ton of farmed salmon. The number of tons it takes varies quite substantially with a FIFO ratio from 3:1 to 10:1. In a report from (Tacon & Metian, 2008) the ratio is concluded to be 4,9:1. This figure, however, has been criticized by the International Fishmeal and Fish Oil Organization (IFFO). They have criticized the underlying assumptions and the fact that not all of the fishmeal and fish oil come from slaughtering of wild fish, but also by – products and trimmings. Looking at the numbers from (Tacon & Metian, 2008) we have the following figures. Assumptions from (Tacon & Metian, 2008) are highlighted in green.

SALMON

Wt of pelagic fish at start kg	**1000**
Wt of Fishmeal kg	225
Wt of fish oil kg	50
How much salmon do I produce?	
Fish oil in the diet %	**20**
Fishmeal in the diet %	**30**
Requirement of oil kg	**50**
Requirement of fishmeal kg	**75**
Amount of feed that can be produced kg	**250**
FCR	**1.25**
Salmon Produced kg	**200**
FIFO	**5.0**
Fishmeal left over kg	**150**

Figure 6: Calculations of key figures. Retrieved from (Tacon & Metian, 2008)

It is assumed that 1000 kg of wild fish yields 225 kg of fishmeal and 50 kg of fish oil. At that point in time where the analysis was conducted amount of fish oil and fishmeal in the diet were 20 % and 30 %, respectively. Thus, by using all of the fish oil of 50 kg we get 250 kg of farmed salmon. With a FCR of 1,25 we have 200 kg of farmed salmon as end product. The corresponding FIFO ratio is therefore 5:1 (1000:200), meaning of the initial 1000 kg of wild fish about 200 kg of farmed fish can be produced. This fits well with the ratio of 4,9:1. In the example there is also an excess amount of fishmeal as all of the fish oil is used. This is considered as waste in this example and is obviously a weakness. This happens due to the calculation method used. The FIFO ratio for fishmeal and fish oil is calculated separately, and then the ratio is based on the highest value. The calculations from (Tacon & Metian, 2008) looks as follows:

$$The\ FIFO\ ratio\ fishmeal = \frac{\%\ fishmeal\ in\ feed * FCR}{yield\ fishmeal}$$

$$The\ FIFO\ ratio\ fishmeal = \frac{\%\ fish\ oil\ in\ feed * FCR}{yield\ fish\ oil}$$

If we insert the conditions, we have

$$The\ FIFO\ ratio\ fish\ oil = \frac{30\%*1,25}{22,5\%} = 1,67$$

$$The\ FIFO\ ratio\ fish\ oil = \frac{20\%*1,25}{5\%} = 5$$

This suggests that in order to produce the fish oil required an amount of 5 kg wild fish is needed.

In the report from (Jackson, 2009) it is pointed out that the excess amount of fishmeal can be utilized in feed for other marine species. The different species use fishmeal and fish oil to a different extent. He argues that for instance a combination of shrimp and salmon is efficient since shrimp require much more fishmeal than fish oil and opposite for salmon. In total all of the fishmeal and fish oil on the world is used, and as a consequence no waste. (Jackson, 2009) has therefore constructed an alternative formula considering these factors:

$$The\ FIFO\ ratio = \frac{level\ of\ fishmeal\ in\ the\ diet + level\ of\ fish\ oil\ in\ the\ diet}{yield\ of\ fishmeal\ from\ wild\ fish + yield\ of\ fish\ oil\ from\ wild\ fish} * FCR$$

For salmon, we have

$$The\ FIFO\ ratio = \frac{30\%+20\%}{22,5\%+5\%} * 1,25 = 2,27$$

These numbers are based on what (Tacon & Metian, 2008) concluded, but (Jackson, 2009) argues for improved processing equipment leading to greater recovery of proteins from the wild fish. IFFO has therefore adjusted the yield of fishmeal from wild fish to between 23,5% and 24,5%. (Jackson, 2009) uses 24% instead of 22,5% in his calculations, and this gives the following result:

$$The\ FIFO\ ratio = \frac{30\%+20\%}{24\%+5\%} * 1,25 = 2,15$$

Furthermore, (Jackson, 2009) argues that the FIFO ratio is even lower. The contributor to this is the fact that an increasing amount of fishmeal and fish oil are obtained from by – products such as guts, heads and other parts previously considered as waste. Approximately 22 % of the fishmeal now comes from by-products. With this in mind the FIFO ratio falls to 1,68.

3.4. The slaughter process

The welfare of the salmon is an important part of the slaughter process. In general, there are widespread usage of inhumane slaughter methods. A report even says that "The overwhelming majority of farmed fish produced throughout the world are killed with little or no consideration for their welfare" (Lines & Spence, 2014). In the EU the Panel of Animal Health and Welfare (AHAW) concluded that "many existing commercial killing methods expose fish to substantial suffering over a prolonged period of time" (Fishcount, 2012). There are a number of slaughtering methods of salmon which are viewed upon as inhumane. Some of them are: Carbon dioxide stunning and live chilling. More humane methods are e.g. percussive and electrical stunning machines. In Norway the method of carbon dioxide stunning is banned effectively from January 2010. Already when the ban came into effect about 80 % had begun using percussive or electrical stunning devices in their abattoirs (slaughterhouse). The leading supermarkets in the UK have seen to that their slaughter practice is as humane as possible (Fishcount, 2012).

3.4.1. Carbon dioxide stunning

Carbon dioxide stunning is a method where the water is saturated with carbon dioxide. Fish exposed to such an environment will end up in a state of narcosis. The problems, or the inhumane part, is visible before this state. When the fish is immersed in water saturated with carbon dioxide the fish starts to show signs of panic and flight reactions. The salmon starts shaking its head and tail rather violently. This stage normally lasts for about 2 minutes, but there are examples of salmon showing these traits for up to 9 minutes. In addition, the salmon will also lose its brain function after about 6 minutes. On top of all this there is no evidence to back up that stunning with carbon dioxide has a calming or anesthetic effect. The immense stress on the salmon has also caused gill hemorrhaging/bleeding, scale loss and other injury. Even though the salmon stops moving after about 2 minutes it does not mean that death has occurred. Despite this, reports show that fish are removed after a time of 2-3 minutes with the possibility of not being completely unconscious before entering the next stage of the slaughtering process (Yue).

3.4.2. Live chilling

Another method of slaughtering is live chilling with carbon dioxide stunning. The results of only using live chilling is too uncertain. When salmon only are exposed to live chilling they might be immobilized, but not become unconscious. This means, as in the case with carbon dioxide stunning, the fish could be alive when the fish is gutted and bled. Therefore, live chilling is combined with carbon dioxide stunning where the salmon are live-chilled in 1 °C water prior to stunning or killing them with carbon dioxide. Whether this method of combining live chilling with carbon dioxide is better than only using carbon dioxide is debated. Firstly, salmon that are chilled show less symptoms of panic and flight reactions when they are stunned with carbon dioxide. However, as reactions happen more slowly in cold water it is a possibility that the state of unconsciousness occurs later. Hence, the effects of stunning with carbon dioxide might be prolonged. One report even showed that live-chilled fish regained their consciousness before they were introduced to water saturated with carbon dioxide. This method has been deemed not to be humane, since the salmon is not sufficiently stunned before the slaughter process commences (Yue).

3.4.3. Percussive stunning

Percussive stunning, also known as knocking, is regarded as a more humane method of killing fish. The proper tool for killing the salmon is called a priest. The priest is a plastic or wooden club. It is of great importance that this tool is administrated in a correct matter so that the fish dies immediately. The best position to ensure instant death is a blow to the skull directly above and slightly behind the eyes. It is not necessary that the blow penetrates the head in order to be effective. If the percussive stun was a success there is no eye movement, no opercular movement (the bony structure covering the gills) (Mackean, 2016) and bulging of muscle ring near pectoral fin. If a failure occurs and the salmon is still conscious and alive an immediate re-stun has to be executed. A failure can occur either if the blow is too far back or too far forward. Both instances can lead to an ineffective stun. Also, a blow too far back could also damage the flesh. The usage of a priest is not suitable at an industrial scale. The possibility of fatigue and exhaustion is present when stunning is handled manually. In addition, the slaughter team needs to be appropriately trained and the equipment needs to be correct and properly maintained (Humane Slaughter Association, u.d.). Following consequences might include that endangers the salmon’s welfare. Therefore, semiautomatic percussive stunning devices are put in use instead. This method is most common in Chile and Scotland. This is designed to deliver a deadly blow to head of the fish when their snout touches a trigger in the channel of the device. Still, the salmon is handled manually by placing it before the device. The solution is to get the fish to swim into the device by itself. Thus removing the need to handle the fish manually. Thereby improving fish welfare through less handling. In a study by Lambooij et al. they used EEG (Electroencephalogram) to measure the electrical activity of the brain (Epilepsy Health Center, u.d.), and found out that automatic percussive stunning almost in an instant eliminates pain perception of the salmon. It could therefore be regarded as a humane method (Yue).

3.4.4. Electrical stunning

The fourth method is called electrical stunning. With usage of electricity the fish can either be stunned, known as electronarcosis, or killed, known as electrocution. This depends upon e.g. frequency, duration and voltage. The milder form, electronarcosis, only induces unconsciousness as brain function is stopped for a short period. As a slaughter method, the fish have to be bled almost in an instant before it can regain consciousness. The other method, electrocution, completely kills the salmon by dismantling brain functions and thereby stopping the breathing function. A present danger of using electrical stunning is the possibility of a poorly executed stun. A poor stun could be due to equipment failure and lack of maintenance. Then the salmon ends up paralyzed, but still with a functional brain able to experience pain. This means that when they are bled they are not able to show pain or flight behavior. Concerns have been expressed by the agency EFSA (European Food Safety Authority) about fish not being insensible when they are bled. If electrical stunning is applied correctly, with the right parameters, it should only take about 1 second before the salmon is irreversible unconscious. Even though it is regarded as a quick and humane method there are some downsides with electricity. Amongst them are appearing of muscle blood spots and fractured vertebrae. Clearly, in theory, this method is one of the best currently available and in use regardless of the consequences. On the other hand, in practice, the electrical stun parameters might deviate from the optimal parameters. This is a concern whether slaughterhouses are aware of the optimal method and employing it. There are also some other advantages with an electrical stunning system. In comparison with e.g. the other humane method, percussive stunning, the salmon does not need to be removed from the water nor are there any excessive pre-slaughter handling (Yue).

3.4.5. Sedative and anesthetics

It is also a possibility of using a sedative in the pre-slaughter process which helps the fish to relax or use an anesthetic which blocks pain. An example of a sedative is AQUI-S. It is in use in countries such as Korea, Australia, Chile, New Zealand, Honduras and Costa Rica. When the salmon has been sedated stunning and/or killing must immediately follow. AQUI-S has a calming effect on the fish, and in the process of moving the fish from water for further handling they have significantly lower stress levels. The usage of anesthetics is a bit more controversial. In the EU anesthetics is prohibited in the slaughtering process, because “barriers to the use of this technique in UK include the cost of overcoming the legislative requirements to introducing a new medication and the possible public response to eating fish that could be perceived as having been poisoned” (Yue). If we exclusively look at pre-slaughter from the fish’ point of view it is certainly a good idea to continue investigating and improving anesthetics (Yue).

4. Costs

4.1. Production costs

An important part of fish farming is the considerations of costs. The production costs are dependent on several factors such as the size of the farm, health status of the salmon stock, location of the farm both geographically and politically, the cost and access of fish feed and how the costs are calculated.

In a fairly short timespan production costs for sea based fish farming will reach the level of production costs associated with land based fish farming, at least in Norway. The technology in aquaculture is developing in a rapid pace, and this is contributing to a downward pressure on the costs. On the other hand, more and stricter regulations from the governments and the problem of salmon lice’ increased resistance against chemical and medical treatment are contributing to the opposite effect on the cost aspect. Combined with increased feeding costs is the total effect increased production costs. In Norway was the production cost around NOK 23 per kg (calculated as 2015 price) between 2008 and 2012. As of 2015 the corresponding cost is NOK 28 per kg. The production costs do not include financial costs neither depreciations. As a result, land based fish farming is becoming more and more viable compared to sea based fish farming. Not many years ago, the latter one was said to be far more superior than land based fish farming. However, as time progressed so did the technology. This made it possible for other production regimes, such as land based fish farming, to establish an alternative for new production capacity.

A detailed study about the production costs for different production regimes has been conducted by Deloitte. They divided their study in three different categories:

- Traditional sea based fish farming with smolt of under 100 g.
- Traditional sea based fish farming, but with smolt pre-grown on land to reach 1 kg.
- Land based fish farming.

If we consider the first case the costs are estimated to NOK 26,50 per kg. The cost for land based fish farming is only a bit higher at NOK 26,75 per kg. This is a meticulous analysis considering a range of costs e.g. delousing costs for sea based fish farming whilst for land based electricity- waste treatment costs are taken into account.

As recently stated sea based fish farming is a bit cheaper. This is largely due to high usage of capacity and low feed factor i.e. a well-run operation. In the same manner the land based option is also based on a well-run operation, but since this is a fairly unexplored area of aquaculture it is reasonable to assume that a period of trial and error will follow. In the first generations of land based fish farming we would therefore experience higher production costs.

4.2. Investment costs

Regarding the investment costs associated with sea based salmon farming, whether for a new production site or increase production by 5000 tons, it is around NOK 325 – 470 mill. Included in this is four concessions with a total prize of NOK 60 – 80 mill. For a land based operation those costs can be assumed to be 0 since production is possible immediately after the construction is built and approved by the proper authorities. The investment costs for a land based operation site could actually be lower than its competitor with a span of NOK 300 – 450 mill for a capacity of 5000 tons.

4.3. Transportation costs

Another type of cost crucial to establish a land based site are transportation costs. When built closer to its market transport costs would be lower. In the US those costs amount to NOK 8 – 10 per kg, whereas in Singapore it is NOK 10 – 12 per kg. Land based operations are being developed in several countries, amongst them Denmark, Poland, China and Canada in addition to those earlier mentioned.

4.4. A comparison between land based and sea based fish farming

We see that based purely on production – and investment costs there are not much difference between the two options, actually slightly lower for land based. In the analysis it is therefore crucial to factor in other aspects. A land based production site could be built literally anywhere as long as it has access to water. The decision about where to place a sea based production site is more meticulous. There are more factors to consider for example placement along the coast and that the sea has the right temperature and conditions.

