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TITLE: Are closed production technologies the solution to the sustainable challenges?

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Summary

Norwegian aquaculture is in a state of sustainable challenges that much be solved regarding traditional open net-pen production infrastructure. The Norwegian aquaculture industry currently finds itself in a state of sustainable challenges with the primary traditional open net-pen production infrastructure. These challenges have led to the stagnant production of salmon in recent years and rising production costs, even with the growing demand for protein-rich salmon. The government wants to invest in the aquaculture industry by increasing production by 2050 and increasing value creation in Norway. This has led to the radical technological development of land-based closed containment systems and sea-based semi-closed containment systems to potentially solve the environmental and biological challenges faced in the industry. Moreover, this phenomenon has spurred the government to develop aquaculture permits intended to promote these technological production initiatives.

In this thesis, we seek to discover *"What economic benefits does society achieve by basing further growth on technology for closed facilities?"* We achieve this through using an exploratory qualitative method. This thesis is considered a comparative case study where the purpose is to provide a basis for assessing the role of two types of closed-cage technologies and how it can play in further growth and development in Norwegian aquaculture. To answer the research question, we have collected primary data through qualitative interviews with Tytlandsvik Aqua and FishGLOBE, representing their respective closed technologies. Secondary data was collected through archival and documentary research from various research reports, news articles, et cetera. Based on our qualitative research methods, we have conducted a cost-benefit analysis, production cost calculations and sensitivity analysis to compare the closed-cage technologies against each other.

The results show that there are advantages and disadvantages with both technologies, and it is challenging to control microbial and chemical water quality. Findings indicate that land-based facilities are more expensive than semi-closed facilities, mainly due to various factors. Common to both technologies is that they can solve the problem related to lice and diseases and reduce the climate footprint. The technologies can thus lead to sustainable production growth while reducing environmental challenges. Furthermore, we discuss the implication of potential repercussions closed technologies can have on society. An increased production volume and implementation can boost the export industry to meet global demand and increase employment. Although the biggest obstacle to closed-cage implementation is the high capital cost, several environmental trade-offs are discussed, compensating for the high investment. Finally, findings imply fostering innovation and research and development for closed-cage technology to develop to its full potential. Today, combining both closed-cage and traditional open net-pen will be a potential solution, as it will only be a supplement to current production.

Keywords: Norwegian aquaculture industry · Production technologies · Technological development · Sustainable production growth

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1. Introduction

1.1 Background

In recent years, the demand for Norwegian farmed fish has increased significantly and will continue to increase. Today, only 3% of food comes from the ocean, although the potential is much higher (Tveterås et al., 2020). Consequently, salmon has become a significant source of protein, at the same time as it has become an essential export item (Tveterås et al., 2020). Salmon exports make up the largest share of seafood exports, as 1.1 million tonnes of salmon worth NOK 70 billion were exported in 2020 (Fisk Media, 2021). The Norwegian government has visions of establishing a fivefold increase in salmon farming by 2050 (Ministry of Trade, Industry and Fisheries, 2013). A prerequisite for the estimate is that growth must be sustainable. This implies the industry's need to solve the current challenges of environmental impact, disease transmission, and fish health. It is also crucial that the industry succeeds in developing new and innovative solutions (Ministry of Trade, Industry and Fisheries, 2013).

Open net pen (ONP) technology has been dominating the Norwegian aquaculture industry. According to The Nature Conservation Association in Norway, fish farms with open cages constitute a significant burden (Christensen, 2019). A growth based on this technology is a substantial threat to the Atlantic wild salmon and does not contribute to sustainable growth. Disadvantages with open cages are high risk of salmon lice, poor fish welfare, and escapes. Only 20% of the fish stocks are in good condition, where salmon lice have the most significant negative impact (Christensen, 2019). As a matter of fact, challenges with salmon lice are estimated to have cost the industry in Norway over NOK 5 billion in direct costs in 2019 (Jensen, 2020).

Attractive basic fundamentals for traditional open cages salmon farming may have formed the basis for the increased attention. From a historical perspective, the price of Atlantic Salmon has been relatively high, and it continues to set new price records, and thus has strong future prospects. This is a result of increasing global demand, while environmental and biological challenges for traditional open net-pen (ONP) limit production growth.

Researchers have in recent years found that one can produce fish without a high risk of salmon lice and escapes in closed facilities (Christensen, 2019). Studies show that the production time is significantly reduced before it is moved to the sea and affects the strength of the fish and how much they can withstand. The Norwegian government believes in growth through the use of closed facilities (NOU 2019: 18). Several facilities are being developed and tested for both land-based closed containment systems (LBCC) and sea-based semi-closed containment systems (SCCS). Nevertheless, there is still minimal research on closed technology, and it will have a significant impact on land use, energy consumption, climate tracks, and sludge production (Kraugerud, 2019).

1.2. Research question

Based on the desired sustainable growth, and the increasing focus on closed farming technology in the aquaculture industry, our research question is as follows: *"What economic benefits does society achieve by basing further growth on technology for closed facilities?"*

1.3 Motivation

This thesis will focus on land-based and semi-closed salmon farming in Norway, as the competences and technology dominate the industry development. The purpose of the thesis is to provide a basis for assessing the role that closed-containment technology on land and at sea can play in further growth and development in Norwegian aquaculture. By looking more detailed into benefits and challenges with closed-containment post-smolt production, and further analyzing the production costs per kilo of adult salmon will give us a picture of how the future of the salmon industry might look like. Thus, this thesis will discuss the repercussions of implementing new closed-containment technology, and whether this can contribute to increasing production in a sustainable way to achieve the government's goal of a fivefold increase. This is highly relevant to discuss and can have an impact on further development of this emerging industry.

The process of writing this thesis has been more challenging than expected. A great effort has been made to study and acquire knowledge about the salmon industry, which is a new subject field to us. A lot of time has been spent gathering information from an array of different sources to create a complete overview of the industry. Furthermore, as closed technology is only in its starting phase, it has required significant efforts to understand and predict the future. We hope our work contributes to increased insight into the land-based and semi-closed farming industry.

1.4 List of Abbreviations

- MAB Maximum allowed biomass
- ONP Open net pen
- LBCC Land-based closed
- SCCS Semi-closed containment system
- RAS Recirculation aquaculture system
- FTS Flow through system
- kWh Kilowatt hours
- TWh Terrawatt hours
- SSB Statistics Norway ("Statistisk Sentralbyrå" in Norwegian)
- CEO Chief executive officer
- CCS Closed containment system
- R&D Research and Development
- NOK Norwegian Krone(r)

1.5 Choice of Companies

This thesis aims to generate insight from intensive and in-depth research within a real-life setting, and it, therefore, falls naturally to conduct a comparative case study. The two technologies are complex, and there is a need to deconstruct the various elements. To answer the research question and acquire the necessary knowledge, this thesis depends on finding two selected case companies that could each represent their respective closed-cage technology. Therefore, Tytlandsvik Aqua and FishGLOBE were chosen as interview objects for the thesis. Both of these companies are well established in Rogaland, Norway. Moreover, these companies are forward-looking and innovative as they contribute to a profitable and sustainable farming industry.

1.5.1 Tytlandsvik Aqua

Tytlandsvik Aqua is a good example that can represent closed technology on land (Tytlandsvik Aqua, 2021). Like many other land-based companies, Tytlandsvik Aqua is under development.

The company was started in 2014 and is currently under construction. The owners of the company are Bremnes Seashore AS, Grieg Seafood Rogaland AS, and Vesthavbruk AS. In the first stage, the company will have a production capacity of 3,000 tonnes and is investing in large smolts for food fish farmers in Rogaland. The planned facility has RAS technology (Tytlandsvik Aqua, 2021). The thesis studies Tytlandsvik Aqua as it is a local company already known. In addition, the media gives the impression that the company has grand ambitions for further development. Based on this, it is desirable to study how the technology works in practice.

1.5.2 FishGLOBE

A good example that can represent closed technology at sea is FishGLOBE. The company was established in 2013 and is today owned by Havbrukskompaniet AS and develops, builds, and sells its patented solution for closed farming (FishGLOBE, 2020). This company is also under development. The company's vision is to create new cost-effective solutions that enable the aquaculture industry to grow further in a good and sustainable way. Today, the company has a so-called "globe" in operation, which has shown promising results (FishGLOBE, 2020). The media highlights the company’s investments and strong desire for success within a new and innovative technology. FishGLOBE is chosen to represent closed technology at sea as this is also a local company. In addition, it is desirable to study how the technology works in practice.

1.6 Outline

The thesis consists of a total of nine chapters, including references and appendices. The next chapter looks at the topic and the following research problem. Furthermore, one introduces the aquaculture industry and creates a knowledge base for further reading. Moreover, the theory presented forms a basis for answering the problem. Chapter 4 explains the thesis’s methodological approach and choices before showing the study's analysis and results. Further, one discusses the results alongside relevant theory and discusses the reprecussions the findings may have on society. One will also present proposals for further research and limitations of the report. Finally, in the conclusion the thesis aims to answer the research question.

2. The Norwegian Aquaculture Industry

This chapter presents the knowledge to form a comprehensive overview of the current state of the Norwegian aquaculture industry. Moreover, the chapter aims to facilitate a better understanding of the significant impact that closed production technology can lead the farming industry´s development path. Thus, this chapter explains the fundamental information in this structure: the industry's and governement’s regulations, productivity and cost development, the salmon´s life cycle, production technology, and finally, sustainable challenges related to the salmon industry.

2.1 Regulations and Permits

The Aquaculture Act is one of the essential laws in Norway and has the purpose of promoting the competitiveness and profitability of the aquaculture industry within the framework of sustainable development and contribute to value creation on the coast (Mowi, 2019; The Aquaculture Act, 2005, §1). Norwegian Aquaculture is a license-based industry, which means that farmers must apply for a permit to establish and operate (Ministry of Trade, Industry and Fisheries, 2017). The government constitutes licenses to control capacity of production and, further, reduce the industry’s negative environmental footprint. Today, production limitations are regulated as “maximum allowed biomass” (MAB) and the license’s standard size is 780 tonnes (Mowi, 2019 :Ministry of Trade, Industry and Fisheries, 2017).

To get a license from the government, the applicant needs to comply with three requirements. Firstly, one must achieve a new production license (FAO, 2020). A low number of licenses are given, and for example, in 2018, the maximum allowed number of 1,041 licenses was utilized (Mowi, 2019). Secondly, applicants are prioritized based on the Aquaculture Act because of the low number of available licenses. Thirdly, to achieve a license, a fee must be paid (FAO, 2020).

In 2015, the government announced another way of assessing license, which had intentions of motivating investments in the environmentally sustainable and innovative farming technology of land-based cage containment systems. The allocation of development licenses was free of charge and lasted up to 15 years (Mowi, 2019). The new regulations have been much discussed for utilizing the scope of investment in new technology as its primary objective, which may not consider the success of the innovative technological explanation (PwC, 2017).

2.1.2 Traffic Light System

In 2017, the authorities established the "Traffic light system" that regulates future growth in the aquaculture industry based on an action rule related to regional sustainability. The regulations contribute to sustainable development in the industry, and as part of the new regulation, it divides the coast into 13 production areas. Growth status quo or reduction of production in each zone shall be calculated based on annual assessments of lice-related mortality. In addition, each location is monitored and has an assigned color. The different colors describe where and how much one can produce salmon considering the environment and impact on the area (Regjeringen, 2017)

The colors are as follows: Green zone is the least affected area by aquaculture production and can produce the most. Farmers can get 6% growth in this zone because it estimates less than 10% die due to salmon lice. The yellow zone is thus the intermediate stage, with moderate production. This zone gives no change in production and is the category that estimates that 10-30% of salmon smolts can die. Furthermore, the red zone which the strictest zone where it is allowed to produce the least concerning the environment, where salmon lice and diseases have the greatest danger of affecting wild fish. The red zone can have a 6% reduction in production, as it estimates that over 30% of the salmon salt dies from lice. Farmers who fall into this category have the opportunity to apply for an exemption from reduction if they can document low lice numbers (Fagerbakke, 2020) Figure 2.1 presents the traffic light system zones (Trøndelag Fylkeskommune, 2020).

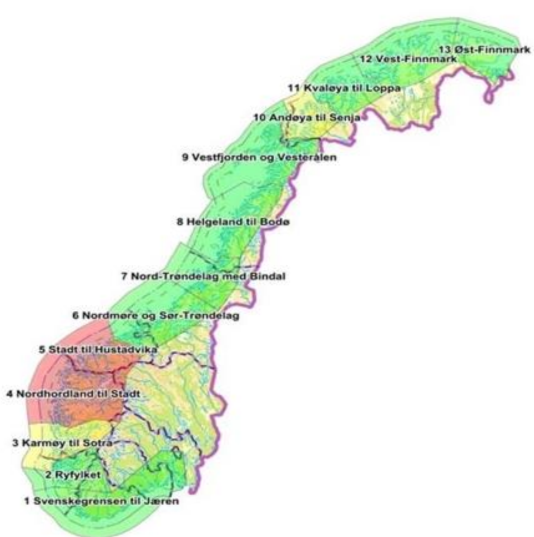

Figure 2.1: The Traffic Light System Zones

2.2 Productivity Development

Historically, the productivity in the Norwegian aquaculture industry has had a significant increase. The aquaculture industry has experienced an adventurous development since the 1970s and has increased production from 400 tonnes to approx. 1.2 million tonnes since 1980. Until 2013, there was a very high production growth of salmon in Norway with an approx. 10% increase each year for the past 20 years. The remarkable productivity growth is mainly due to innovation in several areas, such as genetics, fish feed and feeding equipment, vaccines, information technology, production equipment, and distribution channels (Asche, Roll & Tveterås, 2012; Norsk Industri, 2017). However, in 2012 the industry experienced stagnant growth for years. e.g., production decreased in 2016 by approx. 5% from the previous year due to salmon lice and its consequences (Norsk Industri, 2017).

According to Manolin´s industry data (2020), the salmon companies' production efficiency has declined over the past five years. Manolin´s calculations are based on the production efficiency, i.e., how much each farm or locality can produce on its allocated biomass. Data from the survey reveal that the average Norwegian salmon farm has become less efficient. Furthermore, findings indicate that the small fish farming companies struggle with production efficiency, while the ten largest companies manage to maintain it. Moreover, results show that some variables contribute to this. Still, declining fish health and welfare, increasing regulatory pressure from the Government, increased production cost, and regulatory pressure in recent years are reasons to believe that the odds stack up against farmers (Riise, 2020b; Chen, 2020).

2.3 Cost Development

The Directorate of Fisheries' profitability survey for 2019 shows that profitability is still high for salmon farmers. The high salmon price is the reason for the good result. A low production growth has resulted in high sales price, and the changes in the increased export volume, exchange rate and supply growth (Bøhren, 2021: KBNN, 2019). However, increased costs are said to threaten profitability, which will be further explained below (The Directorate of Fisheries, 2020).

Year	Production cost per kg
1985	69.37
1990	46.39
1995	26.07
2000	18.81
2005	15.75
2010	20.40
2011	19.85
2012	19.31

Table 2.1: Development in Average Production Cost Per Kilo of Fish Produced (Figures in 2012 NOK).

Table 2.1 shows that the average production cost per kilo fell sharply from 1985 to 2001, mainly due to underlying productivity growth. Furthermore, the development of production costs per kilo of salmon produced continued the declining trend from 2002 to 2005. The average production cost per kilo reached the bottom at NOK 16.80 per kilo. The cost level has been somewhat more variable, but with an increasing trend from 2005, as shown in Figure 2.2 (The Directorate of Fisheries, 2013) By 2015 it had increased to NOK 26.15 per kg, an increase in the real price of 55.7% over 10 years or almost a doubling in nominal terms (The Directorate of Fisheries, 2020).

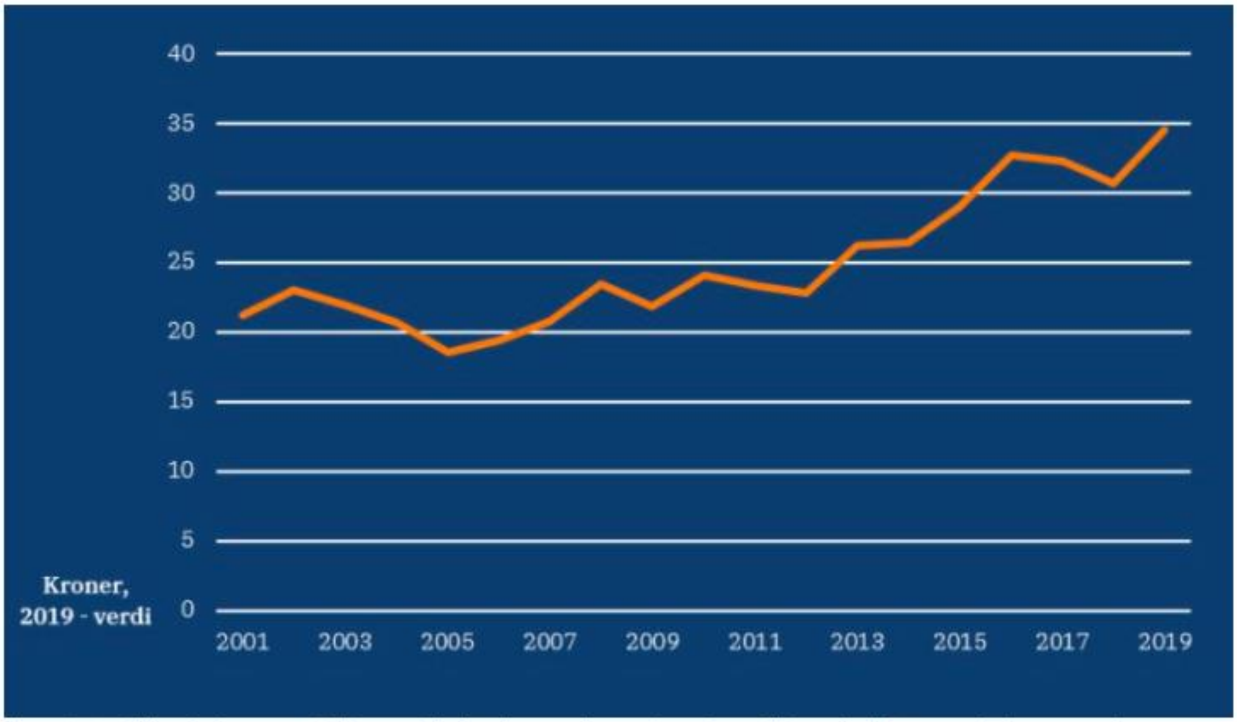

Figure 2.2: Development in Average Production Costs Per Kilo in Adult Salmon Production of Salmon.

The Directorate of Fisheries' profitability survey results shows that production costs have been increasing over several years. For example, from 2001 to 2019, production costs per kg increased by 58.8%. Meanwhile, from 2018 to 2019, average production costs per kg increased by 14.8%. The cost increase from 2018 to 2019 was a general cost increase, and the expenses increased due to lice and other diseases. In addition, the algae outbreak in Northern Norway contributed to increased costs in 2019. Moreover, figures from 2019 show that the average production cost per kg was NOK 34.54 (The Directorate of Fisheries, 2020)

2.4 Lifecycle of Salmon

The farming process consists of several different phases and takes two to three years, from the hatching of eye roe to adult salmon (Nessodden Smolt, n.d.). Figure 2.3 presents the lifecycle of the salmon (Foras na Mara Marine Institute, n.d).

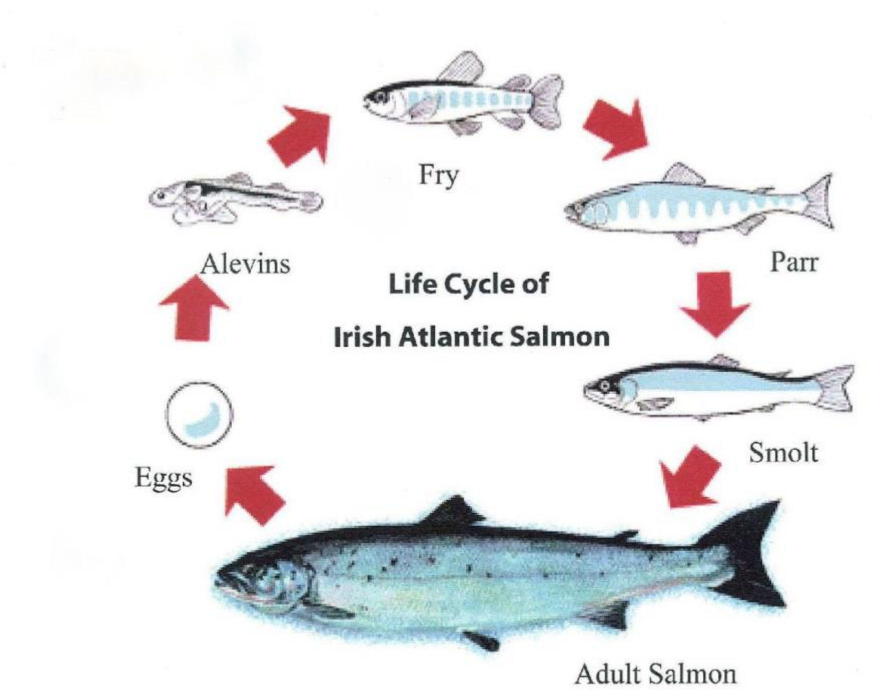

Figure 2.3: Life Cycle of Atlantic.

Roe

The first step of the process is to select the best brood fish based on color and growth. Roe irons from the female and fertilizes with milk from the male. Afterward, the roe is placed on grates in a vessel for hatching.

Fry

The salmon's life cycle starts in freshwater, and the roe is allowed to hatch for about 60 days at 8ºC before it hatches. 4-6 weeks after hatching, the fry can begin to absorb nutrients from the feed, and it is then usually moved to larger tubs.

Parr

The fish is called parr at this phase and can still not adapt to life in the sea. The fish now have dark marks along the side, which are called parr marks. Throughout this process, vaccination and good water quality are critical.

Smolt

This phase is called smoltification, and the fish slowly adapt to life in the sea. After 10-16 months in freshwater, the fish moves to saltwater. The smolt now weighs 60-120 grams.

Adult Salmon

The salmon are kept in cages along the Norwegian coast until they reach a weight of 4-6 kilos. After 18 months, the fish is ready for slaughter. Eventually, a boat brings the salmon to slaughter, where workers pack and sort the fish by quality and size.

2.5 Production Technology

It is distinguished between different types of production technologies as farming can operate in various ways. In the following subchapter there will be an explanation of three different farming systems that are in use and under development in Norway. These include traditional open sea-based farming and closed-cage farming including land-based farming and semi-closed sea farming.

2.5.1 Open Sea-based Farming

The traditional open-cage system is a fundamental reason for Norway's success within salmon farming (Rosten, Terjesen, Ulgenes, Henriksen, Biering & Winther, 2013). Open-cage technology consists of nets that hang down into the sea attached to a floating ring. The technology utilizes Norway's natural advantages with ample access to clean seawater and is an affordable technology. These cages are flexible as it is easy to move both facilities and fish and usually ensures extensive water exchange without using energy for pumping, and they are very flexible. The growth and feeding of fish are predictable, and there has been a success in upscaling traditional cages, as production costs have been reduced. However, there are challenges associated with traditional fish farming. The nets are open and are therefore available to infectious parasites and diseases, like salmon lice. Escape is also a negative effect due to holes in the net (Rosten et al., 2013).

2.5.2 Land-based Farming

Land-based farming technology is produced alternatively to open cages. In land-based fish farms, the salmon grows in facilities on land (Misund, 2021). The fish´s natural behavior is supported by a circular water flow in the tanks. New water is typically introduced on the tank's side and then moves tangentially along the tank wall. When the incoming water pumped in from the outside gains speed, it will adapt to the movement of the existing water in the tank, and less energy is required to maintain speed (Nazar, Jayakumar & Tamilmani, 2013).

The tank's total volume determines the facility's production capacity combined with the storage density, measured in kilograms of biomass per cubic meter. Food fish production of salmon will be considerably affected by what refers to as post-smolt. The aquaculture industry today, substantially uses land-based technology to produce post-smolts up to 1 kilogram, before transferred to open-net farming. There are no restrictions on how large the fish must be before it is released. It is also possible to produce adult salmon on land, but aquaculture permits are required. However, adult salmon production in land-based facilities is currently not commercially successful in Norway (NOU 2019:18).

A post-smolt production of 1 kilo will require a significant increase in the water consumption at the facilities. Farmers can reduce concerns regarding the water demand by recycling the water utilizing recycling technology. Besides reducing the water demand significantly, the intake water can be disinfected (UV-treated), and wastewater filtration will reduce emissions from land-based fish farms, which the thesis will further explain in the following subchapter. Furthermore, it can open up for localization in less ideal areas (Hilmarsen, Holte, Brendeløkken, Høyli & Hognes, 2018)

Post-smolt results from the industry's desire to make the fish more robust and shorten the 18 months production time at sea, which reduces the risk of various externalities and other cost drivers. The post-smolt strategy is mainly about improving fish welfare and achieving a more stable and sustainable production (Senstad & Bolstad, 2017). Moreover, unlike sea-based aquaculture, land-based farming does not need aquaculture permits, because the government wants to speed up the possibilities for land-based farming of salmon and therefore offers free farming permits (NOU 2019:18).

There are two types of land-based aquaculture production technologies: flow-through facilities (FTS) and recirculation aquaculture facilities (RAS). The main difference between these two technologies is the degree of water recycling. In addition, some facilities are combination facilities, with one or more sub-streams to flow-through departments and one or more sub-streams to RAS departments.

2.5.2.1 Flow-through System

Traditionally, land-based farming has been using flow-through technology. The conventional FTS technology has 0% water recycling as it is based on pumping water from a water intake to the fish tanks where it is used once before being disposed of (Holm et al., 2015). Therefore, the total water requirement required in the fishing vessels must be obtained from one water source and passed on to the recipient, which means a large water consumption. However, such technology is perceived to involve a low degree of complexity because FTS does not process the intake of water or wastewater (Bjørndal, Holte, Hilmarsen & Tusvik, 2018).

The FTS technology has shown improvements in recent years, which has resulted in a modern facility where both water recycling and treatment systems for water intake and wastewater (Bjørndal et al., 2018). The recycling technology used in FTS adds oxygen and removes CO_2 from the water, and up to 30-70% of water can be recycled. Researchers find that using proven technology with high reliability, flow-through systems are viewed to involve substantially less risk than recirculating aquaculture systems. FTS has greater availability of verified operating parameters concerning water quality (Bjørndal et al., 2018). Overall, technological development has increased the degree of complexity in a modern flow-through system and making it possible to combine RAS and conventional FTS (Bjørndal et al., 2018).

2.5.2.2 Recirculation Aquaculture System

The knowledge Norway has developed on land-based salmon farming in modern RAS facilities over the last 20 years, has become very sought after internationally (Benjaminsen, 2021). With such closed land facilities where water is recycled, farmers can produce fish almost anywhere as long as freshwater is available (Mota, 2020) RAS facilities provide the fish with oxygen, remove waste and pathogens before being filtrated, oxygenated, and return to the fish. The water treatment process uses mechanical removal of particles and biological filters containing bacteria to remove, transform and defuse waste materials. The cleaning process usually consists of an automatic drum filter, a bio step or biofilter, and degassing (Lomnes, Senneset & Tevasvold, 2019). Further, one removes carbon dioxide, oxygen added, and the water disinfected and controlled for PH level and salinity (Noble et al., 2018). Depending on the scope, this extensive water treatment yields a degree of water recycling of 95-99% (Holm et al., 2015).

It is difficult to have good enough control over microbial and chemical water quality in land-based RAS facilities. In addition, there can be significant differences internally in the facilities. Netzer (2020) emphasizes that efficient water purification and stable microbiology are essential parts of the recipe for responsible and sustainable production in such facilities. Moreover, high demands are according to Waagbø (2021) placed on water quality, pre-quality, hygiene in the facilities, and fish welfare.

2.5.3 Closed Sea-based Farming (Semi-closed)

Semi-closed containment systems (SCCS) can be defined as a fish-producing system having an impenetrable barrier separation the fish from its surroundings (Øvrebø, 2020). The method involves putting out smolt in closed facilities at sea until they are one kilo when they transport to open cages. The facilities vary in shape, volume, material, and size. The water pumps from a 20-30 meters depth, where one can avoid areas where sea lice are the most abundant.

One can expect precise monitoring of the system and stable water quality compared to open cages which is fully exposed. The fish swim constantly upstream due to the water being pumped and forming a continuous stream. The stream have an aerobic effect on the fish. In closed facilities at sea, it will also be possible to handle waste to a greater extent and reduce the period in open cages, and it will be possible to manage and collect the sludge from the fish (Øvrebø, 2021). This technology is often referred to as semi-closed facilities because there is no full control of intake and emissions. The facilities can gather particulate organic material but not the dissolved wastes (Tveterås et al., 2021).

2.5.4 New Production Regime - Combination of Land and Sea-Based Farming

In 2011 as part of the work to further develop and improve the industry, the authorities granted a dispensation for the growth of juvenile fish up to 1000 grams, alongside the previous maximum limit of 250 grams. Moreover, this opens up the possibilities for a combination model of land-based production to 1000 grams and then releases the smolt in open cages for further growth until the desired slaughter size. Furthermore, permission has recently been granted to produce adult salmon on land, meaning the fish is grown on land throughout the salmon cycle, from post-smolt to adult salmon (NOU 2019:18). Thus, both Tytlandsvik Aqua and FishGLOBE use a combination model for farming, which is what this thesis studies.

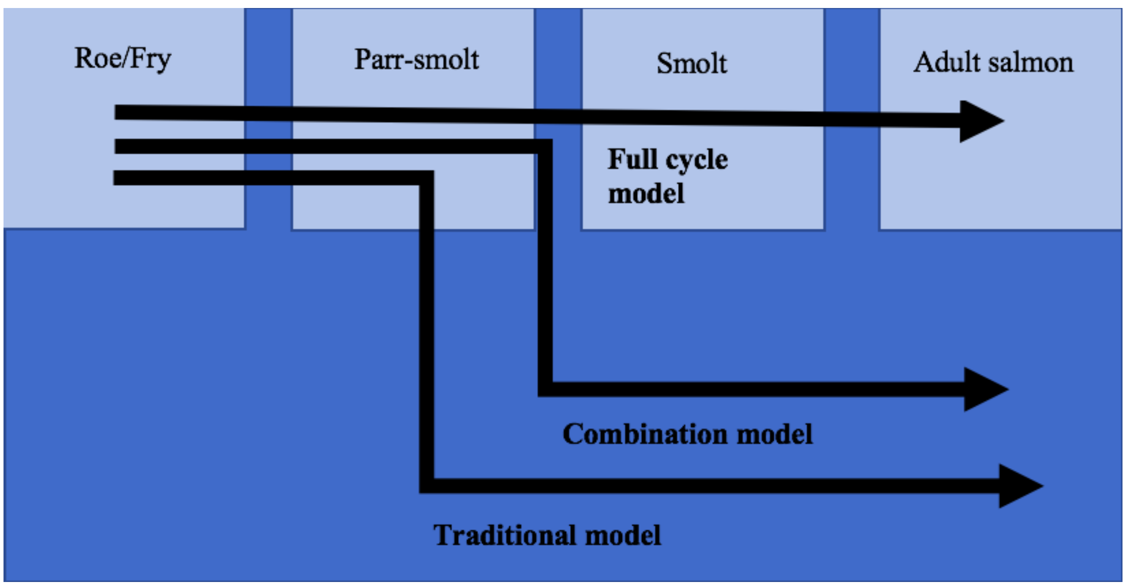

Figure 2.4: Illustration of Different Production Regimes

2.6 Challenges in the Aquaculture

The following subchapter outlines the negative externalities regarding biological and environmental challenges. These are the major challenges that threaten aquaculture and future growth in the industry. Thus, a simple introduction and explanation of the various factors will be given, and further, analyzed in chapter 4.

In the long term, the biological situation in open cages will not be sustainable. Therefore, this subchapter will look at the most prominent challenges regarding traditional farming. It is also worth mentioning that there are many other challenges, but this thesis will be limited to the following biological challenges: mortality, salmon lice, disease, and escape. In addition, there are also environmental challenges threatening the environment and further growth, which refers to land use, energy consumption, and emissions.

Mortality

Mortality in fish farms is skyrocketing because farmers have to use increasingly rigorous methods to control salmon lice. The Fish Health Report, performed by The Veterinary Institute (2021), shows that 52 million salmon died in cages in 2020, compared with 53 million in 2019 and 46 million in 2018. In 2019, algae bloomed along the coast in Nordland and Troms, leading to 8 million salmon dying. The Veterinary Institute (2021) points out that lice treatment and disease are still the leading cause of mortality in farmed salmon, and it was a peak year for non-drug lice treatment where thermal de-lice was the most widely used method. The feed company, Ewos, has estimated that salmon lice cost the fish farming industry in Norway ten billion kroner a year. As lice become resistant to the most commonly used drugs, farmers must constantly use new non-drug methods (Berglihn, 2017). The thesis describes various treatment methods in the next chapter.

Salmon Lice

Salmon lice are the most common parasite on farmed salmon and consider as the biggest problem in the aquaculture industry in Norway. It is a small marine parasitic crustacean and damages the fish by feeding on their blood, skin, and mucus. Further, it reduces the fish's physical well-being and makes them more vulnerable to other infections caused by bacteria, viruses, or fungi. Furthermore, it also affects the fish's salt balance. Large numbers of salmon lice can cause the fish to die, in addition to indirect damage, reduced growth, and fewer habitats weaken the reproductive potential of wild salmonids (Dalvin, Karlsen & Samuelsen, 2021).

Dalvin et al. (2021) reveal that monitoring programs of salmon lice show that the magnitude of the problem is increasing. The infection pressure from salmon lice has risen dramatically in coastal areas with many fish farms (Albretsen et al., 2020). An increase in lice is a considerable threat to the smolts when they migrate out to sea during the spring season, along with being a threat to wild salmon (Norwegian Food Safety Authority, 2018). Farmers use cleaner fish, mechanical methods, and medicines to combat salmon lice. The latter is the most common way to fight salmon lice, which farmers do by adding the treatment to the fish food or bathing. Meanwhile, cleaner fish eat parasites that sit on the farmed fish and are most effective on smaller salmon when the water is not too cold (Norwegian Food Safety Authority, 2018).