It seems that land based considering the facts above is superior to sea based. Therefore, it would seem as a viable reason to support it financially, but in Norway the actors are still a bit reluctant to invest. There are a lot of investors that would like to buy concessions, but there are hardly available sellers in the market. In other countries, such as Poland and Canada, there are substantial subsidies for those who would like to establish a land based operation. The actual investment cost will therefore be lower in these countries, but such countries might not have the required expertise and supply industry as Norway.

In order for Norway to keep up with the continuous development in the industry other options than just sea based have to be on the agenda. Still, the dominant factor in the aquaculture industry in Norway would be sea based in the foreseeable future. An important and crucial step was taken by the Ministry of Trade, Industry and Fisheries on March 20th, 2015 when they announced in a "white paper" that the Government would grant permits for land based production of salmon, trout and rainbow trout continuously and without charging any fees (Gjendemsjø, 2015).

"White papers (Meld.St.) are drawn up when the government wishes to present matters to the Storting that do not require a decision. White papers tend to be in the form of a report to the Storting on the work carried out in a particular field and future policy. These documents, and the subsequent discussion of them in the Storting, often form the basis of a draft resolution or bill at a later stage" (Regjeringen, 2016).

In Norway it has been a debate whether the actors in the fish farming industry should pay a fee to farm fish on land. This might not be a reasonable solution since other industries producing food on land do not have to pay a fee. In fact, most of them receive a subsidy from the government. Prioritizing a land based fish farming solution would develop a core- and specialized competence both for technology and in daily operations. This could be even more utilized by exporting it to other countries in the same manner as the supply industry for the oil and gas industry.

The land based aquaculture industry can also expand into farming other types of fish such as sturgeon, arctic char and probably tuna in the future (Gjendemsjø, 2015).

5. Optimal harvest of salmon with a mathematical approach

5.1. Constraints

In order to obtain an optimal harvesting policy optimal production planning and efficient management practices have to be implemented. There are also a number of crucial steps which have to be executed at the right time. These steps are releasing of smolt, which feed to use, how much feed to use, when to feed. Here the FCR (feed conversion ratio) comes into play. Finally, we have when to harvest.

The optimal harvesting policy is also subjected to other constraints being fish biology and regulations. Under biological constraints we find first of all the stock dynamics. With this term it is meant that it is limited how fast a fish can grow. Even though it is possible to induce growth in a more controllable environment, as with land based, it still exists a limit. The other aspect is release times which usually happens between March – May and August – October. In these periods the smolt will survive in sea water after completing smoltification. With a land based solution this problem would not be apparent.

In Norway the fish farming industry is also subject to a number of regulatory constraints. The first constraint regards biomass. A firm is granted a licensed constraint (maximum total biomass, MTB) which total biomass cannot exceed. More specifically there are also farm/site biomass constraints. The second constraint says that different generations of fish cannot be kept in the same fish farm/site. The last one is the concept of fallowing which states that after one generation of fish being slaughtered the fish site must undergo a period of at least two months where no new fish is introduced.

5.2. The mathematical model

A model of the biology can be established. First of all, production starts when fish are released into pens (or ponds). They are of the same generation (or year-class), so we have that at $t = 0$ a number, R, of fish is released into pens. Let $N(t)$ be the number of fish in the farm at time t. The generation of fish released into the pond will be affected by two biological processes. That is growth (of individual fish). After a period of time t we obtain $w(t)$ which is fish weight at time t. We also denote the mortality rate by $M(t)$. Fish growth itself depends on a few factors. In our case we have size (weight) of the fish, the density (number of fish) and feed quantity. All these factors taken into consideration we get this formula:

$$\frac{dw}{dt} = w'(t) = g(w(t), N(t), F(t))$$

where $F(t)$ is quantity of feed per fish. Further, it is possible to calculate total biomass at time t as

$$B(t) = w(t) * N(t)$$

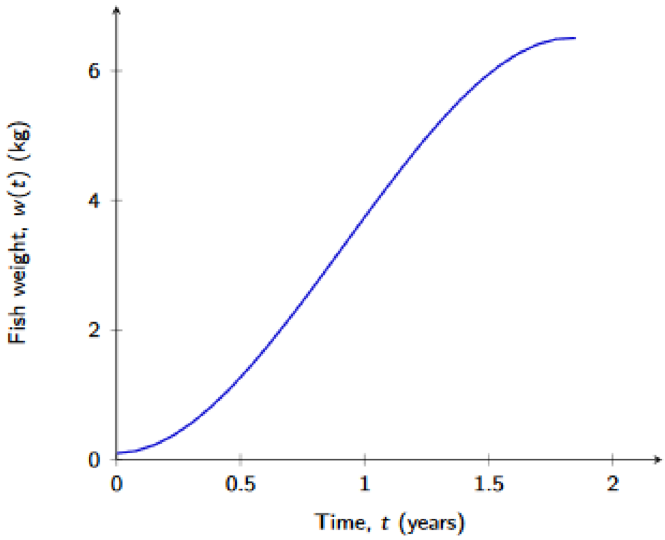

Figure 7: The weight curve for salmon. Retrieved from (Nøstbakken, 2016).

A Beverton-Holt type model is used to model the problem for a single year-class. Our first assumption is that initial number of fish is $N(0) = R$. In the course of time some fish may die. This is expressed by a change in natural mortality:

$$\frac{dN}{dt} = N'(t) = -M(t)N(t), 0 \leq t \leq T$$

Further, we assume for simplicity a constant mortality rate,

$$M(t) = M \forall t$$

We consider the formulas above, and can now derive the function for number of fish at time t:

$$N(t) = Re^{-Mt}$$

This gives us the following biomass function:

$$B(t) = Re^{-Mt}w(t)$$

We also have a price, $P(w)$, per kilo of fish. The price depends on the size of the fish. Our value of fish is:

$$V(t) = p\big(w(t)\big)B(t)$$

Then, feed quantity per fish is dependent on fish growth:

$$F(t) = f_t * w'(t)$$

where f_t is the FCR. Further, we have that cost per kilo fish feed is C_f, a fixed harvesting cost per kilo of fish denoted C_k and the discount rate δ.

In the following we use some simplifications to better model the problem:

- There is no period of fallowing between generations.
- Growth of fish or mortality is unaffected by release of fish into the farm.
- Only variable costs are relevant to the decision process. Fixed costs such as investment costs are irrelevant.
- There exists no seasonal variation in the price, hence it is constant.

With the assumptions established we can now analyze the optimal harvesting problem as an optimal rotation problem. With one rotation we have the following problem: Find the harvest time that maximizes the present value of net revenues from the year-class, given the biological constraints:

$$\pi(t) = e^{-\delta t}\big(p\big(w(t)\big) - C_k\big) * B(t) - PVF(t) = e^{-\delta t}V(t) - PVF(t)$$

$PVF(t)$: present value of the feed costs up until time t.

$V(t)$: value of the fish net of harvesting costs at time t.

We start solving the problem by finding the first order condition (FOC):

$$\pi'(t) = -\delta e^{-\delta t} * V(t) + e^{-\delta t} * V'(t) - PVF'(t) = 0$$

Now we obtain

$$V'(t) = Re^{-Mt} * w(t)\{p'(w)w'(t) + (p(w) - C_k)\left(\frac{w'(t)}{w(t)} - M\right)\}$$

$$PVF'(t) = e^{-\delta t} C_f F(t) Re^{-Mt}$$

We could also model the special case without feed cost. Our optimality condition would look like this:

$$\delta e^{-\delta t} * V(t) = e^{-\delta t} * V'(t)$$

$$\delta = \frac{V'(t)}{V(t)}$$

In the last expression we substitute $V(t)$ and $V'(t)$ and rearrange yields:

$$\delta + M = \frac{p'(w)w'(t)}{p(w) - C_k} + \frac{w'(t)}{w(t)}$$

The latter formula states that optimality condition balances marginal value of delaying with marginal cost of delaying.

Now we can substitute in for $V(t)$, $V'(t)$ and $PVF'(t)$ in the FOC and rearrange yields:

$$\delta + M + \frac{C_f * F(t)}{p(w) * w(t)} = \frac{p'(w) * w'(t)}{p(w) - C_k} + \frac{w'(t)}{w(t)}$$

Also in this case, the optimality condition balances marginal value with marginal cost of delaying harvest. The left-hand side of the equation shows the marginal cost of waiting, and it increases with the additional cost of fish feed.

Finally, we have multiple rotations. In this case we assume that all parameters are constant over time. The problem becomes: Find the harvest time T for each year-class that maximizes the present value of net revenues from an infinite number of subsequent year-classes, given the biological constraints. Release time for the first year – class is at time $t = 0$. The year-classes are harvested at times $t_1 < t_2 < t_3 < t_4$ ... All of the year-classes have the same harvest time, because they are identical: $t_1 = T, t_2 = 2T, t_3 = 3T, t_4 = 4T,$ ... The problem can now be illustrated mathematically:

$$\pi(T) = e^{-\delta t} * V(T) + e^{-\delta 2t} * V(T) + e^{-\delta 3t} * V(T) + \cdots$$

This is identified as an infinite geometric series, and can therefore be written as:

$$\pi(T) = \frac{V(T)}{e^{\delta T} - 1}$$

Now our problem consists of finding the rotation that maximizes π:

$$max_T \pi(T) = \frac{V(T)}{e^{\delta T} - 1}$$

The optimality condition is:

$$\frac{V'(T)}{V(T)} = \frac{\delta}{1 - e^{-\delta T}}$$

which can be written as

$$V'(T) = \delta V(T) + \delta \pi(T)$$

If we compare single to multiple rotations, we can conclude that $T^* < t^*$.

T^*: The optimal multiple rotation.

t^*: The optimal single rotation.

This analysis can be made more complex by adding more constraints to the model for example by complying to the fallowing regulations or smolt release is only possible to viable months.

In addition, most or all of the salmon farming firms in Norway have several production sites. The planning of production is therefore a meticulous task. It has to be planned both across and within sites subject to firm-level and site-level constraints such as firm-level capacity, regulations and biology (Nøstbakken, 2016).

6. Challenges of land based fish farming

6.1. Environmental and technological challenges

A great challenge about this technology is the changing of water in the tanks. This has proven to be quite costly. There are several ways to do this including completely emptying the tank while replacing it with new water. It is also possible to recycle the water and use it multiple times with a technology called Recirculating Aquaculture Systems (RAS-technology) (Myrset, 2015).

These systems are indoor and tank-based. In these tanks the salmon are grown at high density and under controlled environmental conditions. RAS can be built where there is a limitation on sources of water and/or land. It is most common to use this type of technology in freshwater environments. A RAS is a substantial investment and there are costs of running a recirculating system. Before investing huge sums in such a facility the respective company must look into how to design it so it fits their needs. The design should take these characteristics into consideration: The water has to undergo a series of proper treatment to remove waste products. If not correctly executed it could cause stress to the salmon affecting their growth, increasing the risk of disease and even death. It is essential to have sufficient knowledge of the biology of salmon and chemistry of the water. Tanks are also of importance, and they come in different shapes and sizes. In order to best gather unwanted waste the tanks should be smooth, round and with sloping bottoms so that a center drain is created. Another important part of the design is the filters where two types are used together. The first one is mechanical filtration to remove unwanted solids such as uneaten feeds and droppings from the salmon. The second one is biological filtration in order to remove dissolved toxic waste. Other components that should be included are disinfection devices, foam fractionators (or protein skimmers), temperature control and aeration units. At last there are also a number of other support equipment such as water quality testing equipment and a tank to accommodate for bulk feeds.

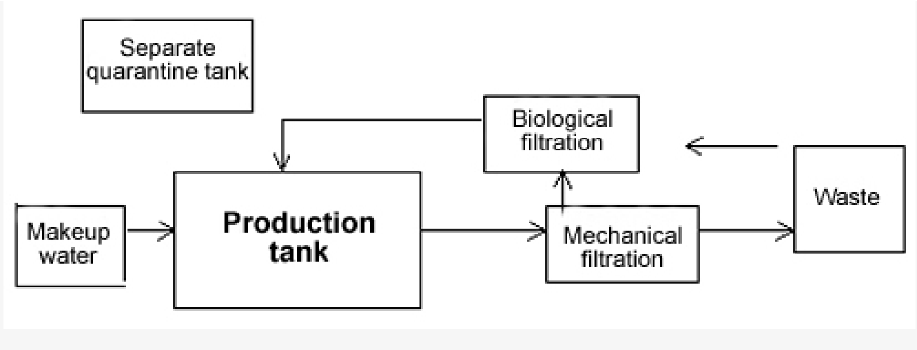

Figure 8: RAS facility. Retrieved from (Queensland Government, 2016).

This method is probably the most likely to be used when salmon are to be produced on a large scale on-land. The replacement of water in traditional cages in the sea happens naturally (Queensland Government, 2016).

Another factor to be taken into consideration is that production on-land claims a large area of land. The tanks and other units necessary on a production site would have to be in proximity of a water source, and have the proper infrastructure in place. One major point of criticism against sea based fish farming is the escape of farmed fish, and therefore an unwanted mixing with the wild fish stock. This has led to problems regarding lice infecting wild salmon and trout. So, with land based fish farming the problem with lice will be reduced. In a tank on-land it is easier to monitor and eliminate.

A great disadvantage of land based fish farming is that it requires more energy to operate than sea based. A major contributor to this is the necessity to change the water in the tanks. In the grand scheme land based may therefore not be that more environmental friendly than a sea based operation. The focus will shift from environmental issues locally around the sea based production site to more global challenges associated with higher consumption of energy.

Fish welfare is also of importance, and with the knowledge we have today it is assumed that the risk we be at least as large onshore as offshore. It is easier to prevent lice and other diseases in a closed environment on-land, but if unwanted viruses or bacteria are to infect the salmon in the tanks the consequences will be huge.

Other issues are wastewater discharge and organic waste that needs proper handling and treatment. Scientists are now trying to figure out how we can utilize this waste. Some suggestions are that it can be converted into fertilizers or biogas or as a mix in concrete. Still, all of the suggestions are a work in progress.

6.2. Economic challenges

The fish farming industry in Norway itself has been a bit skeptical to operations on – land, because of the uncertainties around the profitability. Another source of skepticism is the fear of losing the competitive advantage Norwegian producers currently have in sea based fish farming. Amongst those who are negative to land based fish farming are the CEO Frode Mathisen of Seafood and Tore Nepstad, CEO of Havforskningsinstituttet. On the other side, professor Torbjørn Trondsen at Norges fiskerihøgskole is convinced that land based will be the area we would see future growth.