Pancreatic disease (PD) is also a significant disease, and the number of infected localities is high (Veterinary Institute, 2019). There is no cure for viral diseases, but the most important thing is prevention. When detecting, it is essential not to stress the fish. Thus, one must still work on research on preventive fish health. Illness is a high cost to the industry, reduces fish welfare, and damages the industry's reputation and the shared environment (Veterinary Institute, 2019). Furthermore, The Veterinary Institute points out in the Fish Health Report that more effective disease control will be costly and profitable and will lead the sector to be more sustainable (Veterinary Institute, 2019.

When many animals gather in a minimal space, good dispersal conditions for diseases and parasites occur. Historically, antibiotics in the Norwegian fish farming industry have generally been high, but since 1987 they have reduced consumption by 99%. Smolt vaccinates against the most critical diseases before releasing into cages, and this means that the exact amounts of antibiotics are not as necessary as before (Salmon Facts, 2016). However, drugs and chemicals fighting infections can also negatively affect the environment by spreading rapidly in the water masses (Markusson, 2020).

Escape

The escape of fish is an environmental challenge for the aquaculture industry. The fish can escape from facilities on land, i.e., through the drain or facilities at sea (Barentswatch, n.d). The fish can escape due to reasons such as technical failure, incorrect use of equipment, removal of salmon lice, vessels, and propellers that damage the net, wear from weights, collisions with boats, or lousy weather most common causes (Føre, 2019). One monitors the rivers in Norway, where one can find the amount of escaped farmed salmon. The monitoring takes place in a national monitoring program for escaped salmon. The fish farmers have a joint responsibility to remove escaped farmed fish in rivers with unacceptable levels. The law requires farmers to participate and finance an association with responsibility for this (Hosteland, 2018: Barentswatch, n.d.).

Land-use

It is essential to have efficient and sustainable land use. After the aquaculture industry blew up the last few years, farmers wanted suitable areas, and it became necessary to control the productive area off the coast. Poor planning and placement of facilities will help to strengthen the problems that already exist in the aquaculture industry, while the opposite will help alleviate them. Today, areas are vacant as a result of a high risk of salmon lice spreading and escaping (Regjeringen, 2021)

Energy Consumption

Energy is necessary for the water treatment processes, feeding and lighting in the fish tanks, heating and ventilation of buildings, and various other support functions such as dead fish handling and vaccination. The energy carrier used is electricity, but one can use diesel, oil, or gas in some cases for heating water. Therefore, one can divide energy consumption for land-based farming into heating of water in energy facilities, pumping of intake water, pumping of air for CO2-ventilation, pressurization of water for oxygen supply, heating, cooling, operation of filters, ventilation, and average consumption corresponding to other industrial and commercial buildings **(**Bjørndal et al., 2018**).** Although closed facilities at sea consume less energy, the technology consumes energy by pumping large volumes of seawater (Tveterås et al., 2021).

Emission

Tveterås et al. (2021) distribute the emissions as a share of feed consumption as follows; feces (approx. 26%), feed waste (approx. 7%), and the rest dissolved nutrients. The most significant part of the nutrient emissions in fish farming represents two nutrients, nitrogen and phosphorus (Bellona, 2006). In general, nitrogen is most important in saltwater, while phosphorus is most significant in freshwater. Therefore, fish farming is the largest local source of discharges of nutrients and organic particles along the coast, which have significant consequences on the environment. Such releases can have varying degrees around the facilities, depending on electricity and bottom conditions. Fish farming will often not be a pollution problem in areas with good water quality and water exchange. Meanwhile, in areas where the natural conditions are not as good, the total load can be significant (Vannforeningen, 2016).

Further, if the production is too high compared to the load-bearing capacity of the location, the emissions can negatively affect the environment. To put it differently, it has a fertilizing effect on the water masses. If the discharge becomes too large concerning what the water masses can withstand, it will reduce the water quality. Reduced water quality has consequences both for the surrounding environment and the fish farm's environmental condition. To ensure that the individual locality is not exceeded, the farmer must regularly document that the environmental condition of the locality is satisfactory by Norwegian Standards (NS 9410) (Laksefakta, 2018).

3. Theory

The purpose of this chapter is to explain the theoretical context of the thesis's research question. First, one explains vital concepts related to the definition of sustainability before discussing innovation and technological development. Further, the chapter deals with the existing theory of externalities and capital access before discussing the framework of economic analysis.

3.1 Sustainability

Sustainable development defines as development that satisfies today's needs without destroying future generations' opportunities to meet their needs (UN, 2019). There are three dimensions related to sustainability that must be present to ensure sustainable development worldwide. These dimensions are environmental conditions, social conditions, and economic conditions. The environmental condition of sustainable development includes taking care of climate and nature as a renewable resource for people. The social part of sustainable development is about ensuring that all people have a fair and reasonable basis for a decent life. Finally, the economic condition provides financial security for society and people (UN, 2019).

In the context of aquaculture, sustainability uses two different meanings (FAO, n.d.). The term can refer to the financial sustainability of aquaculture and is about generating a profit and maintaining a stable level of returns over a more extended period. Sustainability can also refer to the environmental responsibility of aquaculture. Moreover, aquaculture can lead to ecological damage and impose costs on society (FAO, n.d.). The industry impacts the environment in five main areas: escapes and genetic interaction, pollution and discharges, disease, zoning, and feed and feed resources. In the thesis, the term "sustainability," uses the aspect of both financial and environmental sustainability.

3.2 Innovation

Innovation is defined as the implementation of ideas that introduce a new product or improvement (Schumpeter, 1983). The word innovation means renewal or innovation of new products or production services. In other words, it is a manufactured change of value-creating activities. This type of activity involves qualitative changes that are often irreversible. Furthermore, one can say that innovation involves unpredictability and risk, and thus demanding for organizations and individuals (Ørstavik, 2019). Several years of sound finances, investment, and innovation will have made the Norwegian aquaculture industry robust and world-leading in this field. A close interaction between the authorities, research and development (R&D), and industry has created an aquaculture hub to develop an innovative and sustainable industry (Henriksen & Thormodsdottir, 2020a).

3.2.1 Technological Development

In recent years, today's conditions with a mixture of high profitability and area and environmental challenges have promoted innovation and alternative production technology in the aquaculture industry. In addition, the allocation of green permits in 2013, the traffic light system, and especially the scheme with development permits have provided strong incentives for technology development (NOU 2019:18). The technological developments have had intentions of reducing environmental impact and fish diseases However, technology for the aquaculture industry depends on a good understanding of technology and biology (Hage, 2021). Existing technologies must further develop and improve, and one should map the potential of new technologies Teknologiradet, 2012).

There is extensive technology development at all levels in the industry, and the technology contributes to challenging the regulations (Mellbye, 2020). Farmers face major investment decisions without knowing what rules and framework conditions will apply to this type of business. A critical and relevant question is whether the government will adopt and make adjustments quickly enough. The government has a clear vision that they want to facilitate aquaculture at sea and has worked for years to lay the foundation for a regulatory basis. Still, the legal framework conditions are not fully in place (Bryde & Bruland, 2020).

The development of new technology in aquaculture goes in several directions, and there is a variation of the different types. In addition to results in traditional open-cage facilities, several facilities are being developed and tested for both land-based farming, semi-closed facilities at sea, submersible facilities, and larger offshore installations at exposed locations further out to sea (NOU 2019:18). However, closed-cage facilities are a significant investment in the country, as it is the technology that is growing the most. In addition, closed technology has also contributed to increased international interest.

3.3 Externalities

An externality is a definition for an economic gain or cost. It exists when economic activities such as the production or consumption of an individual affect others positively or negatively, for which the individual actors are not credited or charged financially (Perman, Ma & McGilray, 2003). Therefore, externalities prevent the free market from achieving optimal economic solutions. Thus, one should address externalities, and by doing that, one can achieve sustainable development. The external effects can be positive or negative, but this thesis will only consider negative externalities, as they contribute to sustainability problems without compensating for these costs. Negative externalities from salmon farming are described as environmental and biological challenges in chapter 2.6.

3.4 Capital access

Several credit institutions and other lenders now offer lower interest rates on loans to climate-friendly projects and companies. One specific example was when DNB announced the new green initiative criteria requirements back in early 2020. DNB refuses to finance companies that do not take climate into account. They are committed to offer lower interest rates to green customers that focus on climate and lower emissions. The bank correspondingly stated that green loans will be the new standard, while DNB now includes climate risk in its credit processes. In practice, this means that projects or companies who want loans in the future must rely on the bank being able to ask about their climate emissions and which measures are to be implemented to reduce climate risk. Depending on these criteria, it will affect and practice the basis for the interest rate they receive. If none of the criteria is met, the price goes up and if both criteria are met, the price goes down (Haugan, 2020). Overall, such practices have also recently been implemented in other credit institutions.

Innovation Norway is a state-owned company, which is established with the aim of increasing innovation in the business community throughout the country. Projects that need funding can apply for financial support from innovation, whether in the form of grants or loans. The increased goal of increasing seafood production means that there is a need for new innovation and development that innovation Norway wants to contribute to (Thormodsdottir, 2020).

In 2017 and 2018, the engagement from the aquaculture industry has been somewhat lower, while the units that were applied for became larger. Innovation Norway did not want to finance biomass, and for that reason was not involved on this front. In recent years, this has changed when fish farmers began to apply to the Directorate of Fisheries for development permits. In 2019, the fishing and aquaculture industry received a total of NOK 1,116 billion distributed on 159 different loans from Innovation Norway. The aquaculture industry has received the largest financing in recent years, and innovation Norway has since helped to provide development grants and loans for numerous CCS projects (Riise, 2020a)

3.5 Economic Analysis

Economy can be defined as how society uses its resources, labor, natural resources, production equipment, and technological knowledge (NTNU, n.d.). There is limited access to such resources, and economics is the science of society's use of these scarce resources. When performing economic analysis, the thesis looks at the benefits and costs that pertain to society. It is essential to point out that the presented definition for economy is used throughout the thesis.

An economic analysis has the purpose of clarifying, making visible, and systematizing the effects of measures and reforms (Directorate for Financial Management, 2018). In this way, the decision-maker will acquire a solid and comparable decision basis that can help make the choices. There are three primary economic analyses: cost-benefit analysis, cost-effectiveness analysis, and cost impact analysis. Table 3.1 provides an overview of the various steps in economic analysis based on the framework of Directorate for Financial Management (2018).

Table 3.1: Economic analysis

Economic analysis	
1	Describe the problem and formulate objectives.
2	Identify and describe relevant measures.
3	Identifying effects.
4	Numerate and value effects.
5	Assess samfunnsøkonomisk profitability.
6	Conduct uncertainty analysis.
7	Describe distributional effects.
8	Give an overall assessment and recommend measures.

Describe the problem and formulate objectives

The purpose of the first step is to build a solid foundation for the analysis. First, one describes the reason for changing the current situation. In this description, one finds the challenges of today's position and the status without change. Finally, one describes desirable achievements with the analysis.

Identify and describe relevant measures

The second step aims to describe and identify measures and select relevant methods for solving the problem identified in step one. For the economic analysis to result in a recommendation of the best efforts for society, finding suitable solutions to the problem is essential.

Identifying effects

The purpose of the third step is to identify and describe the effects of the measure. To do this, one should start by identifying all affected groups. In other words, one should define the impact the actions may have, who, and which areas are affected.

Numerate and value effects

To quantify and evaluate the effects of the measures to be analyzed are the purpose of the fourth step. According to the Directorate for Financial Management (2016), one shall value the benefit and cost effects in kroner as far as possible. When the results have no market price, one should consider other valuation methods. The thesis answers this step in a cost-benefit analysis of the various technologies.

Valuing the benefits, assuming what the population is willing to pay to avoid a disadvantage are the main principles for valuation in economic analysis. The cost effects must be equal to the value of these resources in the best alternative use. Several outcomes are not traded in a market and therefore lack a market price, such as environmental effects. These are often critical benefits of public measures. For environmental impacts, there are cross-sectoral value estimates. Suppose there are no cross-sector value estimates or relevant general rules. In that case, one can consider valuing the results by transferring value estimates from previously carried out valuation studies from home or abroad.

Assess economic profitability

The purpose of this step is to assess the economic profitability of each measure. Economic profitable means that the population as a whole is willing to pay at least as much as the action costs. The thesis answers this step in a production costs analysis of the various technologies.

Conduct uncertainty analysis

The purpose of this step is to highlight the uncertainty of each measure. First, one should map and classify all uncertainty factors. Furthermore, one should consider the most critical uncertainty factors, which one can do in a sensitivity analysis.

A sensitivity analysis is a method for calculating how changes in uncertain factors affect the project's profitability. In such studies, one tests various uncertainty factors to see how they affect the overall profitability. In other words, one examines how sensitive the result variable is to changes in the factors that are included in a calculation. These analyses are often used in studies of a "black book process," where the output is a function of several inputs, such as climate impact, that can't be analyzed (CFI, 2021), which is the case in this thesis.

Describe distributional effects

The seventh step describes how one distributes the effects of the measures between different groups in society. If there are groups that perform particularly poorly due to the actions, one should consider whether one can compensate for these groups.

Give an overall assessment and recommend measures

Finally, one must make a comprehensive evaluation of the results from the analysis. The purpose of the final section is to give the decision-maker a structured overview. One should also give reasoned recommendations for measures.

4. Research Methodology

This chapter intends to present a coherent and comprehensive framework that has led to the empirical answer to the research question. Moreover, it reflects the quality of the study. To provide an explanation of the research methodology, the following chapter will explain this thesis's purpose. Subsequently, the chapter includes the following structure: an explanation of research design, choice of data collection before the quality of research is presented.

4.1 Research Design

There are two main research designs, qualitative and quantitative (Saunders, Lewis & Thornhill, 2016). In addition, one can use a mixed methods of research design. Qualitative research is recognized as a technique that generates and uses non-numerical data. This research design characterizes by studying the participants' opinions and the relationship between them. On the other hand, quantitative research is recognized as a method for collecting numeric data. Therefore, quantitative research design characterizes by examining relationships between numeric variables (Saunders et al., 2016).

4.1.1 Qualitative Method

To answer our research question, the thesis uses a qualitative method to provide insights into the problem is necessary. Moreover, a qualitative method is used to collect essential data to uncover the repercussions of adapting new technologies. The complexity of the theme makes it most appropriate to use interviews and archival and documentary analysis. However, the main focus of this research is inductive, trying to develop an understanding of what economic benefits the society camn achieve from using land-based closed containment system (LBCC) and semi-closed containtment system (SCCS).

There is uncertainty about how closed-containment technology will affect society, as the technology is still new and complex. Semi-closed technology is still in the research and testing phase. Meanwhile, land-based technology is also considered to still be new, but commercial production is in full swing. Many of the existing land-based facilities have been newly started, and therefore there is still a lot of uncertainty surrounding the operation of the technology itself. To answer the question of what economic benefits the society achieves by basing further growth on technology for closed facilities, we must do a deeper study and evaluate the benefits and consequences of this type of closed technology. Archival and documentary analysis is a suitable method to gather evidence and answers regarding the advantages and drawbacks of closed-containment technology. In other words, which problems or solutions can these technologies contribute to today´s sustainable challenges with traditional open net-pen production.

Lack of data from archival and documentary research leads to finding the need to conduct interviews with the respective companies that operate with this type of technology. An interview will allow collecting necessary in-depth information and first-hand knowledge from the companies to answer the research question. In addition, one will also gain a deeper understanding of people's perceptions regarding a particular phenomenon (Merriam, 1988). The interviews are thus mainly intended to fill the gap from the archival and documentary analysis. A more detailed description of the conduct of the interviews and archival and documentary analysis will be discussed further below.

4.1.2 Choice of Research Design

A case study is a research method that allows in-depth inquiry into a real-life setting (Saunders et al., 2016). Case studies characterize by conclusions being drawn based on data and science, and one cannot generalize the results. It is a flexible research design where the different methods are combined to obtain and analyze the necessary data (Sander, 2017). Therefore, the main focus is the archival and documentary analysis, combined with qualitative interviews. One can argue that a case study is a sensible research strategy as the technologies are complex, and there is a need to deconstruct the various elements. Furthermore, case studies use multiple data sources, which provides flexibility.

This thesis aims to generate insight from intensive and in-depth research within a real-life setting, and it, therefore, falls naturally to conduct a comparative case study of LBCC and SCCS technology. Because this thesis studies two technologies, the thesis considers it most apparent to use a comparative case study. A comparative case study is well suited for this type of assignment because it conducts an in-depth examination (Godrick, 2014). The thesis covers two cases in an approximate manner that gives an additional generalizable comprehension about causal questions, such as how closed-containment technologies can contribute to further growth in the aquaculture industry. Interviews and document analysis are also considered dominating research methods when using a comparative study (Goodrick, 2014).

Exploratory studies are valuable means to ask open questions to gain insights about a topic of interest and discover what is happening (Saunders et al., 2016). Based on the fact that this thesis aims to find out what role closed containment technology on land and at sea can play in further growth and development in Norwegian aquaculture, the explorative research design is best suited for this thesis. Choosing an explorative research method aims to achieve greater transparency and discover challenges and opportunities with the technologies. In addition, the thesis uses existing literature to gain insight into the aquaculture industry in Norway. The literature review also explained what to study further and created an excellent academic starting point for the data collection.

4.2 Data Collection

The thesis distinguish between primary and secondary data collection. Primary data is collected directly from the main source, while secondary data is existing data collected for another purpose. To collect data, research methods used are qualitative interviews and archival and documentary study.

4.2.1 Qualitative Interviews

According to Saunders et al. (2016), primary data is collected specifically for the research project. Although the data collection is mainly based on archival and documentary research, it is necessary to collect primary data to fill the lack of data needed to answer the research question. Therefore, this thesis uses qualitative interviews to collect first-hand data. Furthermore, there is minimal data on how much it will cost to produce fish in SCCS technological facilities. Therefore, to perform a production cost analysis, it is necessary to gather data that can provide a basis for estimates of the production costs of SCCS-technology. It is desirable to answer the research question by conducting qualitative interviews with knowledgeable people with insight into the aquaculture industry's current knowledge status. In addition, the respondents must have prospects for further growth and development. By interviewing selected interviewees, one considers it probable that their statements can be descriptive of the technologies as a whole.

4.2.1.1 Justification of interview guide

As mentioned earlier, the thesis uses semi-structured interviews as a method for data collection. The interviews need to have a specific structure as the interviews are to be compared. In this thesis, the research will be conducted digitally through Microsoft Teams due to restrictions caused by the pandemic. Although internet-mediated interviews have their disadvantages, today's society is fortunately accustomed to this type of communication.

The key to successful interviews is to be carefully prepared (Saunders et al., 2016). According to the research question, the thesis's analysis uses two interview guides based on the theoretical aspect of the thesis. The interview guides have approx. 25 predetermined questions adapted to the various technologies. The prepared guides were open to minor changes and additional questions during the interviews. Questions were asked differently with different follow-up questions, depending on what the interviewees responded. In addition, questions were omitted when the interviewers understood that the respondent could not answer them. It was desirable to create an open conversation, and therefore, the interviews were conducted as explained.

4.2.1.2 Selection of informants

The choice of suitable informants is an essential topic within qualitative research. The selection of informants in a qualitative study is described as strategic, which means that the informants are selected based on characteristics or qualifications that prove to be appropriate concerning the research question. Thagaard (2003) defines a selection of informants as the group that researchers use to obtain information in a study. The researcher points out that the choice of informants in qualitative interviews should be relatively small. If a large selection of informants is used, there is a risk of the interview not being in-depth, which is one of the main goals of the qualitative method.

In this research project, there has been chosen a targeted selection of informants. Thus, the informants have not been randomly selected, as they would have in a probability selection of informants. The informants have been selected because of their relevance concerning the research topic and research question, meaning that the research cannot be generalized for the entire aquaculture sector (Bryman, 2016). Nevertheless, it was necessary to use this collection method to obtain informants relevant to the research project and answer the research question. One made assumptions that the CEOs of the companies were best suited as informants. Therefore, the selection of informants fell on the CEO of Tytlandsvik Aqua and the CEO of FishGLOBE. The thesis scaled a choice of two informants. A small selection is used due to the risk of having a more extensive selection mentioned above.

4.2.1.3 Conducting the interviews

In the working process of this thesis, Tytlandsvik Aqua and FishGLOBE were contacted via a formal email with a short presentation of the research's purpose and research question. As mentioned before, an interview guide was made to conduct a quality-assured interview. The interview guide has an overview of topics and questions to be addressed during the interview. Before the interview, the informants agreed to the interviews being recorded. In addition, the informants agreed to the thesis mentioning the company's name, the informant's title, and the answers. The interviews were conducted in one day, and approx. 45 minutes for each interview.

When conducting an interview, it is fundamental to think about where and when the interview will occur. Ideally, it was desired to conduct the interviews in person such that the informants could experience the interview situation as safely as possible. According to Postholm & Jacobsen (2011), this can help influence how open and honest answers the interviewer gets. However, as mentioned before, the interviews had to be done digitally via Microsoft Teams.

For the research to have good internal reliability, both wanted to be present during all the interviews. We were thus both present during the interview, and during the conversations, we both focused on observing and listening. However, one of us interviewed the informants while the other took written notes along the way, which allowed us to discuss what was seen and heard. In addition, it could be addressed together and emphasize how we should interpret what emerged in the interviews (Bryman, 2016). To capture the entire conversation, we used audio recordings to transcribe the interview subsequently. Furthermore, the audio recording made it possible to concentrate on what the respondents communicated during the interviews. Subsequently, the interviews were transcribed to understand better what was answered. Hence, it must be written down exactly what is said not to affect the reliability (Postholm & Jacobsen, 2011).

4.2.1.4 Transcription

Quality and planning are essential in a research interview phase (Kvale & Brinkmann, 2012). The next step after conducting an interview is transcription. Transcription can be defined as a translation from oral speech to a written language to ensure the analysis's quality. Often, the transcription-translation will be more abstract, and much non-written communication may be lost (Johannessen, Tufte & Christoffersen, 2010). The interviews were transcribed with a focus on the answer and linguistic content, where body language and gestures were considered irrelevant. Further, it was desirable to turn the conversation into written text to make it easier to work with afterward. These texts should be a tool from which the researchers should interpret meaning.

The transcription process involved listening to the material repeatedly while writing down the conversation. Even if there is no perfect transcription, several measures can ensure the best possible quality, such as high-quality recording, listening through several times, and thinking about how the wording should be. One must also consider the relationship between oral and written text. Oral speech, written word for word, can alternately become incoherent since we use the language differently orally and in writing. Therefore, we chose to have a reformulation without losing the meaning of the sentences (Johannessen et al., 2010). By transcribing from oral to written material, the interviews are structured so that they are more suitable for analysis (Kvale & Brinkmann, 2015)

4.2.2 Archival and Documentary Research

The creation of online archives and digitization of data have increased archival and documentary research strategies (Saunders et al., 2016). Because of digitalization, it is possible to access governmental, organizational, media websites, and other data worldwide. Organizations can access press releases, regulatory news, annual reports, and company results through their websites. Media websites can also provide access to articles about organizations and management. Archival and documents used for research are considered secondary data. Furthermore, secondary data are known as data collected initially for some other purpose. Using secondary data may enable us to answer, or partially answer, the research question (Saunders et al., 2016). Grønmo (2004) uses the term qualitative content analysis, and he explains that it involves reviewing the content of the documents systematically. Through archival and documentary research, it will enable us to find information that is relevant concerning the current study.

In the process of conducting our research, we found it most valuable to implement an analysis on published archives and documents to accomplish our research question. By engaging in documentary research, the thesis examines vital documents that address LBCC-RAS and SCCS farming technology in the aquaculture industry in Norway. Archival and documentary research encompasses many different sources which can be utilized for investigative purposes. This type of research is not limited to text only, but it includes visual, and audio deceptions of information (Saunders et al., 2016). Moreover, Holme & Solvang (1996) distinguish between personal, institutional, confidential, and public sources. For our usage, we considered textual data from public and institutional sources in the thesis. Sources such as public archives from the Government, the framework plan, companies' annual reports on the aquaculture industry, reports and articles from research institutes, newspaper articles, and companies' websites are the most frequently used sources to conduct the cost-benefit analysis. Furthermore, when utilizing archival and documentary research one may want to think about what the sender's intentions may be and should keep in mind that the source was written for a specific purpose. The various documents selected in this study are written for a purpose, but not with respect to the same research question.

We have been very conscious of the selection of documents and have only selected documents that will help to shed light on the research question. Grønmø (2004) claims that if the researcher has limited source-critical understanding, this can lead to problems. The texts selected need utmost to be credible, which requires us to be critical in the selection. Researchers further claim that a lack of source-critical understanding can also affect the interpretation of the texts (Grønmø, 2004). To prevent such problems, it is important to evaluate the texts in relation to each other. Furthermore, we found that assessment according to existing knowledge is also necessary, because one must be aware of the background of the texts, i. e. why the text was written.

In order to highlight the production cost for the adult salmon produced in a land-based RAS system and semi-closed system, an economic analysis is conducted. It is interesting to compare the expenses in the technologies to assess the different cost drivers' impact on growth and further development. A research report by Sintef, conducted by Bjørndal et al. (2018), is used as a basis for the estimates of LBCC technology. The report has analyzed the production cost and provides credible figures for land-based farming. However, when it comes to SCCS technology, no one has yet studied the cost of production. Therefore, the statistics for this technology are also scaled up or down from the figures for LBCC technology. One will also use this document for data collection throughout the thesis.

The analysis and results in the next chapter will mainly consist of archival and documentary research, followed by interviews conducted with Tytlandsvik Aqua and FishGLOBE. By incorporating these aspects in our study, we wanted to stabilize interview objectives and various published industry news sources and research reports. Furthermore, we also hoped to balance personal discussion with our findings. Moreover, a combination of all these aspects can be considered important in order to capture a holistic view of the industry to answer the research question.

4.3 Quality of Research Methodology

When the research project is conducted, one should assess the quality of the method. The used research method affects the quality and determines the credibility of the results. When discussing the quality of the methods used, one should, according to Saunders et al. (2016), look more detailed into two factors: reliability and validity.

4.3.1 Reliability

When it comes to judging the quality of research, reliability is central (Saunders et al., 2016). Reliability refers to consistency and replication. Research is reliable if the researcher can replicate an earlier research design and achieve the same results (Saunders et al., 2016). As the thesis used qualitative semi-structured interviews, it would in theory not be appropriate to set requirements for high reliability. This is because the results reflect the current knowledge status when the interviews were conducted, which is assumed to change over time. Therefore, the interviewees may have new data material in the future.

A challenge related to the thesis is that the interviews are conversation-driven. Researchers can, to a certain extent, influence the respondents and thus also the results. In addition, other researchers will probably not ask the same additional questions that we did during the interviews. The possibility of conducting the same study with the same result will therefore be unlikely. Nevertheless, to increase the thesis reliability, the interview guide questions have been planned carefully to avoid asking leading questions.

Assessments were done to strengthen the reliability of the research project as much as possible. Efforts were also made to create an open and trusting setting for the informants to feel comfortable to obtain honest answers. When using additional follow-up questions, open questions, as opposed to leading questions, were used. It is also worth mentioning that good feedback was received from the interviewees on the asked questions, and interest was shown in the research and the final results.

Due to the interview's reliability challenges, this thesis is also based on archival and documentary analysis of various public documents. Nevertheless, this analysis has its disadvantages. It can be challenging to find data providing a direct answer to what is desired. For this reason, archival and documentary analysis can be a demanding methodological approach. Although, this type of analysis makes it easier to trace data that supports the study if it wants to be verified. Attempts have been made to find reliable sources, such as analyzes and reports conducted by governmental organizations and other well-known organizations, e.g., Sintef. In addition, it also strengthens reliability due to the interviews filling the gap from the archival and documentary analysis.

4.3.2 Validity

Validity is about the data being accurate and whether the data measure what is intended to measure (Winter, 2020). Regarding the interview guide, we received assessments from Professor Ragnar Tveterås and the CEO of Blue Planet, Eivind Helland, who have excellent knowledge of the aquaculture industry. This was done to ensure the quality of the formulation of the questions, to further ensure it was easy for the respondent to understand. It was also crucial for validity of the thesis that the questions were asked to make it possible for the respondent not to answer their views and instead as representatives of the technology.

Further, one can distinguish between intern and extern validity. Internal validity refers to when the research accurately demonstrates a causal relation between two variables and is associated with the quantitative method (Saunders et al., 2016). Due to this research using a qualitative approach, the discussion of internal validity will be less relevant. When it comes to external validity, it refers to if the research findings can be generalized to other relevant settings. Generalization in this thesis is difficult considering the use of a qualitative research design. We have conducted few interviews, making it hard to generalize as it may not represent the whole aquaculture industry, especially since many Norwegian companies are in different stages of the development phases. Regarding sustainability, there are still opportunities for generalization, as part of the point of moving farming to closed facilities is to reduce environmental and biological challenges. These are conditions that all closed facilities have, regardless of location, and thus apply to the entire industry. Moreover, the thesis deals with the aquaculture industry in Norway, and it is uncertain whether the findings will be valid in other countries. This is substantiated by the regulations being studied in this project, which may not apply to other countries.

5. Analysis and Results

To fulfill the research purpose, this chapter expands the previously presented theory. This chapter presents the analysis from conducted interviews and archival and documentary studies. Further, the results are introduced through a cost-benefit analysis, production cost calculations, followed by a sensitivity analysis.

5.1 Cost-benefit Analysis

This analysis analyzes the individual benefit and cost effects are described verbally, but not valued in numbers. A number of advantages and disadvantages of closed technologies are analyzed regarding sustainable challenges in today's traditional fish farming.

5.1.1 Environmental Impact

In recent years, there has been high interest in new technologies and solutions that help reduce the problems of traditional sea-based farming (Bjørndal et al., 2018). One of the main problems with this technology is the high emissions of particular organic waste. The technology for closed facilities was proposed to the Norwegian aquaculture to reduce this problem (Bjørndal et al., 2018). Norway has some requirements when it comes to the sedimentation of suspended waste (Hilmarsen, 2019). The requirements are that farmers must clean half of the suspended waste. Similarly, companies that use closed containment technology must comply with the requirements.

Answers from the interview with Tytlandsvik Aqua show that closed land-based facilities have a more significant opportunity than closed facilities at sea to collect waste. The results also describe how closed facilities at sea collect sedimentable waste. Firstly, the sedimentable waste sinks to the bottom. Secondly, it is collected and filtered over a sludge inlet. Finally, the sludge enters a separate tank, and when the tank is complete, a boat comes and transports the waste. According to Tveterås et al. (2021), emissions from particular organic waste, such as feces and feed waste, can be collected by all types of closed technologies. However, it requires RAS technology to manage dissolved nutrients (Tveterås et al., 2021).

Looking at a single land-based facility with 5,000 tonnes of fish production capacity, the facility will have produced 825 tonnes of sludge within a year (Hilmarsen, 2019). In total, Norway had a feed consumption of salmon and trout of 2 million tonnes in 2020 (Tveterås et al., 2021), which resulted in a significant amount of waste to handle. It results in a total of 0.66 million tonnes, estimated as discharged particulate organic material in 2020 (Tveterås et al., 2021).

FishGLOBE mentions in the interview that the aquaculture industry has low emissions of CO2 compared to the production of other foods, such as chicken and pork. Through 24 published studies, the research showed that closed facilities at sea have a lower environmental impact than open sea facilities (Philis, Ziegler, Gansel, Jansen, Gracey & Stene, 2019). Further findings indicate that closed land-based facilities have higher climate footprints. Closed sea-based technology had an average total climate effect (kg CO2 equivalents) of approx. 2000 kg per tonne produced salmon. On the other side, land-based technology had an average total climate effect of roughly 6000 kg per tonne of farmed salmon (Philis et al., 2019). Conducted interviews with FishGLOBE support this statement, where the respondent mentioned SCCS technology to have lower emissions of CO2 than LBCC technology. RAS facilities on land were shown to have a low environmental impact concerning nutrient removal but have other factors that overall constitute a more negative environmental impact (Tveterås et al., 2021), which the thesis will further analyze under Electricity Consumption.

According to Hilmarsen et al. (2018), the emissions from land-based facilities come from essential factors such as feed factor, energy consumption, and land use. The feed factor and energy consumed when using water treatment turn out as the most critical factors. In addition, researchers must consider other factors to develop more sustainable technology. These factors include buildings, equipment, other consumer goods, and land change, which stand for almost 10% of the climate footprint.

5.1.2 Land Use

Although land-use restrictions are not a common problem for traditional technology, they can significantly limit further growth in the aquaculture industry. Use of land in Norway has requirements regarding the distance between facilities. The requirements state that there must be

5 kilometers between each facility (Hilmarsen, 2019). Companies that use closed containment technology, whether on land or at sea, must comply with these requirements.

According to Tveterås et al. (2021), current regulations limit efficient land use for closed facilities at sea, which occupies a small percent of the coastal area. Due to the distance requirements, the seizure will be much larger than the facilities' physical area and restrain the many possibilities of closed facilities at sea. Furthermore, it reduces the potential of better utilization of sea areas currently vacant due to the risk of salmon lice and escape. The vacant space represents 1825 square kilometers. It further limits the possibilities of more efficient utilization of the currently used sites for salmon production. Reorganization is estimated to give a 50-75% production increase for Hordaland (Tveterås et al., 2021).

Farming based on SCCS-technology is particularly suitable for localization in Norway as it exploits its natural advantages. According to Heggelund (2021), natural advantages are clean water, a protected coast, deep fjords, and suitable sea temperature. In the interviews conducted, FishGLOBE state that the Norwegian government does not make enough use of the country's natural advantages, like clean seas and fjords, and that Norway should raise this focus.

The requirements of 5 kilometers between facilities at sea also apply to land-based facilities (Hilmarsen, 2019). Due to this condition, land-based facilities must take existing facilities at sea into account. Land-based production also has other concerns regarding capacity. Existing suppliers are currently close to the capacity limit, and the development has put more suppliers under pressure (Bjørndal & Tusvik, 2018). As a result, the capacity is strained, and transferring large parts of sea-based facilities to land can be a potential bottleneck. However, Bjørndal & Tusvik (2018) states that more RAS suppliers will establish themselves closer to the market.

According to Hilmarsen (2019), moving all farming from open facilities at sea to closed facilities on land regarding land use on the coastline will create consequences. First, fish farmers are dependent on buying a plot to engage in land-based fish farming, as property rights apply for land-based facilities (Hilmarsen, 2019). In contrast, facilities at sea only need permission from public authorities. Second, a land-based fish farm with a production capacity of 5,000 tonnes per year will have a gross area of 45,000 square meters, equivalent to seven football pitches (Hilmarsen, 2019). If one multiplies with five facilities, it will correspond to 35 football pitches, i.e., approx. 225,000 square meters.