Some of the participants in the industry are uncertain about the profitability of moving operations on-land. It will require immense investments, and Grieg Seafood has made an estimate stating that a transition to land based would cost Norwegian fish farming industry around NOK 110 billion in total. The food research institute Nofima calculated how much an operation with RAS-technology would cost. Their number where a yearly investment cost of NOK 183 mill for a production capacity of 3300 tons. Yet, in the long run it is expected that a land based operation will be cheaper than a sea based operation. The lower operation costs will then be able to justify the relative high investment cost. In the same report Nofima estimated that the total production cost with investments included would amount to NOK 31,09 for a RAS-operation. If we compare with a sea based the corresponding number is NOK 24,36. It should be noted that the numbers are uncertain. However, there are possibilities to reduce investments in half and cut the usage of area by one fifth (Myrset, 2015).

Some land based tanks have been built, but it will still take some time before we see constructions on-land in a large scale. The uncertainties are still a major factor. It is reasonable to expect that the uncertainties will decrease or diminish completely in the course of time as research is undertaken. So, those who are negative to land based say that it is too much uncertainties around technology and profitability. Those, on the other hand, who are positive say that developing new technology takes time and that it took a long time to develop the technology used in sea based fish farming. Some countries have started to build tanks for fish farming on-land including i.e. Denmark, Canada, USA and China (Myrset, 2015).

6.3. Defying the challenges

In Norway the development is a bit slower, but progress is being made. Several small producers claim that they are able to produce on-land on a large scale with profits in the future. One example is Nordic Aquafarms with production both in Denmark and Norway. They were established 2014 in Fredrikstad, Norway. Under Nordic Aquafarms there are three subsidiaries of which two are in Denmark and one in Norway: Sashimi Royal and Maximus AS in Denmark and Fredrikstad Seafood in Norway. Fredrikstad Seafood has been granted and passed all necessary requirements to start producing salmon in tanks on-land. This process took longer time than expected, but the first step in the building process was made in July, 2016. They expect to be finished next summer in 2017, and then it will be Norway's first commercial land based fish farming operation. An important contributor to make the project possible was a change in regulations regarding land based fish farming. The Ministry of Trade, Industry and Fisheries decided as of 1st of June, 2016 that the regulations around land based should be familiar to sea based and thus increase the competitiveness of the land based fish farming industry. One aspect that was removed was that approvals can be given on a continuous basis and without charging any fees. The fish farming site in Fredrikstad will be built in three modules with three tanks each with a capacity of 1200 tons including a slaughtering facility and showroom. They will not do the smolt production themselves, but buy smolt at 100 g from suppliers. The CEO, Erik Heim, says that the whole investment will be under NOK 200 mill (Nodland, 2016) (Nordic Aquafarms, 2016) .

In Norway it is normal that smolt is produced on-land, and then they are moved to cages in the ocean where they grow until they reach slaughtering weight. In the recent years the government has softened the rules and regulations around farming of smolt. Now it is possible to keep the smolt on-land for a longer time period. This could prove to be important for the future of land based fish farming. Research on smolt grown on-land until they reach a weight of 1 kg would help this cause. Another cost contributor for land based fish farming is rental or purchase of areas which is avoided with a sea based solution (Myrset, 2015).

7. Analysis of production concepts and the competitiveness of Norwegian salmon farming

7.1. Background

Norway has great conditions for fish farming due to discrete sites with good depth, the currents are favorable and there is also good temperature in the water. These are important drivers explaining why Norway is the greatest producer of farmed salmon. However, the salmon farming industry is not a static industry, but it keeps changing and adapting. New technology is being developed both domestically and internationally. Other ways of producing have been invented such as land based fish farming. In a closed off environment conditions are easier controlled and it impacts the surrounding environment to a lesser extent than with a sea based production site. The rapid change in technology could possibly challenge Norway's competitive abilities, because other countries are able to produce more salmon (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

In order to assess whether this is affecting the competitiveness of Norway's fish farming industry a good start would be to look at the competitive advantages we have today. Of course Norway has great advantages through our nature and geography, but other aspects are also important to consider. They include proximity to consumer markets, infrastructure, stable rules and regulations and business clusters. Further, behind the farming of salmon knowledge about fish feed, breeding, medicines, vaccines, biology of production is crucial. Innovative suppliers also play a role (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Research and development of new technology does not imply the same change worldwide. Different countries may have different sets of rules and regulations. This could impact the health and welfare of the salmon unevenly from country to country, but this is not the only issue. The impact on the ocean, energy consumption and other pollution etc. could also vary between countries (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Still, the most important reason that technology is being developed and invested in is that it is profitable. If there are economic opportunities producers and suppliers will funnel money into the new production technology. There are several different production technologies today for salmon. As a base for analysis we will use the traditional sea cages. It will be compared with the other production methods: Optimal open cage in the sea, cage offshore, closed production site in the sea with an exposed location, closed production site in the sea with a protected location and land based production site. The factors they will be compared upon include costs regarding energy usage, area usage, water usage, transport, health and disease (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.1.1. Drivers for development of new technological solutions

As previously stated, the development of new technology requires a lot of resources and commitment. It could have economic reasons as well as being a demand from the government, and this demand may vary along governments both domestic and abroad due to the respective countries' goals and interests. In the following section different types of drivers for technological solutions will be mentioned and explained. The drivers behind are important for the success of new technology and Norway's competitiveness in general, and the drivers that will further be discussed are: Costs, industrialization and specialization, environmental factors, quality, fish health and fish welfare, market growth and political circumstances (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Costs: This might be the factor the industry first notices, because it is fairly easy to determine and make conclusions upon. Up until around 2005 the industry experienced a yearly decrease in costs in farming of salmon, but lately the costs have more or less stabilized around a certain level. The decrease in costs is important for several reasons such as expanding the market through lower prices and making salmon more competitive against other types of fish and meat in general. Hence, further cost reductions are desirable and it will continue to be an important driver for technology (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Industrialization and specialization: Behind the technological development these factors have contributed greatly. During the course of time the production process has been made more effective and it has been automated effectively doubling the production 25 times since 1985 while employment only has increased 50 %. The fish farming industry has moved towards larger and fewer units, and the feeding process and the surveillance are more or less automated. At the same time the productivity (output per employee) is growing. It is not only the fish farming industry that is growing, but also the supply industry. In addition, the supply industry has taken over many of the tasks traditionally undertaken by the fish farmers themselves i.e. fish feeding, smolt delivery and slaughtering. Further examples also include specialized services regarding surveillance, reporting, fish health, environmental surveys and studies and certification. The service industry is becoming more and more important around this primary industry as they are an important part of the value chain and the innovation process (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Environmental factors: The problem with lice is still a highly present issue. This will be discussed further at a later stage. Another problem is the escape of salmon, and the mixing and breeding with the wild fish stock. The industry has been able to solve many environmental issues and challenges, but still there are some problems to be tackled (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Quality, fish health and fish welfare: An important argument for land based fish farming of salmon is that we easier can control the fish itself and the environment it lives in. Any unwanted disease amongst the stock can be easier detected and terminated. The everlasting problem of parasites such as lice might be fully cured. The positive effects of increased fish health and welfare and a higher survival rate for the salmon can then partly or fully compensate for the high investment cost in a land based operation. On the other hand, the more intensive the operation is and with a higher rotation of the stock could induce the opposite which is poorer fish health and welfare (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Market growth: In 2015 the produced quantity of salmon in Norway was 1,39 mill tons at a first-hand value at NOK 46,7 billion (Statistisk Sentralbyrå, 2016). In 2013 the same number was around 1,3 mill tons. This increase is only for the three last years, and the industry has experienced a steady growth due to higher demand because of lower prices, marketing and a wider range of products associated with salmon (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Politics and regulations: Regulations have been present in the Norwegian fish farming industry since the first temporary fish farming law of 1973. The policy of awarding concessions limits the access to the industry and the construction of new farm sites, and thus lowering the production volume. Historically has regulations been imposed of several reasons. In the earlier days of fish farming the laws of 1973, 1981 and 1985 focused more on local ownership, smaller units and spreading the units along the coast (Aarset, Jakobsen, Iversen, & Ottesen, 2004) (Aarset, Jakobsen, Iversen, & Ottesen, 2005). From times to times there have been different regulations due to political pressure from the US and the EU. In recent times the environment and area usage have been more prioritized (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.1.2. Method

In the analysis a three-step model can be applied. In the first step the current production concepts' possibilities will be evaluated along the possibility of technological success and what circumstances in society that can influence these concepts. In the second step the economic side of the concepts is evaluated. In the last step the possibility of success based on previous factors will be summed up, and how this will inflict the Norwegian fish farming industry and whether the new technology can threaten the position and competitiveness of Norway's industry. This is illustrated in the figure below (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Figure 9: Model of analysis. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.1.2.1. Economic analysis

The cage based fish farming along the coast will be used as a reference point, or simply alternative 0, in the further analysis. The other alternatives are evaluated against alternative 0 on economy and productivity. Based on this the unit costs are calculated, and it tries to account for the fact that the investments in the different alternatives are not similar so that they can be evaluated as fair as possible. What complicates this analysis is that alternative 0 has a lot of data regarding costs and profitability etc., but similar numbers for the other alternatives are harder to obtain. They are gotten through e.g. interviews, and there are more uncertainties around these numbers than alternative 0. As a result, the findings are better presented in intervals. The production concepts will be ranked based on their production costs accounting for the cost components in each of the concepts. As earlier stated, the baseline is alternative 0 where the costs have been gathered from The Directory of Fisheries. In the figure below the costs are divided into different categories and further which parameters influencing the costs. It is also necessary to point out the drivers of costs and how they impact development and success (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

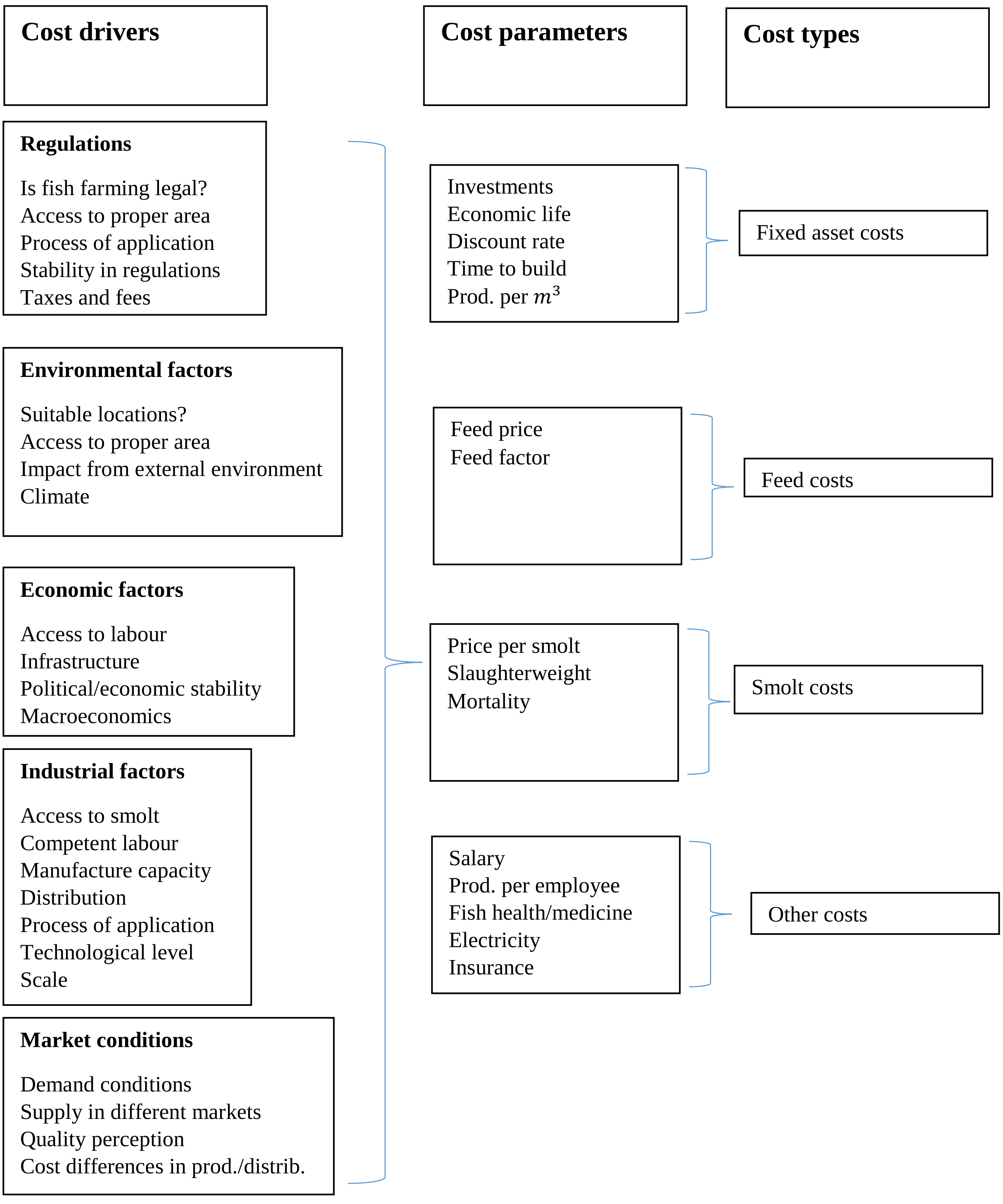

Figure 10: Economic model of analysis. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The costs for traditional salmon farming along the coastline, alternative 0, are, as said, well documented. For land based salmon farming a great amount of data has also been gathered. For the other alternatives, such as closed operations in the sea and offshore based cage systems, the costs are a bit more uncertain. If we look beyond Norway the uncertainty about costs and competitiveness is greater (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.1.2.2. Assessment of probability, consequences and risk

The consequences for salmon farming will be based on the two factors that will be discussed further, technology, society and economy. In the analysis the possibility that a technology will be developed is quantified with a number of 1 – 5. In the same manner the consequences for the fish farming industry are evaluated, also with the numbers 1 – 5. When this is summed up we obtain the risk Norwegian fish farmers are possibly facing (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.1.2.3. Time perspective

When developing new technology it is important to consider the time perspective. It often takes a long time before an idea of a new technological solution is ready to be constructed and utilized on a full commercial scale. A different range of time perspectives are to be evaluated whether they are suitable or not. On a short-term basis of 1 – 5 years it is reasonable to expect that there will be no rapid changes. On the other hand, from 5 – 15 years change and successful implementation of new solutions are plausible. However, if the timespan is too far into the future, say 20 – 50 years, it is harder to model what a new technology will mean economically. In this analysis a timespan of 10 – 20 years is used to discuss the threat from new technology to Norway’s competitiveness (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.1.2.4. Factors of uncertainty in the analysis

Several uncertainties are present in such an analysis. One is technology which takes time to develop and it is not always continuous. This will lead to uncertainty around the economics of the concepts. The effectiveness of the different concepts, the economic life and the cost picture are some examples. Also, the development of new technology might not even be successful after years of work. Uncertainties also revolves around political issues that could include environmental regulations and other regulations through governments and business partners (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2. Established and new operational concepts

Both the established and new operational concepts are going to be discussed further in this chapter. It will start off with the traditional way of fish farming, and then present other concepts in the fish farming industry.

7.2.1. Cage based operation

In the analysis the traditional open, cage based operation will be used as alternative 0. It has been a success for Norway in the salmon farming industry. The great advantage of the cage based operation is that it is relatively cheap, and it is a great solution if you have access to clean seawater Norway being a good example. Another country with great conditions is Chile with stable, high seawater temperature, even more stable seawater temperature than Norway which is favorable. It is also a positive aspect that with a cage based solution the nature provides for the change of water instead of using machines to replace old water with new. The maintenance work on these cages is also fairly easy. They are flexible, easy to clean and easy to replace. It also exists economies of scale in the production through scaling up the cages that lowers production costs. Back in the 1980s one typical cage had a production volume of 300 – 600 m^3. Today it is usual for one cage to have a production volume of 100 000 m^3 (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.1.1. Optimal open cage, sea

The cage based solution is regarded as the established option, but still research is being conducted in order to improve this technology. This includes the fields of salmons' diet, ingredients in feed, feeding technology, feed quality, vaccines, general health of the salmon and improvements in the cages itself. However, there are two aspects especially important for achieving "optimal open cage in the sea": The first one is minimizing salmon escaping and the effects of it and the second one is reducing the problem of salmon louse. Extensive work and research is being put into developing e.g. new material for cages and improved work routines to avoid or minimize the factor of escape. Research on sterilized salmon is fairly new, and can possibly reduce the negative effects on wild salmon stocks if farmed salmon were to escape. Salmon louse is another area which is undergoing extensive research in order to develop a vaccine or other medicines to cure louse if it first occurs. If satisfying solutions are found this could help achieving the optimal solution. Within the industry it exists different practices, and this implies that it is more to be gained before the optimal solution is reached (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.1.2. Cage offshore

The main difference between an open cage in the sea and a cage offshore is that the latter one is built on a more exposed location. The cages are typically bigger, and they are built to endure tough conditions from small exposure (0,5 m significant wave) to extreme exposure (>3 m significant wave) (Shainee, Ellingsen, Leira, & Fredheim, 2013). An operation offshore has great potential advantages such as a vast supply of water and increased flow of water through the cages. The sum of this means that larger cages can be used and therefore higher capacity. Further, emissions could be spread to greater areas thereby diluting the effect and also less unwanted biological material growing on the production site (Shainee, Ellingsen, Leira, & Fredheim, 2013). On the other hand, it is harder to design and build an operation offshore rather than closer to the coast, because they have to withstand harsh conditions. It also has to been built in such a way that the salmon not only survive, but are ensured an acceptable level of welfare and health. There was an attempt of making an offshore production site, called Ocean Globe, but it was never put in production. Also, operating such an offshore operation is linked with some uncertainties, and maintenance work is also a complicated task. Even bringing the work crew to the site is a difficult process. One solution to make offshore production sites a better choice is to construct a “middle station” between cages at sea and offshore (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.2. Closed operations in the sea and on land

The option of having closed operations is a field with growing interest. Investments are being made so that closed operations can be tested both in the sea and on land.

7.2.2.1. Closed operation in the sea, in protected or exposed locations

This type of operation can be defined as a production site where fish within the site is separated through a physical barrier from fish in the surrounding environment (Rosten, Ulgenes, Henriksen, Biering, & Winther, 2011). The interest for such operations is big, not only from the fish farmers themselves, but from suppliers, R&D environments and other organizations with an interest in the operation. The construction itself can vary greatly from flexible cloth material to more rigid material such as glass fibre, concrete or steel. The size of a production site in Norway is ranging from 1000 m^3 to 21000 m^3, but it is built for relative stable conditions. It can be assumed that transporting water into closed operations in the sea demands less energy than pumping water into a land based operation based on today’s technology. A closed environment rather than an open one is also easier to control. Then the fish farmers have the possibility to regulate and optimize temperature enhancing growth of the salmon. This could be done by moving the intake for water in different depths effectively avoiding algae, louse and jellyfishes. As of today a full-fledged operation with a definite barrier between internal and external environment is not operational, as we see in a land based production site (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.2.2. Land based operation

In the 70-, 80- and 90s there was multiple initiatives regarding land based production sites both in Norway and internationally, but it was no great success (Braaten, Lange, & Bergheim, 2010). Amongst the problems they encountered were pump costs, when winter sat in and with the system that controls flow of water through the tank. It is first in the recent years that land based fish farming, especially regarding the RAS (Recirculating Aquaculture Systems). A RAS system recirculate water continuously, and ensures good control with water quality. One problem so far regarding land based fish farming has been the energy cost associated with pumping water into and through the tanks (Emparanza, 2009). When they tried back in the 1970s and 1980s they quickly realized that a RAS was too costly both to invest in and operate. However, there is a major misunderstanding around RAS. It is not necessary to continuously pump in water from the sea since about 99 % of the water is recirculated within the tank. This contributes to lower costs than if it was needed to continuously pump water from the sea. Some of the energy from pumping water is converted into heat, and this heat is stored. By not allowing the heat to go to waste they can increase the heat in the production site, and thereby inducing growth of the salmon. From the 1990s there has been a development how the water is handled and transported through a land based production site in terms of safety, control and efficiency. Another topic today is that the growth potential is not fully utilized, because it is still uncertainties around what specific water quality the salmon need in RAS. Particularly with regards to production of post smolt, since topics such as the optimal content of salt in the water in RAS, the density of salmon in a tank and the welfare of the salmon are matters of uncertainties. With increased knowledge of these topics the production sites can be tailor-made according to specific need and demand. Again this will optimize operational cost (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The number of land based fish farming production sites, based on RAS, is increasing worldwide. Denmark, Canada and China are in front of this development, but multiple countries are exploring the opportunities such as the USA, Ireland, Scotland and Chile. Also, Norway will have its first land based production site in operation during the summer of 2017 if construction proceeds according to plan. The site will have an annual capacity of 9000 tons (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.2.3. Combined production solution (juvenile salmon in traditional sea sites)

In Norway the Ministry of Fisheries and Coastal Affairs gave a few years back permission to start with a pilot project that allowed juvenile salmon up to 1 kg, instead of only 250 g, to be sat out in cages in the sea. This would have several effects on the production as the salmon will be bigger and more robust, and unnecessary loss of salmon is avoided (Alne, M. Oehme, Terjesen, & Rørvik, 2011). At the same time the production time in the cages is reduced implying a lower number of salmon in the cages, and hereby reducing generations of louse on the fish. By choosing combined production solution the louse problem can be decreased. Another effect is that salmon of different sizes can be put in the cages at different times of the year, and as a result produce closer to the maximum allowable biomass (Mathisen, 2011).

7.2.3. Interactions between institutional frames and the surroundings

It is of great interest how the fish farming industry inflicts us and the society in general. There are usually ongoing debates about impact on the environment, usage of area, socioeconomic- and institutional relations. In the further chapters this will be discussed, and how they inflict the different production concepts.

7.2.3.1. Open cages offshore

The baseline is, as earlier stated, open cages offshore.

7.2.3.1.1. Environment

The great advantages of open cages offshore are access to affordable and local sources such as an abundance of water, growth conditions and water exchange. The effect on water quality is in general little with today’s open production concept, and will be even less when cages are moved further offshore. In some cases can organic waste such as feeds and droppings accumulate on the seabed under the cages if the water is fairly still and the cages is located in shallow waters. With offshore installations the challenges with waste and environmental issues will be reduced to a minimum. The problem with crossbreeding between wild salmon and farmed salmon is less with production sites closer to the coastline. By locating the sites offshore where the units are expected to be much bigger the knowledge is not sufficient to conclude with respect to diseases and louse. It is assumed, however, that the risk might be greater. The problem with escaping fish and crossbreeding will not be different with an offshore site, but a breakdown will have much bigger consequences as the units are expected to be much larger. The total risk is also dependent on the possibility of a total breakdown which as of today there is limited knowledge about and therefore hard to draw any conclusions upon. One positive aspect with offshore installations is that distance to river with salmon is greater and the mixing with wild salmon stock is reduced (Fiske, Lund, & Hansen, 2006). Then again an operation offshore will demand more resources related to the production facilities, longer transports and in general more complicated logistics. This will negatively impact the environment (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.1.2. Usage of area

Open cages offshore will not require more space than the ones equal to the system today with cages along the coast. Of course when an installation is located in deeper waters offshore the equipment and anchorage will necessarily be heavier and bigger. However, this would be offset by deeper nets yielding more for the same area. By installing offshore sites land based support systems is required. These can be located more centrally supporting multiple installations, increasing the efficiency and reducing the costs partly due to utilizing established infrastructure and knowhow. Another positive aspect with offshore installations is reduced conflict with other interests and activities in the coastal zone. On the other hand, offshore installations most likely arise conflicts with other industries operating offshore e.g. traditional fisheries, oil- and gas production, windmills and sea transport. To conclude the potential conflicts with offshore production sites are much less identified than conflicts occurring in the coastal zone, but it is expected to be a lower conflict level (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.1.3. Socioeconomic relations

If the production concept offshore is successful it could be an important industrial pillar in Norway giving numerous job positions and adding value to gross national product (GNP). Offshore production requires larger industrial players with more financial muscles, organizational resources and knowhow. This will most likely concentrate the activities to larger companies and resemble the oil and gas industry like living accommodations, rotation schemes of personnel and commuting. The logistics solutions must be adapted likewise with a specialized supply chain centralized to major cities and ports with good infrastructure and connection to the international market (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.1.4. Institutional relations

Offshore installations could be controversial related to international and local regulations and rights. In the US it is considered this has halted the development (Buck, 2012). A country has to balance the right to exercise national economic activity through offshore sites with the international interests in the respective countries' waters for instance unhindered shipping.

Therefore, a set of new regulations and schemes have to be set up accounting for equipment, location and operation. When giving away rights to operate in a specific area offshore means privatizing that area which complicates the relations with national and international law. In Norway such rules and regulations and institutional structures are mostly in place in the economic zone due to the oil and gas industry operating offshore. Norway's knowledge about salmon farming along the coast and the laws regulating it would to some extent be transferable to offshore salmon farming. Clearly, offshore activity is going to challenge and demand sufficient political will, resources and management in order to establish a functional offshore salmon farming industry (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.2. Closed operation in the sea

Closed operations both located in exposed or protected locations will have much of the same impact on the surrounding environment, and based on this reason they both will be discussed simultaneously in the following chapter.

7.2.3.2.1. Environment

A closed production site in the sea is another construction than the open cages. It is more resource and material intensive to build, and in the same way more resource and material intensive when it comes to pumping water in and out of the production site. A positive aspect is that waste from production can be gathered and cleansed, thereby reducing emissions of organic material. This waste management come at a cost, and in addition transportation services are needed which themselves emit and consume energy. All considered, if the total emissions exceeds that of open cages it might not be the optimal solution (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

However, more factors can be taken into account. By pumping up water from greater depths it is assumed that the louse count would be lower, and this would of course help with the problem regarding louse (Rosten, Ulgenes, Henriksen, Biering, & Winther, 2011). Another possibility is to filter water in order to prevent louse. This will have a positive effect, because it helps avoiding the usage of chemicals which impact the environment. It is also possible to prevent diseases or spreading of diseases to the surrounding environment depending of what type of water treatment system installed. The disadvantage is increased use of resources, materials and possibly higher emissions of greenhouse gases (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The dangers of a breakdown of the production site and escape of salmon are highly determined by the technological implementation, and with a closed operation in the sea it is exposed to waves and currents. The number of production sites also has to be increased compared to the solution with open cages which could complicate the issue of salmon escaping. According to (Teknologirådet, 2012) it cannot be concluded whether closed operations in the sea comes with a higher or lower possibility of escape and eventually mixing with the wild salmon stock (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.2.2. Usage of area

An important aspect to consider is available volume meaning how much fish there are and the density of fish. This would greatly influence the installments of closed production sites, and therefore the usage of area. According to (Teknologirådet, 2012) the largest closed production sites are about 3000 m^3 while open cages in comparison have a size of 50000 – 100000 m^3. Considering these numbers, it is easy to see that the usage of area would increase considerably if we were to use closed, floating sites in the sea (Rosten, Ulgenes, Henriksen, Biering, & Winther, 2011). The difference in size is so substantial that in order to make a closed production site viable the technology has to be developed to compensate for the size difference. If bigger units are made in the future, and the density of salmon is up to 80 kg/m^3 the difference in area usage between open cages and closed sites is more or less diminished. This is naturally based on effective operations that work properly. Without the technology development closed production sites takes up a lot more area than open cages to produce the same quantity (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Also, a closed operation is more exposed to currents and other forces of nature. As a reason stronger anchorage points are needed, and possibly longer anchorage lines resulting in more usage of area. This really should not matter that much since this increased usage of area is quite small comparing with the total sea area. Potential area conflicts are dependent on how the concept will inflict the surroundings. An example is reducing the louse problem contributing to a lower conflict level. A reduction in pollution could also help in lowering the conflict with the wild salmon stock. Closed operations can be used together with open cages. By farming more salmon in closed operations it is possible to allow open cages to rest more between generations of salmon giving the water a better quality (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

With the technology that is available today only low exposed, coastal locations are suitable for closed salmon farming. Our baseline, open cages, have the possibility to be located in more exposed areas. Closed operations close to the coast are more subjected to interactions with other fishing activities and humans and their interests say recreational activities and private homes (Teknologirådet, 2012). Bigger closed production units closer to the shore could create conflict of interests due to their anchorage. However, by having more of the industry further away from the coast it could also come in conflict with other fishing interests. The total effect of all this leaves the conclusion rather neutral, not favoring the one over the other, with regards to usage of area and possible conflicts with other interests with a stake in or around the same area (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.2.3. Socioeconomic relations

As stated earlier, a closed operation site would necessarily with today's technology be located close to the coast. Simply by shifting location closer to the shore would not have a huge impact on the business structure in a country. Obviously, some new infrastructure is required for handling the waste and other unwanted byproducts, but most of the infrastructure is already in place. It would also be some minor changes and growth in the supplier- and service industry, but in the bigger picture would the effects in the labor market and value creation be much the same with open cages. To conclude, the concepts of either open cages or closed production sites would not differ much in their impact on socioeconomic relations (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.2.4. Institutional relations

The implications for all ready existing frame of regulations and rules would mean lower level of adaption with closed production sites. These rules and regulations cover for instance classification of location, density of fish, certification of production units, sanitary rules and water- and waste treatment. All these aspects can be treated mostly within the rules and regulations currently in place, and the remaining framework of regulations to be put in place does not require a lot of resources. Politically, this concept is not viewed upon as to controversial. The only matter that complicates and might act as a bottleneck for closed production sites could be the issue of area usage (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.3. Landbased production sites

7.2.3.3.1. Environment

With this technology the feed based emissions would be reduced considerably. It is possible to gather feed and waste in its solid form, but not food dissolved in water. But as earlier stated emissions of feed residues are not a big problem (Anon, 2011), so land based salmon farming would not make a great difference in this aspect. A land based operation incurs some other costs associated with e.g. resources, materials and consumption of energy in order to filter water and manage unwanted byproducts. It is a possibility that organic waste can be used as a fertilizer due to contents of nitrogen and phosphor. Directly use of the organic waste as a fertilizer is not an option, but has to be processed to make it useable (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The great advantages of land based production sites are their possibility to control or solve the problems associated with diseases, louse and escapes of salmon. Still, the knowledge and experience around these topics are limited. The concept in itself does not automatically solve the problems, but depend upon chosen technical solutions. Obviously, escapes of salmon from the production site will be eliminated and the issue with louse can be more efficiently controlled. Main issues are water treatment and management of waste (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.3.2. Usage of area

As of today land based operations are not extensively widespread. The ones in operation are generally small and the experience is limited. In Norway it is estimated that the area needed for land based farming could be about 10 % of area needed for sea based farming to produce equal quantity. This is based upon correct estimates about density and growth of salmon and also size of production unit and water- and waste treatment (Andreassen, Johnsen, & Hersoug, 2010).