Combined with the land acquisition challenges, a transition to land-based farming is also time-consuming. Hilmarsen et al. (2018) point out that it will take nine years to transfer current production from sea to land, assuming that constructors will build 15 facilities with an annual output of 10,000 tonnes. Given a doubling of Norwegian aquaculture, it will take 17 years to get full coverage. On the other hand, if 20 facilities are built with 10,000 tonnes each year, it will take seven years to reach a full range of current production, and the equivalent of 13 years when doubling current production. The ability to realize the projects and build land-based fish farms is also strongly linked to access to necessary capital (Bjørndal & Tusvik, 2018). Capital access will be further discussed under "Reprecusissions".

5.1.3 Electricity Consumption

In 2018 it was invested approx. 22 billion to upgrade and expand the Nordic power grid. In 2021 it is estimated that investments will be approx. NOK 19 billion annually (Hovland, 2018). However, further investment is needed to expand the network in the districts. Therefore, the consequences for farmers are that they have to pay to connect to the distribution network. In addition, they must pay construction contributions to the electricity suppliers in the areas for access to the electricity grid.

A representative from Statnett tells in an interview with Fiskeribladet that they suggest the visions and plans to expand land-based farming in Norway may present challenges and cause a pause in development (Riise & Adolfsen, 2019). The company believes that the distribution network on the coast is sufficiently developed to serve all the planned land-based fish farms. Thus, the alternative will be that the farmers have to pay for the bill themselves, leading to an abrupt break in the significant investments on land, as there is no hiding that electricity for land-based farming can cost farmers very expensively (Tytlandsvik Aqua, personal communication, May 7th 2021).

Statnett further points out that fish farms will seldom be of such a size that it will be financially justifiable for the grid companies to expand the grid or need to strengthen the transmission grid. The facilities can be one of several needs in an area that triggers increased capacity on the power grid. Statnett also highlights that the grid and capacity situation is particularly challenging in Haugaland, the Bergen region, and in the North. Moreover, there are also plans for increased consumption at these places (Riise & Adolfsen, 2019).

In addition, electrification of petroleum activities, industry, and other business development is already taking place, which will utilize large parts of future capacity. For this reason, Westerberg (2019) from Statnett claims that land-based farming is not a top priority. However, Statnett is familiar with increased power use from the power grid due to land-based farming. Concerning further development, farmers will depend on interaction with the regional network companies and the actors themselves. Therefore, Statnett has considered developing the land-based projects in the network development plan (Riise & Adolfsen 2019).

Finding a reference value for energy use in LBCC-RAS is complicated because of poor documentation of underlying assumptions (feed load, smolt size etc.) and systems in many cases (Nistad, 2018; Badiola et al., 2017). According to a conducted master thesis, the researcher was in a personal communication with Øyvind Hillmarsen from SINTEF Ocean AS, referenced that the total electricity use of post-smolt production in LBCC-RAS in Norway ranges from 3-5 kWh per kg post-smolt, with an average weight of 0.5 kilograms produced (Nistad, 2020, p. 9)

The considerably high energy consumption turns out to be a challenge in land-based RAS farming. Previous research shows pumping, supply of oxygen, and water cooling as significant contributors to energy consumption (Association, 2018). Hence, reduction of heights in the facility, more energy-efficient pumps, heat exchange and heat pumping of water, as well as measurement and efficient addition of oxygen can be solutions that can help reduce energy needs (Association, 2018).

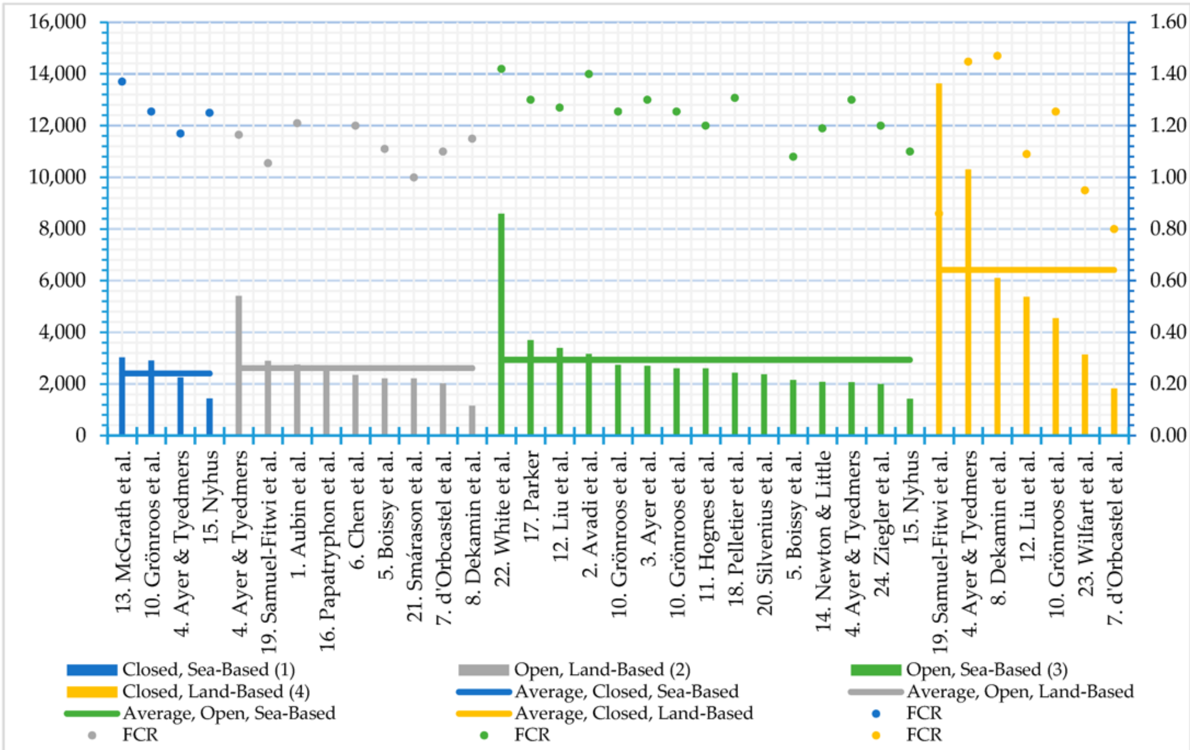

Figure 5.1: Environmental Impact from Various Production Systems for Salmon

Figure 5.1 by Philis et al. (2019) aligns with the findings above, as it shows a review of the environmental impact of various production systems for salmon. This model divides environmental impact into climate effect, acidification, eutrophication, and energy consumption. As mentioned earlier, closed facilities at sea came out overall with the lowest environmental footprint. Additionally, RAS facilities also have a low environmental footprint regarding nutrient removal but have the most significant energy consumption, thus have the most prominent negative climate footprint. Moreover, closed facilities at sea pump large volumes of seawater themselves and consume less power than land-based facilities (Philis et al., 2019).

By personal communication with Tytlandsvik Aqua, the estimated energy use is 7 kilowatts per kilo post-smolt. However, the company aims to reach 3 kilowatts per kilo of post-smolt produced; it is considered one of the sustainability goals the company is striving towards to reduce the environmental and climate footprint. As for FishGLOBE, there were not given any specific numbers, but they claim that the energy usage is estimated to be lower than land-based farming.

There is limited documentation due to SCCS-technology still being under development and testing. Nonetheless, documentation from Philis et al. (2019) be supported by FishGLOBE´s statement.

5.1.4 Fish Health and Welfare

A satisfactory farming economy depends on good fish welfare in all units and all fish groups throughout the entire production process (Tveterås et al., 2021). Open-cage technology depends on the aquatic environment, where the ocean current naturally replaces the water. To increase and develop closed-cage technology, Norway needs better monitoring of fish welfare. Better monitoring includes increased knowledge on ensuring good fish welfare throughout the production chain and better coordination of preventative and controlling diseases (Tveterås et al., 2021). Essential factors for poor fish welfare are salmon lice and other diseases, analyzed further in chapter 5.1.4.1 Biological Risks.

SCCS-technology allows better control of environmental factors such as water velocity and oxygen (Tveterås et al., 2021). Marine deep water also provides better control of the farming conditions. The technology contributes to avoiding significant variations in water temperature and quality and contributing to achieving a more stable environment better adapting to the fish's biological needs. Furthermore, training the fish is one of the most important additional benefits of using semi-closed facilities (Tveterås et al., 2021). Training shows to provide better growth and welfare throughout the production period. In addition, a controlled oxygen supply adapted to the size and metabolism of the fish and the water temperature will contribute to good fish welfare (Tveterås et al., 2021).

Øvrebø (2021) studied how fish is affected by different farming conditions, where he looked at post-smolt production in closed sea-based facilities. The study concludes that one can expect a stable environment, as in high water quality, reduced risk of infection, and steady stream, in an SCCS-technological farming facility. Constant stream and a minimized salmon lice problem will positively affect the fish both in terms of welfare and in the form of increased muscle cell recruitment. When releasing the post-smolt into open cages at sea, the study shows that the fish from semi-closed facilities appeared more robust. One assumed that reduced lice infestation could be related to the fish's first defense barrier skin and ability to handle external effects. Furthermore, one believes that the increased final weight of the fish comes from the training, which results in increased growth of newly recruited muscle cells in the open-cage phase (Øvrebø, 2021).

Today, there is no limit on biomass in Norwegian laws (Tveterås et al., 2021). Feed factor, specific water consumption, and density determine how the water is loaded with waste products from fish metabolism. At the same time, typical water consumption decreases the density increases. Therefore, it is essential to have secure threshold values for minimum water exchange and maximum density. There is documented research that production can be carried out with good water quality within values for good fish welfare in semi-closed facilities. In an experiment at Akvafuture AS, the density varied from 1 to 50 kg/m3 in post-smolt and slaughter fish production. However, there will be high values of CO2 without aeration of the water with a particular water consumption below 0.2 L/kg/min. Therefore, it is possible to maintain control of CO2, with a specific water consumption between 0.2 and 0.3 L/kg/min. On the other hand, water consumption of over 0.3L/kg/min can provide better fish welfare (Tveterås et al., 2021).

Maintaining control of biological processes in RAS facilities is necessary to ensure good fish welfare and puts high demands on competence, safety systems, and technical equipment (Bjørndal & Tusvik, 2018). The facility’s biological filter, which forms the fish’s waste into harmless compounds, is crucial. In addition to filtering waste, it is necessary to filter water from particulate material, add minerals to adjust the pH, and that the general requirement for control of water quality increases. There is a requirement in land-based salmon farming of 65 kg/m3 for post-smolt and adult salmon when it comes to density. Research shows that it is possible to produce post-smolt with a density up to 75 kg/m3. A density between 100 kg/m3 and 125 kg/m3 harms the fish's welfare and growth (Bjørndal & Tusvik, 2018).

According to Tveterås et al. (2021), research shows that one can achieve higher growth and lower feed factor with SCCS-technology than open net-pen facilities. Lighting, oxygen level, and temperature are all critical environmental parameters that control the growth of salmon. The deep water in semi-closed facilities provides higher temperature and faster growth in winter, lower temperature, and slower summer growth than open facilities. The intersections are in mid-May and mid-September. The more rapid growth in winter, where the production time reduces by 4-6 weeks, will give a more significant advantage than the growth reduction in summer. In terms of feed factor, semi-closed facilities are lower than open facilities at sea. A possible explanation for this eliminates the possibility of leakage of feed and overview and easier control of feeding, but there is no research on the causes of this yet (Tveterås et al., 2021).

The growth rate is affected by feed availability, temperature, photoperiod, and environmental conditions (Bjørndal & Tusvik, 2018). It is challenging to realize the planned growth rate of over 1.5 kg in land-based RAS facilities. Results show that this may be related to reduced water quality, high fish density, and challenges with the placement of fish in the facility throughout the life cycle. According to Bjørndal & Tusvik (2018), this has high risk and can lead to reduced growth, leading to reduced production, slaughter volume, and lower slaughter weight. Farmers can reduce risk if LBCC-RAS systems can reduce density, increase water consumption, ensure optimal water quality, increase capacities in water treatment systems, such as CO2 and particulate matter. In addition, risk can be reduced if one allows sufficient time to mature biological filters at start-up and disinfection (Bjørndal & Tusvik, 2018).

In a webinar of "Sustainable growth with closed farming at sea" presented by Stiim Aqua Cluster, Professor Ragnar Tveterås refers to a research comparing production period in a closed facility on land and a closed facility at sea (Tveterås, 2021). The study shows that salmon raised in facilities at sea grew faster. After ten months, the salmon was placed from each facility in open cages at sea. The salmon from the facility at sea was 1 kilo larger than the one raised on land. The study also showed that the fish were more robust, had better health, and grew faster (Tveterås, 2021).

5.1.4.1 Biological Risks

Mortality

Research indicates that mortality has been steadily high over the past 20 years. Recent numbers show that 52 million farmed salmon died in cages in 2020 (The Norwegian Veterinary Association, 2021). Keeping the salmon strong and healthy by providing the right temperature, oxygen level, and fewer ocean currents are challenging and necessary for the salmon to thrive (Jónsdóttir, Hvas, Alfredsen, Føre, Alver, Bjelland, Oppedal, 2019). Although there is a constant discussion that it is crucial to continue to prevent mortality, the industry still fails to reduce the high rates.

On the other hand, land-based farming has existed longer than semi-closed farming, but the technology is also still new. Tytlandsvik Aqua emphasizes during the interview that mortality is without a doubt the biggest challenge LBCC-RAS are facing. They have so far processed seven generations and have managed to go from 1.5% down to 0.5% in mortality rate within 4-5 months they have held the fish in the closed facility. Although mortality in LBCC-RAS facilities still exists, it is significantly lower compared to traditional open-cage facilities.

There is still a lack of adequate data for the mortality rate and causal distribution in SCCS facilities. In addition, the figures for fish mortality in experiments with SCCS technology are variable. For this reason, there is not enough data to make good comparisons of mortality with traditional open-net facilities (Tveterås et al., 2021). However, according to Tveterås et al. (2021) published studies indicate the mortality of SCCS facilities will be at a level or lower than in traditional ONP farming.

The industry is exposed to mass death and distaste for the fish because the biology in land-based facilities is more difficult to control. In addition, smolts are sensitive to poor water quality. In the worst case, many thousands of smolts can die at the same time shortly. Tytlandsvik Aqua confirms that ongoing research is still needed to establish strategies and technical standardization to study the welfare of fish in closed facilities and improve water quality. It is difficult to have good enough control over microbial and chemical water quality in land-based RAS facilities. Netzer (2021) states that efficient water purification and stable microbiology are some of the important critical factors for responsible and sustainable production in such facilities.

The risk of mass mortality is exceptionally high in facilities that use seawater. For example, hydrogen sulfide has been reported as a cause of mass mortality in BCC-RAS facilities. Such a problem can occur because there are no analysis methods that can detect H2s before the fish shows signs of poisoning, and then it is usually too late to save it. Thus, the goal is to develop a warning system that sounds an alarm when the water quality changes before the fish are damaged (Netzer, 2021).

Escapes

In semi-closed cage facilities, there are tight walls between the fish and the surroundings, and this will significantly reduce the chance of escape and ensure the exclusion of lice. Furthermore, closed cages in the sea are not dependent on passive water exchange and can thus be added to less exposed localities, reducing the risk of escape (The Nature Conservation Association, 2020). Moreover, other factors that will reduce fish escape are loss of risk associated with major de-lice operations (Tveterås et al., 2020). Land-based facilities will also reduce the risk of escapes as it has greater security against cage failures than traditional open-net systems. Furthermore, in LBCC it is possible to add double protection by building a wall around the tank area (Bjørndal et al., 2018)

Salmon lice

Salmon lice are one of the biggest challenges for fish health in the aquaculture industry. This type of parasite makes it challenging to sustain sustainable growth in the aquaculture industry, as it can result in reduced disease defense and growth and increased mortality in the host fish (NINA, u.n). As stated by the Norwegian Food Safety Authority (2016) main reason for salmon lice problems is that salmon lice have developed reduced sensitivity and resistance to the drugs.

After repeated lice infestation, the lice may develop resistance to the drugs. It is a natural development since it is the individuals who best tolerate the lice repellent that survives each time. The problem is that the drugs work either poorly, and the farmers cannot use the drugs to reduce the salmon lice level. However, the lice control aims to prevent and limit the harmful effects of salmon lice on fish in fish farms and on wild stocks of trout and salmon. Furthermore, the goal is also to be able to counteract the development of resistance to the lice repellents (Food Safety Authority, 2016)

Researchers have conducted a mapping study of salmon lice in open and closed-cage at sea for three years. The research shows that deep water from 20-25 meters will provide good protection with the intake of salmon lice, even without any form of filtration or disinfection. (Nilsen et al., 2017a, Nilsen et al., 2020). Furthermore, in an attempt to move fish with lice from open cages to closed cages it was “indicated” that the infection gradually disappeared without signs of reproduction of light inside the cages (Nilsen et al., 2017).

The explanation, in this case, is that roe released into the closed cage will be flushed out of the cage before they have time to develop into ineffective lice larvae (Jevne et al., 2020). Thus, without the infection of salmon lice in facilities with semi-closed cages, there will be less need for both lice treatments and cleaner fish. Moreover, it could contribute to reducing the spread of lice to wild fish (Tveterås et al., 2021). Nevertheless, it is important to keep in mind that there is currently limited knowledge and experience and biological data from SCCS as it will require further research and development.

Land-based farming will also be able to reduce the salmon lice problem. Being able to have complete control over the aquatic environment and the conditions in the facilities means that the problems with salmon lice can be avoided. On the other hand, the fish density will be much higher than open cages in the sea, making it easier for infection to spread in a facility. This risk can be partially counteracted by dividing the facilities into isolated zones, preventing transmission between fish in different zones (Tveterås et al., 2020).

The current traffic light system, regulated by the Ministry of Trade, Industry and Fisheries, determines which colors and growth or reduction the production area can have. What determines the color is the extent to which salmon lice affect wild salmon and where it can be potentially problematic with escape. For example, Sogn og Fjordane is currently a red code, meaning no new permits are issued to produce fish in the sea. The latter supports a solution for farming on land because LBCC does not fall under the traffic light system. Therefore, a facility on land will be allowed to produce without restrictions which come with the color codes. Furthermore, there are yet no specific regulations for semi-closed cage systems, but since this technology operates in the sea, it is suggested that the traffic light system will apply to SCCS technology.

Disease

Common diseases such as heart and skeletal muscle inflammation HSMB, and pancreatic necrosis have been detected in semi-closed facilities. Tveterås et al. (2020) claim that the transmission routes and the potential for disease outbreaks in the semi-closed facilities have not been mapped well enough compared to open sea facilities. However, deep water will reduce the risk of ingesting harmful algae because they depend on sunlight. On the other hand, Jellyfish is a risk factor in semi-closed, as they are independent of light and weigh down to greater depths. In addition, the nettle cells in the jellyfish's catch threads can cause gill damage to the fish and have caused problems in larger accumulations in semi-closed facilities.

One of the challenges with closed facilities is the risk of the internal spread of infection. Viruses, bacteria, and parasites can quickly spread to more tanks through the water system. Therefore, good hygiene is crucial in such facilities. Salmon can be vaccinated against some infectious substances or pathogens, but not all diseases can be vaccinated for; this applies to, for example, gill disease (AGD). Since the biofilter in the tank consists of live bacteria, the use of antibiotics should be avoided as the treatment will also kill the necessary bacteria. In addition, the facilities can be contaminated from, e.g., fish that are brought in from hatcheries or from new water that comes in (The veterinary Institute, 2018)

Despite these advantages, land-based also has significant infection hygiene challenges. The major challenges in using BCC-RAS technology are the necessary set-aside and cleaning of installations and production units that must be carried out regularly. The LBCC-RAS of the future should thus be built to be more flexible when it comes to carrying out routine disinfection of the entire facility, including the biofilter (Veterinary Institute, 2016)

5.2 Production Costs Analysis

In this chapter, an analysis of production costs for salmon in land-based RAS technology and closed technology at sea in Norway will be conducted. As a basis for the analysis, it will look into Tytlandsvik Aqua's concept-level facility with a production capacity designed for a production of 3,000 tonnes of salmon (iLaks, 2020a). The facility has an investment cost of approx. NOK 300 million, and a feed capacity of 8,500 kg every day, which gives an annual feeding capacity of 3,102,500 kg. To compare with, FishGLOBE's two 10K facilities with a production capacity of 3200 tonnes will be used (FishGLOBE, personal communication, May 7th 2021). The investment cost for this project is approx. NOK 200 million.

SCCS-technology also has a license fee for operating at sea that is often included in the calculation of investment cost. To better compare the two technologies, the licence fee or lice treatment is not included in the calculation. An estimate for feeding capacity is set to the same for both technologies. However, it is worth noting that these operating costs can change with the choice of location due to differences in feed shipping, electricity costs and other factors.

5.2.1 Estimates for LBCC-technology

Due to the fact that land-based technology is in the early stages of operating, assumptions will be made in the analysis. Estimates will mostly be based on the report of Bjørndal et. al. (2018), where an analysis of land-based farming has been performed. The assumptions will also be based on qualitative interviews conducted with Tytlandsvik Aqua, in addition to public information.

Estimated Variable Costs

Variable cost items include roe, feed, oxygen, vaccine, electricity, sludge, biomass insurance, labor. The figures for selected variables are taken from the report of Bjørndal et. al. (2018) and the Norwegian Directorate of Fisheries, while other figures are based on assumptions in line with the current market. Assumptions for the variable costs are given in Table 5.1. In this case, 21 employees in the production have been estimated, who have an annual salary cost of NOK 501,900 per year. This annual salary is based on actual figures in Statistics Norway's (2021) category 6221 aquaculture workers in the private sector. Labor costs for both LBCC facilities include fish culture technicians, laboratory technicians, maintenance mechanic and primary processing staff.

The variable costs such as sludge, feed and oxygen are directly related to the quantity produced, while the remaining costs will not vary directly with the quantity produced. Electricity consumption is determined by production capacity and is therefore an indirect cost. Consumption of sludge and oxygen is determined by realized production and therefore these are direct costs. The latter is dependent on the feed required. It is crucial to be able to achieve the best possible capacity utilization in order to further reduce the average cost per kg produced.

Table 5.1: Estimated Variable Costs for LBCC-technology

Employees in production	26 employees in total, of which *21* are employed in production. Based on figures from SSB, the average annual salary in 2020 was *501,900*, which is taken into account when calculating production costs.
Price on roe	Price on roe is somewhere between 1-1.6, depending on genetics. An estimate of NOK *1.5* per egg is used in the calculation. An estimate for the annual purchase of roe is set to *865,748* roe.
Price on feed	An estimate for price on feed is NOK *14* per kg. An estimate for annual consumption of feed is *3,102,500* kg.
Price on vaccine	Price per vaccine is somewhere between 1.5-2.0, depending on content. An estimate of NOK *1.8* per egg is used in the calculation.

	Annual purchase of vaccines is estimated to be *692,857* vaccines.
Electricity	Price per kwh is estimated to be *0.80*. An estimated consumption is *6* kwh per kg production capacity.
Oxygen	Price on oxygen is estimated to be NOK *2.60* per kg It is assumed a consumption of *0.9* kg per kg realized production feeding.
Sludge handling	An estimate of NOK *800* per tonne is included in the analysis. A quantity of *1.5* kg of sludge is handled per kg of feed.
Biomass Insurance	*2.5%* of incurred variable costs.
Other variable costs: Lye/bicarbonate/PH adjustment, medicine, laboratory and veterinary services and various costs (well-being/household/other)	An estimate for other variable costs is set to NOK *2,078,078*.

Estimated Fixed Cost

Fixed costs in the financial calculations include interest and depreciation, management, maintenance and insurance building and construction. Assumptions for the fixed costs are given in Table 5.2. It is assumed that salaries are given to five employees in management positions with a salary cost of NOK 975,000 per year. It is then estimated that approx. NOK 2,000,000 goes to various office teams, administration and reporting. To be able to keep everything in good condition, one must reckon with maintenance costs calculated at 1.5% of the investment cost of NOK 300,000,000 per year. For building and construction, the insurance cost per year is set to

420,329, which is half the insurance cost used as an estimate in the report of Bjørndal et. al. (2018). The estimate is halved because the investment cost is half of what is used as a basis in the report, but also to make it more comparable to SCCS.

Table 5.2: Estimated Fixed Costs for LBCC-technology

Management	26 employees in total, of which *5* are employed in the management. Labor costs per leader is estimated to be *975,000* per year.
Maintenance/service	Estimated to be *1.5%* of the investment cost.
Insurance building and construction per year	An estimate for other variable costs is set to NOK *420,329*.

5.2.2 Estimates for SCCS-technology

There are still major uncertainties regarding production costs for SCCS-technology because the installations are not completed as it is still being developed. Hence, estimates will be adjusted based on the production costs of LBCC-technology. Estimates will also be based on qualitative interviews conducted with FishGLOBE, in addition to public information.

Estimated Variable Costs

When it comes to labor costs, a lower cost compared to land-based production can be estimated (FishGLOBE, personal communication, May 7th 2021). In closed production at sea, there is less need for employees in the production. An estimate for 20 employees in total is used, where 15 are employed in the production. Roe cost, feed cost, vaccines, oxygen, sludge handling and other variable costs are set to the same as for land-based production. According to Philis et al. (2019), closed production at sea has an electricity consumption approx. 66.6% lower than land-based production. This is used as an estimate in this analysis.

Table 5.3: Estimated Variable Costs for SCCS-technology

Employees in production	20 employees in total, of which *15* are employed in production. Based on figures from SSB, the average annual salary in agriculture, forestry and fishing in 2020 were *501,900*.
Price on roe	Price on roe is somewhere between 1-1.6, depending on genetics. An estimate of NOK *1.5* per egg is used in the calculation. An estimate for the annual purchase of roe is set at *865,748* roe.
Price on feed	An estimate for price on feed is NOK *14* per kg. An estimate for annual consumption of feed is *3,102,500* kg.
Price on vaccine	Price per vaccine is somewhere between 1.5-2.0, depending on content. An estimate of NOK *1.8* per egg is used in the calculation. Annual purchase of vaccines is estimated to be *692,857* vaccines.
Electricity	Price per kwh is estimated to be *0.80*. An estimated consumption of electricity is set to *66,6%* lower than the consumption of land-based production, which corresponds to a consumption of *1.998* kwh per kg production capacity.
Oxygen	Price on oxygen is estimated to be NOK *2.60* per kg

	It is assumed a consumption of *0.9* kg per kg realized production (feeding)
Sludge handling	An estimate of NOK *800* per tonne is included in the analysis. A quantity of *1.5* kg of sludge is handled per kg of feed.
Biomass Insurance	*2.5%* of incurred variable costs
Other variable costs: Lye/bicarbonate/PH adjustment, medicine, laboratory and veterinary services and various costs (well-being/household/other)	An estimate for other variable costs is set to NOK *2,078,078*.

Estimated Fixed Costs

An assumption of five employees in the management is also estimated for closed production at sea, where a salary of 975,000 per year is assumed. For this technology it is also estimated that NOK 2,000,000 goes to various office teams, administration and reporting. A maintenance cost of 1.5% of the investment cost of NOK 200,000,000 is included in the calculation. The cost of insurance for building and construction is set to NOK 279,939, which is lower than for land-based production due to the lower investment cost.

Table 5.4: Estimated Fixed Costs for SCCS-technology

Management	20 employees in total, of which *5* are employed in the management. Labor costs per leader is estimated to be *975,000* per year.
Maintenance/service	Estimated to be *1.5%* of the investment cost.
Insurance building and construction per year	An estimate is set to NOK *279,939* based on the investment cost of building and construction.

Total Production Costs Per Year

One can now estimate the total production cost for each technology per year. The analysis is based on the production going according to plan, and that the capacity is fully utilized. In the sensitivity analysis, the opposite will be analyzed in several cases. One can also analyze the percentage share the various costs have of the total production costs.

Table 5.5: Total Production Costs Per Year

Input factors	**LBCC-RAS**	**SCCS**	**% (LBCC-RAS)**	**% (SCCS)**
Labor costs	10 539 900	7 528 500	8.78%	7.65%
Roe	1 298 622	1 298 622	1.08%	1.32%
Feed	43 435 000	43 435 000	36.19%	44.15%
Vaccine	1 247 143	1 247 143	1.04%	1.27%
Electricity/Energy Cost	14 400 000	5 114 880	12.00%	5.20%
Oxygen	7 259 850	7 259 850	6.05%	7.38%
Sludge handling	3 723 000	3 723 000	3.10%	3.78%
Biomase insurance	2 047 588	1 740 175	1.71%	1.77%
Other variable costs	2 078 078	2 078 078	1.73%	2.11%
Interest on working capital	3 849 957	5 128 143	3.21%	5.21%
Sum Variable Costs	86 029 180	73 425 247	71.68%	74.63%
Salary to management	4 875 000	4 875 000	4.06%	4.96%
Maintenance/Service	4 500 000	3 000 000	3.75%	3.05%
Insurance buildings and constructions	420 329	279 939	0.35%	0.28%
Depreciation and interest on investment/fixed capital	22 200 000	14 800 000	18.50%	15.04%
Other office maintenance, administration and reporting	2 000 000	2 000 000	1.67%	2.03%
Sum Fixed Costs	33 995 329	24 954 939	28.32%	25.37%
Total Production Costs	120 024 509	98 380 186	100.00%	100.00%

The production costs for LBCC-technology gives a total of NOK 120,024,509, while SCCS-technology gives a total of NOK 98,380,186. This corresponds to a difference of approx. NOK 22 million. One can also notice that variable costs account for approx. 70-75% for both technologies, while fixed costs account for approx. 25-30% of the total cost. Several of the cost items for both systems are relatively similar, but LBCC-RAS are higher as the results show. This is mostly due to the high electricity cost which corresponds to an amount of NOK 9,285,120 in difference. LBCC-technology has a higher consumption of electricity because it operates on land. Hence, the energy cost is higher for closed production on land. The immediate benefit of semi-closed facilities is to be able to operate out at sea at low cost. The low cost is due to less energy used in the recycling system and heating and cooling of the facilities.

Feed costs stand out as the largest cost for both technologies, but SCCS-technology represents a larger percentage of the total production cost compared to LBCC-technology. It is calculated based on the feed required for growth multiplied by feed conversion ratio. Feed cost is the most critical variable in estimation because it drives the largest component of production cost during the grow-out phase.

According to a report prepared by Nofima it is pointed out by industry actors that feed costs are a significant source of increased production costs (Iversen et al., 2015). This was also shown in the historical review of costs, where the feed cost in 2005 was about NOK 8 and increased to about NOK 11.83 per kg in 2014 (Iversen et al., 2015), while Sintef (2020) estimates that the feed cost is NOK 14 per 2020 (Bjørndal et. al. (2018), Especially for the de-lice processes that are necessary for open cages can have adverse effects. Treatments affect growth negatively through lost feeding days, which is due to starving prior to the treatment as well as subsequent restitution. Moreover, a higher mortality rate late in the production cycle, resulting from mechanical de-lice methods, give a higher average weight on the loss, and also contribute to an increased economic feed factor (Iversen et al., 2015).

When comparing LBCC-RAS and SCCS technology, the traditional ONP remains cheaper when looking at production cost and overall investment cost. Although it is less expensive both in investment cost and production cost, it is the primary biological and environmental factor preventing increased sustainable production. However, a shift to a closed-cage system can include changes in some variables, affecting the operation and investment cost. The thesis will further discuss this in chapter 5.3.

5.2.3 Total Production Cost Per/Kg Alive and Per/Kg WFE

Table 5.6: Production Cost Per/Kg Alive and Pr/Kg WFE (LBCC-technology)

	LBCC-RAS	
Input factors	**NOK/kg Alive**	**NOK/kg WFE**
Labor costs	3.5	3.7
Roe	0.4	0.5
Feed	14.48	15.45
Vaccine	0.42	0.44
Electricity/Energy Cost	4.80	5.12
Oxygen	2.42	2.58
Sludge handling	1.24	1.32
Biomase insurance	0.68	0.73
Other variable costs	4.80	5.12
Interest on working capital	1.28	1.37
Sum Variable Costs	28.68	30.60
Salary to management	1.63	1.73
Maintenance/Service	1.50	1.60
Insurance buildings and constructions	0.14	0.15
Depreciation and interest on investment/fixed capital	7.40	7.90
Other office maintenance, administration and reporting	0.67	0.71
Sum Fixed Costs	11.33	12.09
Total Production Costs	40.01	42.69

Table 5.7: Production Cost Per/Kg Alive and Pr/Kg WFE (SCCS-technology)

Input factors	SCCS	
	NOK/kg Alive	**NOK/kg WFE**
Labor costs	2.4	2.5
Roe	0.4	0.4
Feed	13.6	14.5
Vaccine	0.4	0.4
Electricity/Energy Cost	1.5	1.6
Oxygen	2.4	2.6
Sludge handling	1.2	1.2
Biomase insurance	0.5	0.6
Other variable costs	0.6	0.7
Interest on working capital	1.6	1.7
Sum Variable Costs	22.8	24.4
Salary to management	1.5	1.6
Maintenance/Service	0.9	1.0
Insurance buildings and constructions	0.1	0.1
Depreciation and interest on investment/fixed capital	4.6	4.9
Other office maintenance, administration and reporting	0.6	0.7
Sum Fixed Costs	7.8	8.3
Total Production Costs	30.6	32.7

Table 5.6 shows that land-based farming has a production cost per/kg alive of NOK 40.01, while table 5.7 shows that closed farming at sea gives a total cost per/kg alive of NOK 30.60. This is equivalent to NOK 42.69 for land-based farming, and NOK 32.7 for closed farming at sea in WFE (conversion factor 1.067). As mentioned earlier in chapter 5.2 the license fee is not included in the calculations to better compare the two technologies. If the license fee had been included in the calculation, the production cost for SCCS technology would have been significantly higher than the estimates in table 5.7. According to the interview with FishGLOBE, the license fee is considerably high. Therefore, one can assume that the difference in the production cost per kilo

WFE between LBCC-RAS and SCCS will significantly lower. Thus, the production cost in SCCS will still principally be estimated to be higher than traditional ONP farming.

5.3 Sensitivity Analysis

In the production cost analysis, a number of assumptions were made, and many of these are uncertain. There is a lack of knowledge in these new areas and closed-cage fish farming is risky by nature due to technological and biological uncertainty. Because of uncertain assumptions, it can be useful to perform a sensitivity analysis around important variables, to see how the production cost changes with variation in selected variables. In this case, important variables which make up for one of the highest costs include feed, energy, oxygen and sludge handling. In the following, the effect on cost and production will be analyzed by looking at different changes. Moreover, the production cost of NOK 42.69 per/kg WFE will be used as a basic scenario for land-based farming. Similarly, NOK 32.7 per/kg WFE will be used as the basic scenario for semi-closed farming at sea. A percentage of 20% will be used as an example for change in both increase and reduction in cost.