A land based concept requires biophysical, technical and interests of the society to be properly considered. Examples are access to seawater and land with the correct qualities such as terrain, size and soil conditions as well as established infrastructure and communications. In central areas land is less available and more expensive which put limitations on construction of land based sites (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.3.3. Socioeconomic relations

With a larger portion of the industry being land based conflicts with other interests relating to sea based production sites and conservation would decrease. On the other hand, by building on land other conflict of interests would appear. According to (Hersoug & Johnsen, 2012) the conflicts arising from building close to the shoreline are highly overdramatized, and therefore by moving operations on land would make little difference (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

On land production demands investments and the right expertise. The significance it has for employment and value creation will depend on location and size of the production facility. Several factors point out that the production would be done in fewer and larger tanks rather than in many, small tanks. One economic factor is costs, and other includes appropriate and available locations, owners' rights and infrastructure. Therefore, many of the installations would be built around the bigger cities already with an established infrastructure and access to greater markets. The decision of where to locate the production tanks are also dependent on where the slaughtering facilities are built and where the production of smolt is being undertaken. The whole process with producing on land is more high tech and requires the correct competences which is easier to find in bigger cities. The supplier industry would also be affected, and has to become more high tech as well in their solutions and services. The current supplier industry has to adapt or be phased out. A high portion of the supplier industry is also involved in other coastal- and maritime industries (Robertsen, Andreassen, & Iversen, 2012). A change in the supplier industry as a consequence of moving salmon farming on land would affect the other coastal- and maritime industries. How much the industry around fish feed, slaughtering and transport will be affected is mostly determined by the concentration and size of the production facilities. To conclude, a certain level of centralization is expected meaning some slaughtering facilities would disappear (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.2.3.3.4. Institutional relations

It would not require much changes or additions in the framework valid today to adapt to a land based industry. Though, some minor changes are needed with respect to density, size and welfare of the salmon. There also have to be some changes regarding the rules dictating waste management and water treatment.

7.2.3.4. Summarization

A table can be made summing up all of the aspects discussed above. Considering the emissions the impact on the surroundings decreases with increased control of production. The land based concept also has an advantage when it comes to louse and interaction with wild fish. This is based on the assumptions that there is a proper waste- and water treatment.

	Open cages, sea	**Cages, offshore**	**Closed, exposed**	**Closed, protected**	**Land based**
Environment					
Local emissions	-	+	+	+	++
Louse and infections	--	?	+	++	+++
Influence on wild salmon	-	-	?	?	+++
Material and energy consumption	-	-	--	--	---
Usage of area	-	-	--	---	-
Socioeconomic relations					
Change in employment and value creation*	0	-/+	0	0	--/++
Interaction with other interests	--	-	--	--	--
Institutional relations					
Juridical	+	--	0	0	-
Administration	+	--	0	0	-

*Displays change, not whether they are positive or negative

Table 1: Summing up aspects. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The total effect on the environment is a product of which aspects that are considered, and how they are prioritized. However, by increasing control and reducing usage of local ecosystem services energy and material costs increase. (Ayer & Tyedmers, 2009) did an analysis where the traditional cage fish farming, closed cage systems, land based throughput of fresh seawater and land based RAS were analyzed according to seven environmental criteria. They concluded that the traditional open cages were the most environmental friendly of the concepts. Following suit, the closed cage concept, land based throughput and land based RAS. This is based on use of fossil fuel to power the water pumps in these concepts. The consumption of energy is the main driver behind the ranking of the concepts. In addition, the analysis also points out that the problems of moving to a more land based production shift the environmental issues on to a more global scale.

Considering the isolated effect of the usage of area it is negative, but not necessarily more negative than the other concepts. Largely, it is determined by the size of the units. As units become bigger and bigger the negative effects on the area decreases. If the assumptions of higher density of salmon and higher growth are met the usage of area would be better than today’s concept of open cages (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

When it comes to employment and value creation it would not change much moving from open cages to land based salmon farming. By moving the cages offshore there is some change from the initial concept. Land based salmon farming demands noticeable changes in the value chain. The service industry around the cage concept has to adapt and develop to a new service industry. This could mean that employment and value creation is more centralized (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

In the area of institutional relations both closed production sites and land based operations can be adjusted to fit today’s regime. Open cages offshore could pose some challenges, and would demand a new set of rules and regulations (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3. Productivity and economy

The economy is a major contributor to the possibility of success for the different concepts, and they differ greatly in productivity and use of inputs. With today’s concept of open cages in the sea there is a low investment- and production cost per kg of salmon. For other concepts the investment would be much higher. On the other hand, they could have some advantages when it comes to delousing, feed, vaccine, deceases, growth and quality of salmon. So, in order for newer concepts to be competitive the operating costs have to offset a higher investment cost. The investment costs could also be offset by higher production per unit of volume or lower transportation costs (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1. Economic comparisons

In the following chapter the economic aspect will be analyzed. This is a crucial part of the success of a concept, and in order to make the analysis a bit easier only the production costs are considered. Other factors such as investment costs and economic lifetime of equipment are accounted for through financial costs and depreciations.

From the sites of The Directorate of Fisheries (Fiskeridirektoratet, 2016) some data with respect to production costs for the base alternative can be found. This is presented in the table beneath. The data for the other concepts are much more limited and harder to come by. A number of assumptions and simplifications have to be made to make it possible for a complete analysis, and they will be the subject of this chapter compared with the base alternative (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Within the industry of salmon farming it is a great variance in the production costs even though the technology is basically the same. Based upon this a variance for the other concepts can be expected. The uncertainties around the inputs are much greater for the other concepts than the base alternative yielding higher uncertainties about the production cost. A possibility is to deal with this through adding some dynamics by using a probability distribution for the inputs giving a probability distribution to the production cost for the different concepts (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1.1. The base alternative

As mentioned, a table of production cost from 2011 to 2014 can be constructed based on data from The Directorate of Fisheries (Fiskeridirektoratet, 2016). Every number is per kg of salmon.

	2011	2012	2013	2014	Ratio 2014
Smolt	2,28	2,16	2,19	2,52	9,8%
Feed	11,02	10,85	11,50	11,83	45,8%
Insurance	0,14	0,12	0,11	0,10	0,4%
Salary	1,61	1,55	1,80	1,92	7,4%
Depreciation	1,09	1,15	1,23	1,26	4,9%
Other prod. costs	3,37	3,26	5,58	5,54	21,4%
Net financial cost	0,19	0,22	0,28	0,20	0,8%
Slaughtering	2,53	2,67	2,64	2,46	9,5%
Prod.cost	22,23	21,98	25,33	25,83	

Table 2: Average production costs for Norwegian salmon farmers. Retrieved from (Fiskeridirektoratet, 2016).

From the table, we see that the biggest cost item is feed with about 45,8 %, and the two dominating cost items make up about 2/3 of the total. In the last years the production cost has shown an increase with a noticeable increase in e.g. feeding costs.

The smolt cost is a product of the price of smolt and amount of smolt purchased. The purchased smolt is obtained by dividing the annual production by slaughter weight. Feeding cost is a product of annual production and economic feeding factor. Insurance is a product of price per current- and fixed asset NOK and the different balance sheet items. Depreciation is just fixed assets divided by expected economic lifetime. The item denoted “other production costs” is a considerable one in the total picture. Under this category there are a numerous of other costs such as fish health, administration, delousing and electricity. Delousing amounts to about 0,66 NOK/kg, vaccine/fish health to about 0,5 NOK/kg, administration to about 0,2 NOK/kg and a residual of 2,01 NOK/kg. Financial cost is based on a capital cost of 7,5%. This is used a basis for estimating the production cost in the other concepts. Now, a table of all the production concepts can be constructed. The numbers are calculated based on variables and parameters presented in the appendix (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

	Base	Land based RAS	Cages offshore	Closed, exposed	Closed, protected	Land based RAS, low-cost
Smolt	2,19	1,94	2,19	2,06	2,06	1
Feed	11,19	9,77	11,19	10,66	10,21	9,77
Insurance	0,13	0,06	0,13	0,13	0,13	0,05
Salary	1,61	1,97	3,22	2,82	2,42	0,98
Depreciation	1,09	2,78	1,67	5,71	3,13	1,88
Delousing	0,66		0,66			
Vaccine/fish health	0,5	0,25	0,5	0,5	0,5	0,2
Administration	0,20	0,4	0,2	0,2	0,2	0,2
Electricity		1,68		0,84	0,84	1,68
Oxygen		0,77				0,77
Organic waste		0,14		0,07	0,07	0,14
Alkalinity		0,07				0,07
Other	2,01	3,02	2,01	2,51	2,51	1,51
Capital	2,27	5,71	5,71	6	4,06	4,36
Slaughter	2,53	2,53	2,78	2,78	2,53	1,27
Total	24,36	31,09	27,51	34,28	28,65	23,87

Table 3: The production costs for different concepts. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1.2. Land based RAS

By looking at the table there are some changes compared with our baseline, and even new cost items come into play. The experience working with land based operations is not yet as great as the baseline option, so numbers might not be as accurate. The numbers are calculated on basis of our baseline. Investing in a land based site requires a substantial amount of money, and has to be considered in the total cost picture. In this example the production site has a capacity of 3300 tons annually, the productivity is 180 $\frac{kg}{m^3}/year$ and an investment cost of $10000 kg/m^3$ (Olsen, 2012). In total, investments amount to about NOK 183 mill.

If we compare smolt cost with the base alternative the cost is lower for RAS, due to a lower mortality rate of 10 % instead of 20 % and a lower price of smolt (Summerfeldt, et al., 2013). The price of smolt is set to be 6 $NOK/each$.

The next cost item is feed which is easier to control with a land based RAS solution. Hence, the cost is lower. Assumed in this analysis is an economic feeding factor of 1,1 and same price of feed as with our baseline. The insurance cost is also lower, because the risk of losing salmon is considerably lower. In addition, the production time is shorter resulting in that the biomass is about half the insurance cost of the baseline (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

In the analysis it is calculated with a workforce of 10 (Roll, Bergheim, & Gravdal, 2008), and the assets are depreciated over an economic life time of 20 years. Also, it is assumed that delousing is a non-existing subject in a land based operation, and other fish health costs are half of the baseline. On the other hand, since there are more employees and increased complexity with a land based site the administration costs are 50 % higher (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

A cost our baseline does not need to account for is water treatment. For a land based RAS, however, this cost is estimated to 0,28 USD/kg (Summerfeldt, et al., 2013). Per kg of fish feed 0,35 kg of oxygen has to be added and 0,25 kg of organic waste has to be removed (Timmons & Ebeling, 2007). The water also has to be around an acceptable level of pH achieved by adding 0,25 kg of bicarbonate for each kg of fish feed.

Other costs are, because of a higher complexity, about 50 % higher than the base alternative. The capital costs for both land based RAS and the baseline is calculated in the same manner. Slaughtering costs are similar for both alternatives. All in all, the production cost for land based RAS is 31,09 NOK/kg (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1.3. Cage offshore

This concept is not widespread in the salmon farming industry. This results in little data meaning it is hard to say something about the costs without using the base alternative as a baseline.

Some assumptions are needed for the analysis. The first one is a production capacity of 10 000 tons annually. The investment cost is around 500 NOK/m^3 making it more expensive than the base alternative since it has to endure the harsher conditions offshore. The productivity is the same as our baseline at 30 $\frac{kg}{m^3}/year$. As a total, the investment amounts to NOK 166,7 mill. The costs for smolt, insurance and fish feed are calculated to be the same as our base alternative. On the other hand, costs related to salary would be higher operating offshore. When operating offshore it is assumed that two work crews are needed, and this type of scheme is usually more expensive. The equipment used has an economic life time of 10 years, and combined with higher investments the annual depreciation is higher. The cost of slaughtering is estimated to be 10 % higher than the base alternative due to longer transport from production site to slaughtering facility. Summing up, production cost for cages offshore is 27 NOK/kg (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1.4. Closed exposed operation

In this case, as in the previous one, the costs are mostly based on assumptions and the uncertainties are therefore highly present. The production capacity is set to be 3300 tons, the investments are 4000 NOK/m^3 and the productivity is 70 $\frac{kg}{m^3}/year$. In total, the investment amounts to NOK 189 mill, and the economic life time is 10 years. Higher investments also mean higher depreciations. The mortality rate is expected to be lower resulting in lower smolt costs. Also, the control with feeding is better giving lower fish feed costs. A cost item that is higher than the base line is salary, because the technical complexity is higher. Costs of administration and fish health are assumed to be the same as the baseline. Pump cost is also a part of such an operation, but the cost is expected to be half of the pump cost associated with RAS. The same applies for organic waste, and the slaughtering costs are 10 % higher than our baseline. To sum it up, the production cost is estimated to be 34,3NOK/kg (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1.5. Closed protected operation

This type of salmon farming is in the starting grounds meaning that data still is quite limited. The data in the analysis is therefore partly reliant on comparisons with other alternatives. The assumptions made are for example that investments are 2500 NOK/m^3, the productivity is 80 kg/m^3 and this yields an investment in total of NOK 103 mill. The economic life time is set to be 10 years. The smolt costs are lower due to a lower mortality rate of 15 % and higher efficiency of utilizing the fish feed. The salary costs are between what can be found in the base alternative and the closed exposed operation, because they are more technical complex than the baseline but closer to land than the closed exposed option. The depreciations are also lower than the closed exposed operation by the fact that investments are lower. In total the production cost is 28,6 NOK/kg (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.1.6. Land based RAS low-cost country

By using a low-cost country some of the cost items will be influenced. Naturally, the prices of inputs would be lower. The influenced cost items include a lower smolt cost of 25 %, activities related to fish health is 20 % cheaper and a 50 % reduction in salary, administration, slaughtering and other. It is also cheaper to invest in a low-cost country (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.3.2. Summarization

In table 3 presented above all of the numbers are gathered. From this table we see that the difference in for example fish feed, smolt, slaughtering and administration are relatively small compared with the differences in cost items such as capital and depreciations. In between we have electricity, oxygen, salary, delousing and other. It must be said that some of the estimates come with great uncertainties since they are based on the best of one's judgement. The production costs can also be simulated with a probability distribution assuming a normal distribution of parameters. By running the simulation 1000 times through a program for the different concepts we achieve the following figure showing the distribution of production costs.

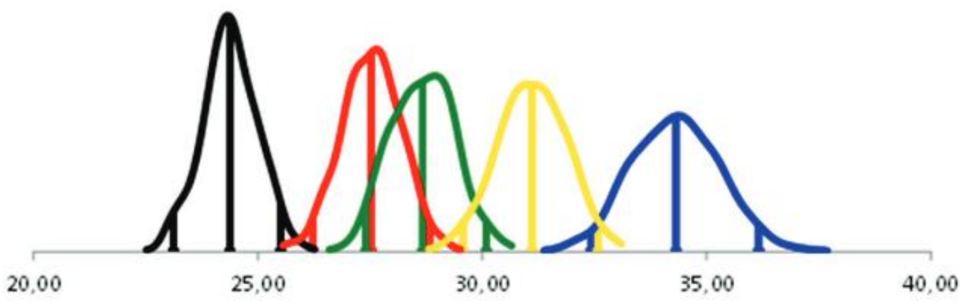

Figure 11: Probability distribution for production costs (NOK/kg) for different concepts. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Legend:

Black color: Baseline

Red color: Cages offshore

Green color: Closed protected operation

Yellow color: Land based operation

Blue color: Closed exposed location

The base alternative, as shown in the figure, is the cheapest one in terms of production costs. The option closest to the baseline is cages offshore, but the overlapping is rather small. This only applies for the least cost effective sites among the base alternative and the most effective sites among the cages offshore. Therefore, exclusively looking at production costs would not contribute to a more diversified salmon farming industry. As known, the estimates come with uncertainties, and the investment costs are also a crucial part of the investment making. A sensitivity analysis can tell us how much parameters have to change in order to achieve the same production cost as the base alternative. In this case the parameters of investments per m^3 and life time will be subject to change. In the table shown beneath we see that investments must drop to a different extent before production costs is at the same level as the base alternative. For cages offshore zero investments would not be sufficient. Only closed protected production sites could match the production cost of the baseline with an almost infinite life time (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

	Land based RAS	Cage offshore	Closed exposed	Closed protected
Invest. per m^3	88 %	Not possible	99 %	78%

Table 4: Sensitivity analysis. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4. How Norway's salmon farming is influenced by changed competitiveness

In the following chapter it will be evaluated how new technology will influence the competitiveness of Norway's salmon farming industry. At first Norway's competitive advantage and potential challengers are discussed. Then, important trends and possible scenarios are a subject. Further, the possibility of technological and economic success of the different concepts including the consequences of success for different scenarios are of importance. At last, the chapter includes the risks the production concepts pose for Norway's position as a salmon producer (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.1. Norway's competitive advantages

In the following section a number of factors contributing to Norway's competitiveness will be discussed.

7.4.1.1. Nature-based advantages

Norway's nature is well known, and the foundation for fish farming is great with its coast, tempered and clean seawater, good depth and current conditions. With todays' technology of cage based salmon farming it is a steady flow of clean seawater and oxygen and removal of droppings (Ayer, N. W.; Tyedmers, P. H., 2009). However, Norway is not the only country in the world with such conditions. Examples of countries with at least as good conditions as Norway are Canada and Chile. The water temperature in Chilean waters is more desirable since it is more stable around a level of 14 ℃ all year around which is almost optimal for salmon farming. In Norway the temperature varies more between 0 and 20 ℃. This induces low growth and also stress due to a lower level of oxygen (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.1.2. Proximity to markets

The European market is of great importance, and it prefers fresh salmon giving e.g. Norway a great advantage. Norway is not the only country which can offer fresh salmon such as Ireland, Scotland and the Faroe Islands, but Norway has a great potential of future growth in the industry. If the market would prefer frozen salmon producers in North- and South-America would be competitive due to lower transportation costs (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.1.3. Knowledge environment

Knowledge is important for innovation, and the fish farmers themselves is not the only one innovating. Suppliers and other participants providing services to the salmon farming industry also contribute to innovation (Robertsen, Andreassen, & Iversen, 2012). They are involved in the innovation process in areas such as fish welfare, feed, vaccine, feeding- and supervising systems. There are also numerous of specialized services, and Norway is the world leader on this matter. Norway is also exporting a lot of equipment and knowledge, and there are close connections between producers, suppliers and R&D participants contributing to cluster effects. There are also strong connections between suppliers to the fish farming industry and suppliers to the fisheries industries and the maritime and oil based suppliers. Norway is also amongst the world leaders with regards to managing maritime resources giving Norway great advantages in knowledge based development of the industry (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.1.4. Infrastructure

The infrastructure is important, and makes it possible in Norway to transport salmon from the outermost islands. Many of Norway’s competitors have production sites situated in areas with a very low density of people making the transportation route longer to the market.

7.4.1.5. Management
Knowledge about how to properly manage the salmon stock and setting up a proper framework of rules can give a country a competitive advantage. In Norway there are stable political conditions, and the fish farming industry has to comply with numerous of rules and regulations (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.2. Potential competitors with new technology
Whenever new technology is introduced to the industry it can change how activities are operated, and give a modified or new situation with regards to competition. In order to achieve a competitive advantage all aspects mentioned above including technology, nature-based advantages etc. have to be in place. An important part of the following chapters is looking at where and why new or increased production is taking place. New concepts such as landbased operations have made it possible for areas or countries to farm salmon without considering the nature-based conditions to such an extent as with sea based salmon farming. This contributes to decoupling production from traditional factors important for a competitive salmon farming industry (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.2.1. An overview of production and markets
In total is the production 1 790 000 and 227 000 tons for Atlantic and Pacific salmon, respectively. The largest producer of farmed salmon is Norway with a market share of 60 % of the Atlantic salmon. Following is Chile with a market share of 17 % of the Atlantic salmon and a market share of 25 % of the total market. Other major producers are Great Britain, the Faroe Islands and Canada. Minor producers are Ireland, the US, Australia, Japan and New Zealand (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The trade of farmed salmon is shown in the picture below, and the size of the markets and the flow of goods between producers and consumers are also depicted.

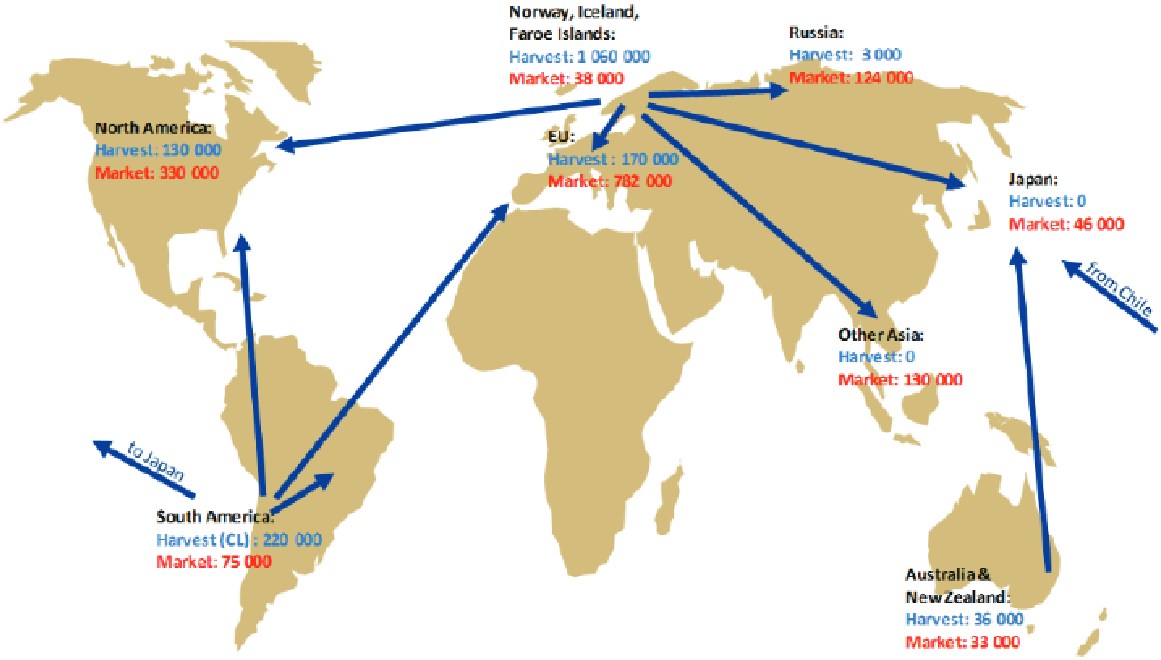

Figure 12: Markets and flow of goods for farmed salmon in 2011. Retrieved from (Marine Harvest, 2012).

As shown in the figure, the EU market is the largest followed by North-America, Asia and Russia. The EU, Asia and Russia is mostly supplied by Norway. Chile is mostly supplying North- and South-America.

7.4.2.2. Available areas for sea based fish farming

Only certain areas of the world are applicable for sea based salmon farming. Beneath a map is provided (Kapetsky, Aguilar-Manjarrez, & Jenness, 2013) to show the most favorable spots.

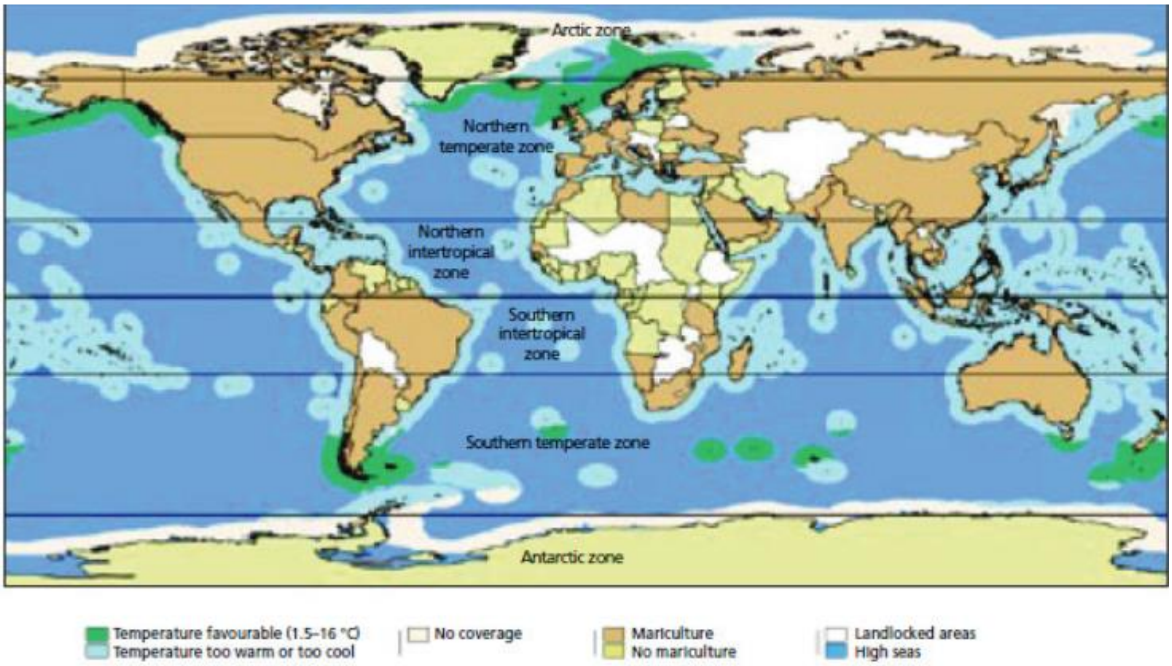

Figure 13: Sea temperature and its impact on sea based salmon farming. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The most prominent areas for salmon farming are along the coast of Norway up to the Kola Peninsula, Scotland, northern parts of Ireland, southern parts of Iceland and Greenland. Other suitable areas are the west coast of Canada, the south coast of Alaska and southern part of Chile and Argentina. Southern parts of New Zealand are also a possibility. With today’s problem of global warming would higher sea temperature mean that suitable areas for salmon farming would change. In general, the suitable areas on the northern hemisphere would move north and the suitable areas on the southern hemisphere would move south. Hence, the salmon farming must move to areas which are harder to reach, with less infrastructure and further away from the markets. The estimates of the effects of the climate change varies from study to study. (Melsom, Lien, & Budgell, 2009) predicts an increase of 0,5 °C from the period 1986-2000 to the period 2051-2065. (Ellingsen, Dalpadado, Slagstad, & Loeng, 2008) estimates an increase of about 1 °C in the Barents Sea from 1995 to 2059 and (Ådlandsvik, 2008) estimates an increase of 1,4 °C over the next 100 years for the North Sea.