Following changes that will be analyzed individually:

- Change in feed cost (+/- 20%)
- Change in electricity cost (+/- 20%)
- Change in oxygen cost (+/- 20%)
- Change in sludge handling cost (+/- 20%)

Table 5.8: Change in Price and Production Cost Individually (LBCC)

Variables	Basis Scenario	Increased cost	Reduced cost	Basis Scenario	Increased cost	Reduced cost
Feed	NOK 14	NOK 16.80	NOK 11.2	NOK 43 435 000	NOK 52 122 000	NOK 34 748 000
Electricity	NOK 0.80	NOK 0.96	NOK 0.64	NOK 14 400 000	NOK 17 280 000	NOK 11 520 000
Oxygen	NOK 2.60	NOK 3.12	NOK 2.08	NOK 7 259 850	NOK 8 711 820	NOK 5 807 880
Sludge handling	NOK 800	NOK 960	NOK 640	NOK 3 723 000	NOK 4 467 600	NOK 2 978 400

In Table 5.8, the increase/reduction in price is calculated for each individual variable in LBCC-technology. In addition, an increase/reduction in production cost is calculated.

Table 5.9: Change in Variables and Production Cost Individually (SCCS)

Variables	Basis Scenario	Increased cost	Reduced cost	Basis Scenario	Increased cost	Reduced cost
Feed	NOK 14	NOK 16,80	NOK 11,2	NOK 43 435 000	NOK 52 122 000	NOK 34 748 000
Electricity	NOK 0,80	NOK 0,96	NOK 0,64	NOK 5 114 880	NOK 6 137 856	NOK 4 091 904
Oxygen	NOK 2,60	NOK 3,12	NOK 2,08	NOK 7 259 850	NOK 8 711 820	NOK 5 807 880
Sludge handling	NOK 800	NOK 960	NOK 640	NOK 3 723 000	NOK 4 467 600	NOK 2 978 400

Similarly, Table X 5.9 the increase/reduction in price and production costs is calculated for each individual variable in SCCS-technology.

Table 5.10: Production cost per kg WFE (LBCC)

Scenario 20%		**Reduced cost**	**Basis scenario**	**Increased cost**
Energy cost +/- 20%	WFE	41.64	42.69	43.74
	Change in %	−2.5%		2.5%
Oxygen cost +/- 20%	WFE	42.16	42.69	43.22
	Change in %	−1.2%		1.2%
Sludge handling +/-20%	WFE	42.42	42.69	42.96
	Change in %	−0.6%		0.6%
Feed price +/- 20%	WFE	39.52	42.69	45.86
	Change in %	−7.4%		7.4%

Table 5.11: Production cost per kg WFE (SCCS)

Scenario 20%		Reduced cost	Basis scenario	Increased cost
Energy cost +/- 20%	WFE	32.45	32.80	33.15
	Change in %	−1.05%		1.08%
Oxygen cost +/- 20%	WFE	32.30	32.80	33.30
	Change in %	−1.52%		1.52%
Sludge handling +/-20%	WFE	32.50	32.80	33.10
	Change in %	−0.91%		0.91%
Feed price +/- 20%	WFE	29.80	32.80	35.80
	Change in %	−9.15%		9.15%

The sensitivity analysis does not present the probability that the various variables will change in one direction or another. Moreover, the effects of a possible adaptive behavior will not be discussed in this analysis. An adjustment to counteract negative trends will be a natural part of management's behavior and may help to reduce the impact of such changes. The results from the analysis are summarized in a calculation based on three scenarios. A distinction is made between basic scenario, worst case scenario and best-case scenario. The analysis does not provide quantitative information about the risk, as it is not stated how likely it is that the various events will occur.

Calculations reveal that feed costs are the largest cost for both LBCC and SCCS technology. Table 5.10 and 5.11 shows that some changes in price cost and feed utilization have the greatest impacts on the economic performance of production. An increase in feed price by 20% will increase production cost per kg WFE from NOK 42.69 to NOK 45.86 on land, which equals to WFE 7.4% change. The same increase also goes for production in closed cages at sea with an increase from NOK 32.80 to NOK 35.80 this will give an increased price of NOK 3. The increase in feed costs is mainly due to increased feed prices. Increased raw material prices, where especially prices for fishmeal and fish oil have increased considerably (Andreassen et al., 2015).

The cost of feed depends on mortality, and therefore reduced mortality rate is expected to reduce feed costs. In cases where mortality rate is high, production cost will be reduced. A reduction in the feed price will give the cheapest production cost per kg WFE, in comparison to other variables. A cost reduction of 20% gives the fish on land as cheap as NOK 39.52 and even cheaper in closed sea facilities with NOK 29.80. Overall, the sensitivity analysis shows relatively high sensitivity to feed costs.

A change in energy and oxygen costs makes up a smaller difference in production per kg WFE compared to feed cost. The energy cost for semi-closed facilities at sea is less sensitive to a change in production than it is to land-based farming. An increase in energy cost for SCCS will result in a production price of NOK 33.15 per kg WFE, which is a change of 1.08%. An equivalent reduction in energy cost will give a production cost of 32.45 per kg WFE. In addition, an increase in energy cost for land-based farming will give a production cost of NOK 43.74 and a 20% reduction will result in a production cost of NOK 41.64 per kg WFE.

The oxygen cost on the contrary, is relatively similar at both land-based and semi-closed facilities. However, the oxygen cost for SCCS-technology is more sensitive to a cost increase and decrease. Energy and oxygen are necessary factors for supply in the water tanks that are necessary in the production. Regardless of whether there is an increase or decrease of these costs, it is absolutely essential and cannot be adjusted or avoided.

Less sensitive variables are sludge handling. An increase or decrease of 20% in this cost will not make a significant difference from the basic scenario. This alludes to cases where there may be increased sludge handling costs; it will not have a more or less effect on production cost per kg WFE than a 20% increase in feed cost. Sludge handling cost of both land-based and closed-cage facilities at sea will not have a significance on the production cost per kg if a change in cost occurs. Nonetheless, it is worth noting that costs related to future sludge treatment are very difficult to stipulate correctly, because sludge management is still under development and a lot is happening in this field to this day. In general, it can be said that sludge treatment facilities become cheaper per tonne of dry matter to be treated the larger the facility is (Fylkesmannen, 1995).

6. Discussion

An implementation and increased investment in closed-cage systems in the aquaculture industry will have some repercussions. These activities have both positive and negative effects on society. Some of these may contribute to value creation, and further be of interest to a decision-maker. Therefore, the thesis will further discuss the repercussions of investing in closed containment systems (CCS) below.

The supply growth of Norwegian salmon can indicate to be low for several years, because of three identified reasons. First, current production limits growth due to sustainability challenges and continuous cost increase with salmon farming. Second, it is assumed that it takes time to immediately upscale production from new technologies. Finally, the regulatory restrictions help prevent increased production.

The high-cost level indicates that Norway cannot compete in low-price segments (Henriksen & Thormodsdottir, 2020b). Conducted calculations reveal that costs in a closed-containment facility are higher than open net-pen farming. The trend shows that production costs in open net-pen farming have almost continuously increased since 2008, and there is a danger that costs will continue to grow. However, various factors in CCS can indicate a reduction in production costs, and the differences may even out over time. Researchers claims that increasing sale pric, facility capacity and decreasing capital cost, are the most significant savings affecting economic viability. These factors can contribute to either success or failure to implement this type of technology (De Inno, Wines, Jones & Collins, 2006).

Findings from calculations show no significant financial savings in switching from ONP farming to closed-cage farming in terms of operating costs per kilo WFE. Nevertheless, some advantages speak in favor of investing in closed facilities, including reducing the negative externalities. Tytlandsvik Aqua expresses in the conducted interview that one can reduce these costs as farmers gain more knowledge to operate more efficiently. This implies the importance of developing a quality standardization to control the water quality and other factors in the facilities in the best possible way.

As shown in the sensitivity analysis, feed cost is susceptible to an increase as it is the most significant cost item in production. The risk of an increase leads to even higher production costs for CCS, making it even more difficult to become more profitable than traditional ONP. High costs are used to manage salmon lice because delousing in open cages gives increased feed costs due to loss of feeding days. Therefore, the increased feed cost and feed price make it more advantageous to reduce the costs of using closed facilities. Moreover, feed requirements are also lower in CCS due to the avoidance of lice and escapes. In addition, more negligible feed waste can provide savings on feed costs. As a result, the fish becomes healthier, grows faster, and can achieve a better market price.

Replacing ocean currents with electricity in land-based closed containments (LBCC) facilities and collecting and utilizing nutrients produced by the salmon are some of the potential environmental tradeoffs for both technologies. Another potential environmental trade-off is reducing transport distance by placing the production close to the market or independent of oceans. An advantage of a land-based recirculation aquaculture system (RAS) is that it can be established almost anywhere near the market because production is not dependent on traditional localities along the coast. Today, large quantities of fish are transported by airplane over long distances. From a climate footprint perspective, it is advantageous that salmon do not have to be transported far to reach consumers. Besides climate footprint, an implication is that it can have significant savings on transport due to the expensive exports to countries such as the USA and Japan, as these countries buy large quantities of Norwegian salmon. According to the salmon exporter company Seaborn, the costs related to air freight cost between NOK 20-22 per kilo to export whole Norwegian salmon to the USA (Njåstad, 2021). Moreover, it may also reduce the risk of fish mortality over long export distances, and LBCC-RAS can therefore be considered a sustainable alternative to salmon production.

Since LBCC can be developed at most places, one can build expertise locally, and Norwegian suppliers can deliver equipment and expertise needed. An example that can be cited is the Norwegian company Atlantic Sapphire, a pioneer in land-based farming who has recognized that the United States is the biggest salmon market in the world, and they are currently conducting its operations in Miami, Florida (Atlantic Sapphire, 2020a). They have acknowledge the benefit of subsequently minimizing their airfreight expenses and therefore believe in lower costs than the Norwegian fish (Atlantic Sapphire, 2020b).

A disruption of the land-based RAS system can be said to potentially threaten the competitive advantages of Norwegian aquaculture. Fierce competition can lead to price battles where companies that are able to exhibit lower production and distribution costs will suffer less financial hardship. The Atlantic Sapphire example shows the challenges of predicting the results of LBCC-RAS replacement for traditional farming. The company is struggling to make money as its production started in 2020. Thus, it is unclear and difficult to say whether air freight costs have compensated for increased production costs and obscure its effects on the Norwegian salmon industry's future competitive position abroad. However, if an implementation of LBCC-RAS can indicate that the total costs will be economical enough to replace the traditional farming production, the risk of new actors may also want to establish themselves in other countries. On the contrary, frozen salmon is often the best solution for export because of its lower costs, although it cannot be directly compared with fresh salmon (Liu, Rosten, Henriksen, Hognes, Summerfelt, & Vinci, 2016). However, this points to a future alternative regarding product development and improvement of logistics chain management Furthermore, frozen intercontinental exports can compete with the locally produced salmon in LBCC-RAS and SCCS farming to maintain quality through transport and market acceptance (Liu et al., 2016).

If establishments of land-based RAS gain increased commercialization abroad, this could eventually lead to consequences for the Norwegian aquaculture industry. A potential establishment in a few years may indicate a change in the salmon market, especially in the fresh produce market. Furthermore, a possible increased competition from land-based facilities abroad might raise the Norwegian aquaculture industry’s need to expand with more species. However, there are currently more essential drivers in the development of cleaner fish, including significant funding for R&D work for the salmon industry (iLaks, 2020b).

The most significant limiting factor in investment in a closed-cage system is the high investment cost, which confirms Intrafish´s article (Intrafish, 2019) and what Tytlandsvik Aqua and FishGLOBE underlines in the conducted interview. Thus, financial incentives for an advancing technological innovation of CCS can reduce the investment cost to become more competitive with traditional farming. Findings according to research find that economic incentives have a more significant effect than traditional command and control policy (Bailly & Willmann, 2001; Liu, Chuenpagdee & Sumaila, 2013). Eco-labels, subsidies, taxes, and fees are examples of market-based economic instruments that can help provide incentives in the growing industry to foster cost-effective technology innovation and adaptation of a CCS (Rosten, Ulgenes, Henriksen, Biering & Winther, 2013). It is worth noting that such incentive-based approaches should be, according to research, executed regarding “vectors of the market and social forces such as environmental policy and consumers” (Liu et al., 2016).

Eco-labeling of farmed salmon will be a market-driving force and benefit to change consumers' buying behavior (Liu et al., 2016). This is the type of labeling that certifies the environmental performance of a product. As a result, concerned and environmentally conscious consumers are more likely to be willing to pay more for environmentally sustainable produced salmon. In addition, subsidies, fees, or taxes can be applied to encourage cost-effective innovation and technology adaptation. Some examples which can stimulate technology innovation are rewarding improved environmental performance by capturing and controlling waste streams in LBCC-RAS (Liu et al., 2016). Moreover, one can be rewarded when farmers are able to eliminate salmon lice, diseases or reduce the mortality rate.

The environmental policy that deals with complying with the authorities' environmental requirements is essential to consider. Still, Norway’s "green" license for salmon farming require aquaculture to require investments that can be significant in advance. Nevertheless, the researcher believes that in the long run, such technological innovation will increase the social license to several things; by operating through improved environmental performance and thus less conflict with other resource users, experienced market benefits through lower costs to obtain and maintain a license to operate, and lastly to monitor and reduce negative consequences such as costs of recapturing salmon escapes (Liu et al., 2016).

According to Tveterås et al. (2020), development permits have stimulated innovation. The challenges in the aquaculture sector have promoted radical innovation in new farming solutions.

In addition, the use of new technology can provide further opportunities to foster new advanced and exciting growth areas within the industry and open up the market internationally and increase competition. An implication is to continue stimulating research, innovation, and technological development in order to develop new solutions to solve challenges. In this way, Norway secures its position as one of the world's leading aquaculture nations.

The limited financial resources can be said to be the factor that hinders innovation and development. Financing can be received from credit institutions, private investors, and public organizations. Access to capital is crucial for the success of closed containment technology. Credit institutions today will only provide loans for green and sustainable investments. However, banks are just starting to learn and open up about closed-cage farming, as they have historically been reluctant to finance land-based farming. The skepticism comes from the fact that new technology is significantly risky and unclear, and very costly. Whereas the risks have now eased, and banks are willing to provide financing for new technology or, more specifically, land-based farming. This is because the technology is now more widespread as there is more documentation and research, and several companies have shown that they have succeeded on land.

Receiving external financing is still a major challenge, even though the tide seems to have turned to an extent. According to an EY report (2019) cited by Salmon Business, DNB states that they have become more nuanced in their thinking concerning land-based farming and may open up to financing land-based. DNB markets have looked into 42 different land-based projects, and the bank has concluded that in seven years, 600,000 tonnes of salmon can be produced on land in Norway and elsewhere in the world. This is approx. 40% of what is currently produced in Norwegian fish farms in the sea (Fiskeribladet, 2019). DNB´s footprint might lead in the right direction and contribute to increased investments from other financial institutions.

It can be said that the banks are quite indifferent when it comes to financing closed technology, which says something about the risk. Given the positive development of the salmon aquaculture industry in recent years, EY (2019) reports that there is an increased interest in this industry among investors entering the aquaculture value chain (EYGM Limited, 2019). There are dozens of plans for the production of salmon on land, which involves huge technology risk, and to finance this, there is an ongoing money hunt. Capital is given to various projects, as some actors are more serious than others.

Most of the LBCC projects are still in the planning phase and are financed by investors, but there is still a lack of sufficient funding. Thus, more companies have gone public on the stock exchange and managed to raise limited capital. Today there are about six companies listed on the stock exchange, as this also shows the great interest in land-based farming (Berge, 2021). This example can indicate confident investors' strong belief in adapting land-based technology being a success, or could it be the fear of missing out on potentially high returns.

Historically, the freight premium has been what has attracted land-based farmers. But in recent years, environmental factors have gained increasing focus in the capital market. The fact that more land-based players present themselves as a greener alternative may have affected investors' appetite. Moreover, the threshold is very high to gain trust in investors' success, as they have become more educated on this type of project. Furthermore, it is implicated that technology choices, followed by localization quality, are high on the agenda. It is assumed that these things should most likely check all the boxes to gain investors' trust.

Apart from credit institutions, one can also apply for funding from Innovation Norway. The financing opportunities for development and export projects have seldom been better today, during the corona-pandemic period. Therefore, an implication to Norwegian companies is to be forward-looking and take a larger share. Innovation Norway is, in this case, worth mentioning because the organization can be a good supporter and contribute to guidance. Moreover, Innovation Norway has been given an increased framework for loans and grants for numerous land-based development projects due to the corona crisis (Innovasjon Norge, 2020). As far as semi-closed facilities, there is not yet any documentation on the financing situation. However, FishGLOBE mentions in the interview that SCCS projects struggle to acquire capital to finance its project. Banks and investors think such new and advanced technology is too expensive and entails high risks. Investors choose to invest in land-based farming projects instead of semi-closed at sea because of the license fee.

Investment in LBCC and SCCS facilities is capital-intensive and thus depended on both equity and external financing. Although the government claims that Norway needs new sustainable and innovative solutions in the aquaculture industry, it can be discussed that the limited capital access inhibits further innovation, as innovative technological solutions struggle to raise capital. Thus, an implication is that the authorities should provide more room for environmentally oriented innovation by financing such projects. Greater capital access can help solve environmental and biological problems in the aquaculture industry. However, the EY analysis states that proven technology and industrial competence will continue to be critical lending criteria to get credit institutions and private investors on board going forward (EYGM Limited, 2019).