7.4.2.3. Localizations of land based production sites

When operating on land there will be more options of locations since it is not restricted to certain areas in the sea. Some of the options are:

Production closer to the market: Closeness to a market is beneficial when it comes to e.g. production and further processing. This could be an advantage with regards to local producers knowing the market and cheaper logistics. Examples of countries suitable for this are countries in East-Europe, Russia and France. However, as the ways of distribution is increasing with production transportation is becoming cheaper (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Production in low-cost countries: Here there are several possibilities. The land based production sites can be located in countries more closely to Norway such as Poland or the Baltic countries. The costs would be lower, and it is close to the European market. In countries such as Vietnam, Thailand and China the costs are even lower, but the distance from the European market is much greater. The Asian market can be supplied with fresh salmon from these countries. When considering frozen salmon from Asian producers they can compete in the North-American and European market (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.3. Trends and scenarios

The industry of salmon farming, like many other industries, is subjected to trends influencing the industry. In the long run some of the variables have shown a consistent growth while others have developed less consistent. In the following chapter some long-term development features and heavy trends will be discussed. Also, important events called “jokers” could alternate the rankings of the different production concepts by influencing the cost picture. The consequences of such events will also be discussed (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.3.1. Heavy trends

Economic growth: This factor varies from year to year and between countries. In the time of history there has been financial crisis, but in the long run the economy is growing steadily and it is quite reasonable to expect that it will continue to grow. This will therefore, most likely, contribute to a higher demand of salmon (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Higher demand for fish in general: Not only the economy is growing, but the population as well. With this comes a greater need of food, and the production of fish has actually grown faster than the population growth. Fish can therefore be an important source to feed the growing population, and in the last years the consumption of fish has been around 160 mill tons. In the illustration below it can be concluded that catch from wild fisheries has been around 90 mill tons the last couple of decades. Considering only the population growth and the wild catch there would be a substantial deficit. The fish farming industry therefore has an important role closing this gap, and ensuring a supply of fish to a growing population. This will be become more and more important as time progresses (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

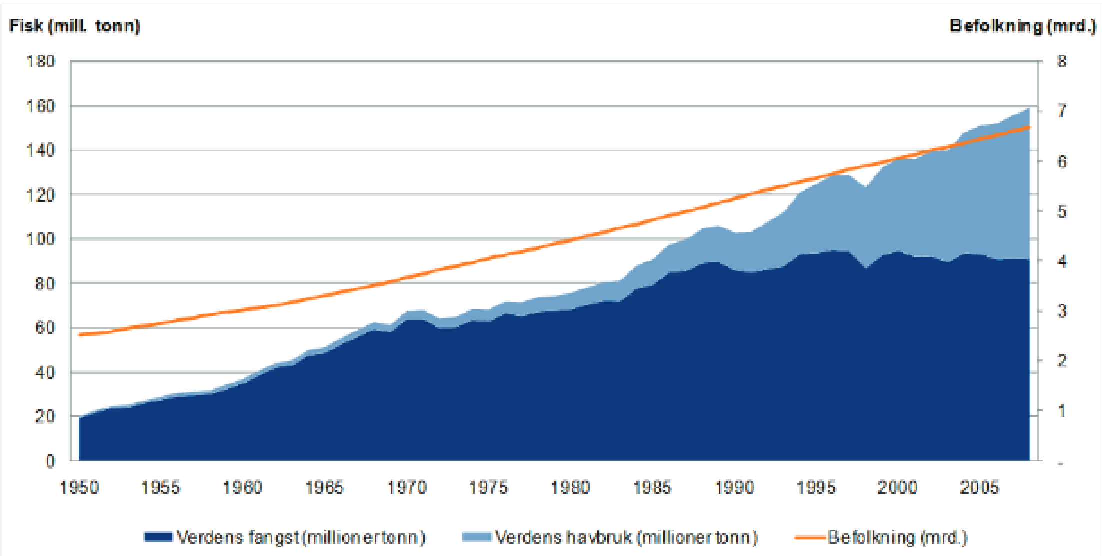

Figure 14: Growth in population and production of fish. Production on the left-hand axis. Population on the right-hand axis. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Focus on environment: Over the last years consumers have placed a greater interest in food being produced more environmentally friendly. This is a trend that has grown steadily, and it probably will in the future. The work of finding a cure against louse and hindering escape of fish is a high priority. In the early stage of fish farming the production sites were usually located in shallow, protected areas, but nowadays they have moved to areas with greater depths and currents. These are better locations for salmon since they have more favorable conditions. With such a strong focus on environment it is also expected that waste from either sea- or land based production sites is disposed and handled properly (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Social sustainability: The great focus on the environment is mostly a factor in western countries. In countries with poorer economy the focus is mainly on economic gains, and aspects as social sustainability and the environment are more in the periphery. Lower focus on environmental aspects could give those countries a competitive advantage as their costs would be lower. This depend upon how strict customers are in reviewing and prioritizing the environment. However, in the long run it is plausible that social sustainability will be as important in these countries as in western countries (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.3.2. "Jokers" influencing the development

There are factors that could happen suddenly and unforeseen that could greatly impact or even change a long-lasting trend in the industry. This makes it harder to predict the future, and examples of such events are for instance the terrorist attack on World Trade Center in NYC, the fall of the Berlin wall and the dot.com. crisis. As "jokers" they made a huge impact economically in the short run, and maybe, more importantly, they impacted our mindset forever. Not just certain events, but technological innovations could have the same effects. The possibility of "jokers" occurring is relatively low, but they usually make a great impact when they do (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Drastic environmental measurements: Political decisions have the opportunity to radically change the prerequisites for the daily operations of the different production concepts. Those who strongly favor the environment would prefer the production to be on land (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Trade policy: Political decisions can be made with regards to trade. These can also have great impacts, and include decisions such as imposing customs barriers or other restrictions on trade (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Climate change: This type of factor can give arise to unpredictable changes with potentially great negative impacts (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Change in technology: With such a change the cost picture for the different production concepts can change radically, and shift competitive advantage from one production concept to another (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.3.3. Scenarios

In this analysis assessing Norway's competitive position it will be based upon two scenarios, a Basis+ scenario and a scenario with a strong focus on the environment. Possibilities and consequences attached with these two scenarios will further be discussed (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Basis+ scenario: Inherent in the name is a continuing of the development as we see and predict it today, with a stable set of rules and framework and a modest heightened focus on the environment. More specifically it means that treatment of louse is becoming more efficient and the escape of fish is at a low level (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Drastic increase in environmental focus: The Norwegian government is in this scenario strict with regards to environmental requirements when faming fish e.g. by imposing stricter limitations on number of parasites, lower mortality and lower emissions. These requirements are substantial enough to impact the cost picture considerably. Again, this would influence the relative profitability between the different production concepts and how participants adjust to the modified market situation (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Heightened focus on environment in western countries: Other countries than Norway are also discussing how to influence the environment in a more positive way. Examples of that are in North-America where there is a pressure from different interests to get fish farming on land, and in Scotland where the discussion about the influence on the wild salmon stock is just an important topic as in Norway (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Political commitment: This have the potential to challenge Norway's leading role in the fish farming industry. If important customers of Norway decide to start land based production sites in order to increase value creation in their own countries, it means a tougher market with more competition. It is also possible that other countries impose trade restrictions on Norwegian salmon or subsidize their own fish farming industry to give it a strengthened position (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.3.4. Time perspective

Time perspective is essential when it comes to discussing the possibility of economically and technological success. In the short term it is easier to predict change than in the longer term. Assessments of economic and technological success in the short run is based upon today's knowledge and technology. In the long run it is harder to foresee change and what consequences it would have. Therefore, in this analysis, the focus would be somewhere in the middle of the short and long term i.e. 10-20 years (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.4. Probability, consequence and risk

The analysis of consequences is divided in several parts which form a basis for final assessment. Besides the technological development there is another important factor to consider which is how the conditions in the industry change due to political decisions and change in the market. Itself they can influence the development of technology, but are hard to predict. This will be simplified by defining certain scenarios for future development (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

For each scenario the possibility of technological success for each production concept will be assessed. We talk of economic success when in a scenario a production concept lowers its production costs enabling it to be competitive with the base alternative (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Then, the consequences for the salmon farming industry in Norway will be discussed. One way to do it is by using a scale from 1-5, where 1 is small consequences and 5 is great consequences. The term “consequence” in this matter means Norwegian market share of salmon production and the size of the Norwegian production (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

In the end it is possible to obtain the risk level by multiplying probability and consequence. This scale goes from 1-25, where 25 is the highest risk. The scale can be illustrated with a table displaying the risk levels in different colors (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Risk	1-5	6-10	11-15	16-25
Color code				

Table 5: The scale in colors. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

We have low risk colored in green, fairly low risk in yellow, medium risk in orange and high risk is marked with a red color.

7.4.4.1. Scenario 1: Basis+

As previous stated, technological- and economic success is treated separately in the analysis. Technological success means that the technic side of the production concept is working properly. That includes growth of salmon, feeding factor and water quality. Also, it is important that a production concept succeeds in question of economics meaning it is competitive with the base alternative. The results of the analysis for the basis+ scenario are summed up in a table later in this chapter (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.4.1.1. Technological success

The possibility of success when it comes to the development of land based RAS is deemed as quite high. As we know, a large part of the technology is already in place and even some production sites are already built. The offshore technology is evaluated to have a moderate possibility of success, whereas the closed operation in the sea is evaluated to have a low possibility of success (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

When discussing the consequences for Norwegian salmon farming industry they are difficult to predict. By researching and developing offshore technology is the area available for fish farming expanding, because it is possible to have locations in areas with higher waves. Another factor beyond our reach of control is sea temperature which confines salmon farming to certain areas. However, the most important factor is production costs. As we have seen earlier, the production costs attached with offshore production sites are higher than the base alternative. The most likely case is then that most of the production would be undertaken by the more primitive and cheaper technology. The consequence of offshore technology is therefore deemed as rather small (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

If land based technology is a worldwide success the consequences would be much greater. It makes it possible to produce without being dependent of a location in the sea. Production is therefore not limited to certain areas, but is possible in most parts of the world. The production itself for land based is more expensive than for the base alternative, but some factors may counter that picture. It is also important to consider transportation costs in certain markets. If the distances are of such a length that flying is the best option could land based sites be the best choice. The Asian market for Norwegian salmon is predominantly supplied with air freight. About 10 % of the Norwegian production is exported to Asia. In Japan is the position of Norwegian salmon strong, because of quality and origin. If land based fish farming becomes a great success in the future a substantial part of this export could be replaced by inland production in Asian countries. All in all, the consequence is viewed as small. Some countries in Eastern-Europe are low-cost and have close connections with the Norwegian market. If RAS technology is employed it would have a negative impact on Norwegian fish farming since the costs attached with this are extremely low in Eastern-European countries (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

When considering closed protected production sites in the sea the conclusion would be much the same as with offshore sites. Also, the production concept of closed protected sites in the sea has less potential to expand the area viable for production and has higher production costs than the offshore option. A better technology in closed protected production sites would make the exchange of water better and more effective. This is largely a case for Norway, and could give Norway a competitive advantage. Since only a few countries would utilize such a technology the consequences would be small (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The option of closed sites in exposed locations would expand the potential production area more than an offshore operation, because of the possibility to gather water with different temperature than just gathering water in the water surface. Other countries than Norway could benefit from this, but the production costs are evaluated to be quite high meaning that the consequence is small (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.4.1.2. Economic success

Even though it is not very likely it is still possible that the technology being developed gives production costs that are comparable with the base technology. This would have great implications on the consequences, and therefore is it evaluated separately. The results are displayed in a table below, and the situation with comparable production costs between different production concepts and the base technology is less likely to occur (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

If offshore technology becomes a success it could mean higher production in several countries since it opens up a larger area to fish farming previously unattainable with the base technology. Still, production is limited by sea temperature. Countries that in particular could compete with Norway are Scotland, Ireland and the Faroe Islands. They are in a position to benefit from access to vast areas of possible locations with offshore technology. Norway could also utilize offshore technology. The consequences for Norwegian production would therefore be limited (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

On the other hand, a competitive land based industry would have great consequences. The production sites could be located in low-cost countries which are closer to the desirable markets which again ensures lower transportation costs (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Closed sites in protected locations are more accessible for Norway than other countries. Norway would be able to utilize the technology more than other countries, so the consequences are assessed as small (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Closed sites in exposed locations will increase the production area more than closed sites in protected locations. Relative to Norway other countries would therefore increase their production more. Still, Norway would increase their production as well effectively resulting in small consequences (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

	Technological success			Economic success		
Concept	Probability	Consequence	Risk	Probability	Consequence	Risk
Offshore	3	1	3	2	2	4
Land based	5	2	10	2	5	10
Closed protected	3	1	3	2	2	4
Closed exposed	1	1	1	1	2	2

Table 6: A matrix showing probability, consequence and risk for Norwegian salmon farming for different technologies: Basis+ scenario. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.4.2. Scenario II: Increased environmental requirements in Norway

In this scenario, the salmon production is subject to stricter environmental requirements from the Norwegian government. This could be done by imposing stricter rules on allowed mortality amongst the salmon, a lower limit on parasites and regulations about emissions. The effect of all this is that the production costs are expected to increase for the base alternative (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.4.2.1. Technological success

The possibility of technological success is not influenced in this scenario, because the driving force behind development of technology is mainly international conditions. The arising consequences are now due to the fact that the costs of the base alternative are higher. The cage technology has shown itself to have a high level of adaptability, and combined with higher costs threatening Norway's competitiveness there will be a pressure for new innovations (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

With offshore installations would, as previous stated, the area available for salmon farming be extended. Still, salmon farming is restricted by sea temperature. When costs in Norway are increased, other countries would become a greater competitive advantage. Some of the production is then assumed to relocate in favor of those countries which still use the base technology. In addition, the supply curve of Norway will shift in the negative direction resulting in lower Norwegian production. This is evaluated as a medium negative consequence (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Most of argumentation about offshore installations could also be applied for land based technology. If the costs increase for the base technology the land based option would become more desirable. Also, lower transportation costs can be realized by a location closer to the market. The result is lower Norwegian market share. The conclusion is the same as previous chapter i.e. medium negative consequence (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

The potential production area would also increase by using closed production sites in the sea. The expansion outward from the coast is not as great as with offshore sites. On the other hand, the possibility of using water of different depths with closed production sites is a positive feature that increases production area along the coast. Altogether, the expansion with closed sites is presumed to be smaller than offshore sites. Also, Norway probably has more to gain from closed sites than other countries due to protected locations. However, the cost increase results in higher market shares for other countries with the base technology. In total, the consequence is moderate negative (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.4.2.2. Economic success

In this part the different production concepts are competitive on costs, and this come with consequences. The probability, however, of economic success is somewhat lower than technological success. Still, the probability of economic success is greater in scenario I than in scenario II, because of the increase in cost on base technology in Norway (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

Offshore operations are a likely choice in countries with limited possibility of using the base alternative. In Norway, there will also be such operations, but with lower production caused by the cost increase. The consequences are therefore moderate (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

With regards to land based operation there will be great consequences for Norwegian production if they are established in low-cost countries.

When it comes to closed sites in protected locations Norway has the most available areas, and can therefore use this to gain some "terrain" over other countries. Even though this is a good option for Norway the main consequence is still a decrease in Norwegian production due to higher costs. With regards to closed sites in exposed areas Norway has less to gain since other countries also increase their potential production area relatively more to Norway than the situation with protected locations (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

	Technological success			Economic success		
Concept	Probability	Consequence	Risk	Probability	Consequence	Risk
Offshore	3	3	9	2	3	6
Land based	5	3	15	3	5	15
Closed protected	3	2	6	2	2	4
Closed exposed	1	2	2	1	3	3

Table 7: A matrix showing probability, consequence and risk for Norwegian salmon farming for different technologies: Basis+ scenario. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

7.4.5. Summarization

Most of the production concepts are fairly low on the scale. The ones that score 10 or more are outnumbered.

In the Basis+ scenario only land based production sites could pose a risk for the base alternative in Norway.

-10 points (land based, technological success): According to the analysis there is a great possibility that land based sites would be a technological success. The consequences of it, however, are relatively modest since there are some questions around the investment costs whether they make it a viable choice compared with other concepts (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

-10 points (land based, economic success): The consequences would be great if it becomes an economic success, but because of the uncertainty attached with future success the score assigned to it is only 10 (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

In Scenario II we have these three options with the highest score:

-15 points (land based, technological success): In this scenario, the base alternative comes with higher costs and thus a higher threat from the land based option. The consequences would be greater with higher costs (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

-15 points (land based, economic success): The consequences would also be greater in this scenario if it is an economic success (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

-9 points (offshore, technological success): There is also a possibility that offshore sites could be a technological success. It has a score of 9 points with a moderate possibility of success and moderate consequences (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

8. Q&A fish farming companies in Norway

In the last chapter I will provide the results of my interview with companies in the fish farming industry in Norway. The company names are anonymized for their convenience.

8.1. Questions

1. What is your company's current view on land based fish farming?
2. The Ministry of Trade, Industry and Fisheries decided as of 1st of June, 2016 that the regulations around land based should be familiar to sea based and thus increase the competitiveness of the land based fish farming industry. One aspect that was removed was that approvals can be given on a continuous basis and without charging any fees. Do you have any plans or activities related to land based fish farming?
3. Is land based a threat and can it produce sufficient quantity?
4. With land based farming typically less medicine and toxins are used compared with sea based. Does this make it a more exclusive product?
5. Bakkafrost has successfully used freshwater as a mean to reduce lice problems. Is this something you consider? How do you handle the lice problem?
6. Amongst the ingredients in fish feed are fishmeal and fish oil, and they can be replaced by a number of substitutes. Fish oil can be replaced with linseed, sunflower, rapeseed, soybean, olive and palm oils. Regarding fishmeal, it can be replaced with foodstuff from land based animals such as meat and bone meal, blood meal and byproducts from poultry. However, it is important that the substitution of ingredients does not compromise the final product. A consequence might be a change in the omega-3 content or overall content. This might be a non-optimal solution for the consumers. What is your view on this?

8.2. Answers

8.2.1. Company 1

1. They are the largest producer in Norway with regards to land based salmon farming. However, this is not within the area of salmon ready for slaughter as they use land based farming for smolt. Their capacity is 7000 tons smolt.
2. They already have specific plans of expansion. Before a change in the law it was only possible to produce smolt up until a maximum limit of 250 g on land before the smolt had to be further farmed in the sea. Now the limit is at 1 kg. This does not mean that all of the smolt will reach 1 kg before they are placed in a cage in the sea. It would

rather be a mix of groups of smolt with a size of e.g. 250 g, 500 g and 1 kg. At the moment, they have no plans of starting a full-scale land based production site with a purpose of farming salmon until slaughter weight.

3. The benefits of sea based fish farming more than make up for the positive sides of land based fish farming. As of today, the land based solution is no threat. The costs associated with land based is much higher. It requires large areas of available land and a huge amount of energy. On the other hand, the land based option could make it easier to control the problem with lice. With time, it could become a threat as technology progresses making it possible to produce in larger quantities. If the costs for land based become equal to or lower than sea based fish farming other countries would be prioritized over Norway in establishing production sites.
4. There have been a number of studies on organic waste and their effects on the seabed. A common result from all of these studies is that the effects are insignificant. It is the media that is constructing a problem and misleading people about this topic. The main issues in the salmon farming industry are lice and salmon escaping.
5. They are already utilizing freshwater in order to reduce lice, and started with it before Bakkafrost. This form of treatment is associated with high costs, and it is also a rough method. During this process the salmon is physically held in place as it is being treated with a high-pressure water stream. This is a concern when considering fish welfare. Therefore, this company uses a variety of methods, both active and passive treatment methods. They are also developing new methods on a continuous basis. A promising way of treatment is the usage of a laser, but this method is still not efficient enough to handle the lice issue by itself. As a result, they use a variety of different methods. An example is that they farm their own cleaner wrasse and lumpfish.
6. There are several projects ongoing. It is favorable that pelagic fish is being used directly for human consumption instead of as food for salmon. The omega-3 content in farmed salmon has decreased as a reason of this. Some of the marine ingredients have been replaced by vegetable ingredients in the fish feed. Even though the level of omega-3 is lower farmed salmon is still a very good source today. One meal a week based around salmon is enough to cover a person’s need for omega-3. The level of omega-3 content has fallen from 12 g/kg to about 6 g/kg due to the substitution of the marine ingredients. However, this is not a critical level. The wild Atlantic salmon and farmed Atlantic salmon contain approximately the same level of omega-3. Still, farmed salmon is highly ranked among the omega-3 sources.

8.2.2. Company 2

1. They think they will see an increase in capacity on land with regards to post-smolt production (until 1 kg).
2. They invest in increased capacity for post-smolt production.
3. At the moment it is not a threat. It would require huge investments before landbased poses a threat to the sea based option. On the other hand, there will be an increase in on land production for post-smolt.
4. There is no guarantee that these problems can be avoided, but there is a certain possibility that the risk will be lower.
5. They have used freshwater. Now they are using mechanical delousing such as Thermolicer.
6. Over the last several years the fish food industry has conducted a lot of research in how fishmeal and fish oil can be substituted. It is important to differ between fishmeal (protein) and fish oil (fat), because it is converted and stored differently in the salmon. All protein consists of 20 different amino acids. 10 of them are essential and have to be supplied through the diet. The protein the salmon is consuming is broken into amino acids, and then reassembled according to the salmon's genetic code. In principle, it is possible to fully stop using fishmeal in the fish feed, because a balanced diet with e.g. soy or other concentrates would result in the same amino acids. With fish oil the picture is different. The fat is stored, and utilized later for energy. Some of the fatty acids have important life functions e.g. DHA and EPA. They have a positive effect on human health, and salmon themselves do not produce much of it. Fish oil, and especially fish oil from South America, has a high content of DHA and EPA. The vegetable alternatives have more or less none or low content of these important fatty acids. The quality of the salmon could therefore be compromised if DHA and EPA through fish oil are replaced by vegetable ingredients. Even with 70 % of rapeseed oil, which is generally the industrial standard in Norway today, salmon is a better alternative than comparable meat. The reason it is about 30 % fish oil in the fish feed is that it is not sufficient knowledge about how much the salmon needs to ensure proper health and welfare. In addition, there are no options that really can replace fish oil due to its combination and amount of DHA and EPA. The company's view on fish feed is that it ensures good fish health, growth and welfare. They have also set a minimum requirement of DHA and EPA in the fish feed.

8.2.3. Company 3

1. They only produce smolt on land. This is possible since salmon is an anadromous fish living the first part of its life in fresh water. There are great costs and biological challenges producing on land. It is also a question about available space and size of the landbased operations. The capacity of the operations must also be considered. A typical landbased tank has a capacity of 2000-3000 m^3, whether a single sea cage has a capacity of about 16000 m^3. This company has invested NOK 500 mill in land based production sites for smolt up to 200 g. By doing this it could have a positive effect on the lice problem through fallowing of sea based sites.
2. Ideally the fish farming does not take place in fjords. Most favorable would be production of smolt on land and further growing offshore. As of now they only produce smolt on land.
3. It does not pose a threat today simply because of the low volume. A relocation to an on-land production site does not necessarily solve the problem with diseases. Typically, in such a facility the water is fairly still, and if any diseases break out the whole tank must be emptied and cleaned. This results in a disrupted production and financial loss. Biological issues and challenges are still present in a land based facility.
4. They have to handle the lice issue much like any other participant in the fish farming industry. In the treatment process they have a clear policy of not using antibiotics. The exclusivity aspect has to be evaluated by the consumers themselves. Land based fish farming without using medicines in the production process can be highlighted. In the same manner could the exclusivity aspect be underlined by the fact that the salmon has been grown in a clean Norwegian fjord. A drawback of the land based option is the requirement of energy when recirculating water through the tanks. The same could be said about the area a land based facility claims.
5. They have several non-drug based methods under development. Some of the methods already implemented include cleaner wrasse and skirts around the sea cage preventing lice larvae to interfere with the salmon. Basically, it is a skirt of plankton that ensures free flow of water, but restricting lice larvae from entering the sea cage. All the company’s sea cages are now covered with such skirts. They are also looking into investing in larger facilities for production of smolt. Smolt could then be grown for a longer time on land before they are moved to a sea cage. This shortens the time in the sea, and therefore the exposure to lice larvae. Furthermore, a longer fallowing phase ensures a longer time period to get rid of lice. The company also evaluates it as highly

favorable to farm salmon offshore, and move the fish to an offshore production site when its weight is 1,5 kg. The risk of infections and diseases is lower in the ocean, and farming operations offshore contributes to a longer fallowing phase for production sites closer to the shore.

6. It is important that the salmon is a quality product meeting the standards and requirements of the consumers. With regards to fishmeal and fish oil only the latter one is a limiting factor. This problem could be solved with the help from omega-3 producing algae. Instead pelagic fish, which fish oil is deducted from, should be a source of direct consumption rather than feeding salmon. It is the task of the industry specialized in fish feed to come up with sustainable, healthy and safe pellets of feed.

8.2.4. Company 4

1. They have production of smolt in land based facilities, but are not considering facilities to accommodate for salmon being grown to slaughter weight. That would require immense investments and huge land areas. It is also problematic to solve practically.
2. They have on land facilities for post-smolt up until 300-500 g.
3. It is not viewed as a threat. The share size of the market and the demand for salmon is simply too high to only be served by land based operations.
4. If lice can be avoided a huge amount of costs would be saved. They have a range of non-drug based methods already in place. It is up to the consumers to evaluate whether the product is exclusive or not.
5. They are already using freshwater to reduce lice. It is not a perfect solution, because lice can survive this treatment. This could be a problem for the wild salmon stock since lice might develop immunity, and wild salmon uses freshwater naturally as a mean to get rid of lice.
6. The concerns regarding omega-3 have been raised for a long time. A lot of important marine fatty acids such as EPA and DPA are produced by marine organisms. They think that within 2-3 years the production of marine algae would be cost efficient enough to implement on a large scale effectively solving the omega-3 issue.

8.3. Comments

It was interesting to get the companies' view on these issues. In general, the companies have fairly the same opinions on all of the questions above. Addressing land based production sites they all were engaged in this form of fish farming, but to a limited extent. Their commitment to investments and capacity differed a bit as they are companies of different sizes. They have on land facilities accommodating for smolt of different sizes. The companies also do not see land based facilities as a threat today mostly due to low volumes and the huge investments it would require. In the field of treatment of lice all of the companies have a range of methods covering non-drug based treatments, both active and passive such as freshwater treatment and cleaner wrasse, respectively. They also have an interest in the quality of the fish feed, and that it contributes to a healthy and safe salmon on the dinner plate.

9. Conclusion

Theory and practice differs a bit. In theory land based is almost as good as sea based at least isolated for costs. The production costs for traditional sea based fish farming with pre-grown smolt on land up to 100 g are NOK 26.50 per kg. The corresponding number for a full-fledged land based operation is NOK 26,75 per kg. Both numbers are from a study conducted by Deloitte.

As recently stated sea based fish farming is a bit cheaper. This is largely due to high usage of capacity and low feed factor i.e. a well-run operation. In the same manner, the land based option is also based on a well-run operation, but since this is a fairly unexplored area of aquaculture it is reasonable to assume that a period of trial and error will follow. In the first generations of land based fish farming we would therefore experience higher production costs.

Regarding the investment costs associated with sea based salmon farming, whether for a new production site or increase production by 5000 tons, it is around NOK 325 – 470 mill. Included in this is four concessions with a total prize of NOK 60 – 80 mill. For a land based operation those costs can be assumed to be 0 since production is possible immediately after the construction is built and approved by the proper authorities. The investment costs for a land based operation site could actually be lower than its competitor with a span of NOK 300 – 450 mill for a capacity of 5000 tons.

Despite these numbers, it seems that the industry itself is expectantly, but by no means negative to the concept of land based facilities. They have utilized land based production sites to produce smolt, and also have specific plans of expansion. The companies are also very aware of the challenges, and they are committed to finding solutions for the betterment of salmon and humans.

10. Attachments

	Base	Land based RAS	Cage offshore	Closed, exposed	Closed, protected
Production	10000	3300	10000	3300	3300
Productivity	30	180	30	70	80
Investments	219	10000	500	4000	2500
Current assets (NOK/kg)	23	20,6	23	23	23
Lifetime facility (year)	6,7	20	10	10	10
Mortality (%)	20	10	20	15	15
Price of smolt	8,75	6	8,75	8,75	8,75
Economic feed factor	1,26	1,1	1,26	1,2	1,15
Price feed	8,88	8,88	8,88	8,88	8,88
Insurance fish (%)	0,5	0,25	0,5	0,5	0,5
Insurance facility (%)	0,15	0,10	0,15	0,15	0,15
Oxygen (kg/kg feed)		0,35			
Price oxygen (NOK/kg)		2			
Organic waste (kg/kg feed)		0,25			

Price organic waste (NOK/kg)		0,5			
Alkalinity (kg/kg feed)		0,25			
Price alkalinity		0,25			
Employees		10			
Price (NOK/full-time equivalent)		650			

Table 8: Prerequisites for production costs' model. Retrieved from (Iversen, Andreassen, Hermansen, Larsen, & Terjesen, 2013).

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