The thesis’s findings indicate that the current regulatory framework does not facilitate solid growth. Output restricting effects of the traffic light system can have led to the challenge of the salmon industry´s limited production volume growth. The regulations may have a strong and long-lasting effect on further development. This leads to a possible contradiction between the government´s ambitions of a fivefold production of salmon and the effects of the governments’ regulations on the industry´s development (Olafsen, Winther, Olsen & Skjermo, 2012). In other words, while the government aims to promote increased production output, it is the traffic light system that prevents SCCS technology and traditional ONP from reaching this goal. An implication is that the government should grant more licenses, but the authorities are running a restrictive line. Moreover, it can be discussed that the causal relationship between the regulatory framework and the government’s goals needs to be aligned with one another. These two factors should complement each other while evaluating measures that can both reject the negative externalities that are inflicted on the environment. This further aligns with Asche et al. (2012) about how the industry should be allowed to grow on its terms and that the authorities should only limit themselves to regulations based on what is biologically and environmentally sustainable.

The development permits are incentives to increase production. Aquaculture development permits provide an alternative way to generate growth in production volume by implementing innovative and sustainable farming solutions (Basso et al., 2021). However, it can be said that these licenses are often seen as an economical means of experimenting with different solutions rather than an incentive to increase production output.

What can be interpreted from the analysis is that some advantages and disadvantages weigh against each other when it comes to closed technologies. A lot of uncertainty is still associated with new technology due to ongoing research and testing. Thus, several factors indicate that closed alternatives should supplement the open cages of the industry. Nevertheless, one can ask questions as to why the government provides incentives exclusively for land-based projects and does not provide similar encouragement to those who want to invest in semi-closed solutions in the sea. Both technologies adhere to a closed-cage system and to some extent, solve the same challenges. The licensing fee for sea-based farming represent a disadvantage in the development of SCCS-technology. It can be discussed how obstructive it would be to charge when closed cages at sea do not constitute an environmental burden. Thus, an implication is that the government should provide the same guidelines given at sea as at closed facilities on land. The high licensing fee can be an obstacle for fish farmers to invest in semi-closed facilities at sea.

The aquaculture industry creates jobs throughout the value chain and repercussions industries (Tveterås et al. 2020). Richardsen et al. (2019) show in the Sintef report how the sector contributes to employment. The research indicates that approx. 42,000 full-time equivalents (FTE) related to aquaculture in 2018, the industry accounts for about 8,200 FTE, while 34,150 FTE are in the value chain and repercussion sectors. Tveterås et al. (2020) assume an increase in labor productivity in the period up to 2050. Over time, this will produce salmon with fewer FTE in aquaculture, other value chains, and repercussion sectors (Tveterås et al. 2020).

In the Norwegian government's report “Ny vekst, stolt historie” one of the main goals is to increase employment (Ministry of Trade, Industry & Fisheries & Ministry of Petroleum Energy, 2017). To achieve this goal, the government wants, among other things, to facilitate technology and knowledge development in the aquaculture industry through. A fivefold increase in the farming facilities using CCS can affect Norway's employment both positively and negatively. On the one hand, the growth can negatively affect suppliers of drugs, chemicals, and mechanical de-lice equipment (Horjen, 2020). Since 2015, the aquaculture industry has reduced the consumption of most medicines by about 90% due to the reduced risk of lice and other diseases in CCS facilities (Horjen, 2020). Therefore, a rise in investments of CCS will have a negative repercussion on the industry’s employment. On the other hand, the development of CCS can positively affect the number of job positions. A facility needs approx. 15-25 employees, which means there will be a need to hire when new facilities occur. If one multiplies Norway's current number of facilities by 5, it will lead to several new jobs. Nevertheless, the industry is dependent on permission to expand land-based facilities and develop SCCS-technology to make a positive contribution to employment in Norway.

Furthermore, the construction industry can also be positively affected. The development of closed-cage systems requires a workforce that can build extensive facilities. Therefore, the buildout will influence the construction industry’s activity level and lead to new job positions. At the same time, a rise in closed-cage facilities can positively affect the transport industry. The Norwegian aquaculture needs to transport both input and output factors. The export requires predictable, fast and cost-effective transport, as it mainly consists of fresh products. An estimate of 130 vehicles drive out of Norway or to an airport terminal with the fish each day (Norsk Indstri, 2017). An expansion of the number of facilities positively impacts the transport industry as products need transporting between different locations. At the same time, facilities require the transport of waste. Therefore, the development will contribute to a higher level of activity for trucks, boats, and other means of transportation, leading to improved employment.

Offshore aquaculture, together with floating offshore wind, offshore CO2 storage, and offshore mineral production, appears to be the most promising new aquaculture industry in Norway (Tveterås et al. 2020). Despite the excellent growth potential, it is a prerequisite that growth in the aquaculture industry must be sustainable. When discussing closed facilities as a contributor to achieving the goal of 2050, it is essential to point out that research is in its early stages, especially for closed-cage facilities at sea. Minimal research comes with some uncertainty in the further expansion of closed facilities.

Today, no technology will be satisfactory if one looks at particulate and dissolved waste products, greenhouse gases, and infectious substances (Tveterås et al. 2021). As mentioned in the analysis, CCS facilities have significantly fewer waste emissions than traditional cages. According to (Tveterås et al. 2021), sedimentation of particulate waste is currently only a local problem in Norway. With a five-fold escalation in today’s production, this can become a bigger problem.

However, one can argue that the closed-cage technologies currently have a good starting point. Nevertheless, an implication is to further research CCS's emission to find a better solution and achieve sustainable growth using closed facilities.

Another uncertainty is the energy consumption of RAS facilities. According to (Hilmarsen et al. 2019), a transfer of current Norwegian production to LBCC-RAS technology provides an estimated total energy consumption of between 7.8 and 11.7 TWh per year. Thus, total energy consumption is estimated to vary between 39 and 58.5 TWh per year, with a fivefold increase in production. The significantly high electricity consumption turns out to be a challenge in land-based farming, leading to significant consequences for society. The thesis will present potential solutions to the energy consumption problem below.

It came to light in the results that uncertainty related to the capacity for land use of LBCC technological facilities is currently strained. Land-based facilities require large areas, which is currently difficult to envisage the extent of area-intensive land-based farming. A production on land contributes to a reduced need for new localities in common at sea. Moving production to land will be possible to reduce conflicts related to aquaculture-based use and protection interests. Conflicts related to aquaculture and anadromous wild fish interests must be assumed to be reduced. However, possible consequences of land-based farming can first and foremost come in relation to reputation in the short term. Relocation of production on land could contribute to increased conflicts related to the beach zone development and the use of large land areas. The biggest negative challenge is probably that a LBCC facility will be very visible in coastal areas. In contrast to open-cage farming, the establishment of LBCC can also be an irreversible, permanent encroachment on nature (Holm et al., 2015). Furthermore, as the number of projects increases and becomes extensive, the skepticism of the population of this industry will potentially grow. An implication is that the industry should focus on reputation building around the new technology, focusing on how new technology and new forms of production will ensure the best possible health and quality of the fish.

Because of the high climate footprint of LBCC technology, changes in energy consumption are needed for the technology to contribute to sustainable growth. Energy Harvest is a company that has tested a new pumping system for land-based fish farming, and they envisage that such a system may also be relevant for RAS technology later on (Salmon Business, 2018). This system can recover some of the energy required to get water into the system and help solve the most significant weakness with LBCC technology. The system utilizes the energy used to set the water in motion and pressure to introduce new water into the system before the water runs out again. The returned water must give off the same energy on the way outwards as it supplies inwards. Energy Harvest's system can help reduce the high energy cost, and in fact, Melhus from Energy Harvest claims that the system can reduce energy costs by as much as 80-85% (Salmon Business, 2018). There is a need for innovative methods that intend to disprove that land-based farming is expensive and energy-intensive. Together with other studies, the study of Energy Harvest, gives opportunities to develop new approaches to reduce the high climate impact land-based facilities currently have. Although the research is minimal, there is great potential for improvement.

Another potential opportunity is that particulate organic waste from fish farming has gone from being a cost to becoming a resource in recent years. Since closed facilities produce far more sludge than open cages, it is necessary to utilize it as a resource instead of an expense. Both technologies have the opportunity of collecting and recycling particulate organic waste (Hilmarsen, 2019). Tytlandsvik Aqua and FishGLOBE mention turning sludge into a resource in the conducted interviews. Today, the companies sell sludge to IVAR and facilities outside of Norway, such as Denmark. Although companies now sell sludge to other industries, the respondents mention that there is still a need to establish a market fully. An incomplete market may indicate that there is still minimal knowledge about recycling private waste. Therefore, it is essential to point out the possibilities for new market potential.

It is equally important to cover the research gap and encourage further research. A research project conducted by Cabell et al. (2019) aimed to evaluate the potential for recycling organic waste from fish farming. The study wanted to cover the research gap regarding waste recycling and concluded with waste from fish farming being good nitrogen fertilizer. In other words, the study shows great opportunities for recycling waste, which gives reason to research this to establish a potential new market. Therefore, one implication is to investigate the possibilities of turning waste into a resource.

Another reason to further analyze the potential of turning sludge into a resource is that waste from fish farming has the potential of becoming biogas (Biogass Oslofjord, 2019). The aquaculture industry depends on other sectors, including the industry itself, to do more research on shaping sludge into biogas. The high potential is because the sludge from land-based fish farming is easier to collect and clean, unlike waste from open cages that deposit on the seabed. In addition, the waste contains fat and protein, which is well suited for biogas production (Biogass Oslofjord, 2019). Especially the waste from smolt farming, including feces and feed waste, have recirculating possibilities. Experiments show that putting fish waste into biogas production can significantly increase output (Biogass Oslofjord, 2019).

Turning waste into biogas is one thing, but it is also possible to turn waste into fuel (Steien, n.d.). Like biogas, the aquaculture industry depends on other sectors to do more research on shaping sludge into fuel. Norcem's factory in Kjøpsvik has tested this, where they have concluded that there is good potential. It may appear that each tonne of dried fish sludge will replace 400-500 kg of coal (Steien, n.d.). The mentioned research on turning waste to fuel and recycling to biogas show that a market for organic waste from aquaculture has potential. Nevertheless, the industry is dependent on more research to map functionality, efficiency, and demand of biogas and fuel from fish farming. Along with further research on transforming waste into biogas, an implication is to study the potential for converting waste into fuel.

Norway has previously experienced a trade deficit with other countries despite large revenues from the petroleum sector. According to researchers, Norway has a structural dependence on large export revenues from petroleum. When petroleum exports fall in the future, this deficit will become permanent if export revenues from new industries do not replace those that shrink. Aquaculture is probably the industry that can contribute most to closing the export gap in Norway as oil and gas production will be reduced (Tveteårs et al., 2020). The aquaculture industry might contribute to increased value creation and increased exports.

When the world community shut down due to the corona pandemic, seafood exports lost essential sales channels: the restaurant and hotel segment. Thus, there were challenges in logistics, and companies essentially moved sales to online shopping, grocery chains, and takeaway leftovers

(Fisk, 2021). In other words, consumers did not stop eating salmon when restaurants closed but moved consumption home to the kitchen, which created increasing salmon demand globally. The corona situation thus produces not only challenges but also new opportunities for Norwegian seafood. In addition, demand continues to grow due to an increasing focus on healthy and sustainable food, as Tveterås et al. (2020) also point out. The industry must take advantage of this in the future, as Norwegian seafood is a highly sought-after global commodity that has contributed to stable growth.

Increased production might help boost export potential and contribute to meet the global demand. According to research demand continues to grow more than farmers can produce (KBNN, 2019), and Norway will in all likelihood have lower supply than demand due to negative externalities. The stagnant growth due to today´s sustainable problems makes it challenging to increase further production. This speaks in favor of the implementation of SCCS and LBCC, as the technologies can contribute to a sustainable increase in production volumes.

To conclude, today´s salmon production challenges are mainly represented by regulatory, environmental, and biological restrictions on the industry’s uncertainty and production growth. Closed-containment technologies have the opportunity to shape Norwegian aquaculture´s central challenge of its uncertain profitability and contribute to value creation. Implementing CCS for the cultivation of post-smolt can be a first step in building requisite technical competencies that provide option value if this technology reaches economic and technological maturity. These CCS production technologies are still going through technological fermentation, making it difficult to predict whether CCS can become the industry's dominant farming technology. We interpret from our findings that the industry should acknowledge the future performance potentials to remain competitive.

7. Conclusion

We found that land-based farming was partly a well-researched topic, while semi-closed farming was less researched. There was limited material on the industry when we examined the roles of LBCC and SCCS technology in practice. Thus, we conducted qualitative interviews with Tytlandsvik Aqua and FishGLOBE, in addition to performing archival and documentary research. When completing the interviews, we uncovered practical solutions within the technology and specific numbers that we could not find through archival and documentary research. Hence, we filled the gaps from documentary research with interviews with two industry representatives from their respective companies.

This thesis aimed to answer the research question on *what economic benefits society achieves by basing further growth on technology for closed facilities.* To answer the research question, we established a comprehensive overview of the Norwegian aquaculture industry current state, which was explained in chapter 1 and 2. Furthermore, to fulfill the thesis's purpose, we defined the advancement of CCS, thus we highlighted the sustainability challenges the aquaculture is currently facing. More precisely, our findings discovered negative effects of salmon escapes and salmon lice. Meanwhile, land use, high energy consumption, and emissions are the negative environmental drivers. These factors constitute to the most critical sustainable challenges, which government's regulations seek to reduce.

The ongoing salmon trend might predict a substantial increase for the salmon. However, the industry in Norway struggles to increase its production volume mainly due to two reasons. First, domestic regulations such as the permit regulations and traffic light system limit the potential growth. Second, biological challenges constrain farmer's ability to optimize the fully MAB they already hold permits for. On the other hand, closed-cage systems struggle to upscale production mainly due to the fact that the technology is still under development, in addition to the high investment costs. It can thus take several years before production reaches the level of traditional ONP farming.

We identified an implication option for salmon farmers in Norway to overcome restrictions on future production volume growth. Open cages and closed-containment farming methods have their challenges, but a combination of closed-cage and traditional open-net facilities might realize the desired condition within the aquaculture industry. A complete replacement of the conventional open-net cage with the closed-cage variants that exist today will require high investments. Overall, the production and capital cost are still too high, and restrictions on production can indicate to the utilization of combined technologies which will utilize Norway´s natural advantages to a full extent. Thus, an implication is that closed technologies should supplement open sea-based farming as a temporary solution until closed-cage technologies are fully developed and an upscaled production will be possible.

Production costs in LBCC and SCCS are higher than in traditional ONP farming. Through this master's thesis, we have identified which variables stand out as significant cost drivers. Furthermore, we have also identified the sustainable challenges that closed technologies can solve to earn the production cost and even out over time, with lower expenses related to, e.g., lice, disease, and feed costs. These factors can facilitate cost reduction in CCS, and these savings could be significant and contribute to either success or failure to implement this type of technology.

Implementation of closed technologies will lead to many repercussions that will affect society. It will open up to new potential market opportunities, increased employment, and value creation. The aquaculture industry is already a solid export industry, but increased production could further boost salmon exports and meet global demand. The implementation of new technology will positively contribute to creating more and new jobs that prove to be one of the main goals of the Norwegian government. However, it can also impact employment because it will affect suppliers of drugs, chemicals, and mechanical de-lice equipment. In addition, an implication is to continue to stimulate research, innovation, and technological development to develop new solutions and create more jobs within the aquaculture industry. In this way, Norway can secure its position as one of the world's leading aquaculture nations.

7.1 Further Research

This thesis includes an analysis to elucidate the economic benefits of using land-based and semi-closed technology. Several studies have analyzed LBCC technology, but fewer studies of SCCS technology have been conducted. Recently, closed technology at sea has shown promising results regarding solving environmental and biological challenges. Therefore, a suggestion to further research is to go deeper into this theme and study whether the technology can contribute to sustainable growth in aquaculture. This can be illustrated by analyzing the technology in various companies in a large production country, such as Norway, where there are the most available data.

Today, SCCS technology is only in its development phase, and there is minimal documentation on whether it contributes to solving environmental and biological challenges, in addition to the technology's production costs. Due to the few studies on the technology, it would further be interesting to study the technology in the future when there is more documentation and available data.

Further, we have chosen a qualitative approach with the main focus on un-numeric and other qualitative data. However, a more quantitative approach may also be interesting to study further. For example, further studies can conduct profitability analyses by comparing the technologies presented in the thesis or by looking at the profitability of SCCS technology individually. This type of analysis can provide insight into the technologies' prospects for further contribution to growth in the industry. Finally, it would be interesting to investigate whether the thesis’s results from the Norwegian aquaculture industry can relate to other large production countries, such as Scotland, Canada, and Chile.

7.2 Limitations

The limitation of the study lies in the lack of primary and secondary data. This thesis includes a comprehensive collection and processing process of qualitative data from archival and documentary research and semi-structured interviews. We have chosen to interview two companies, which are not a sufficient number of observations to achieve reliability and significance in theory. Our purpose is to look more closely into the technology that these two companies operate with, and thus an in-depth interview with a few respondents will be most significant for the thesis. Furthermore, we have not studied the company itself but used the interview objects that each represent their respective farming technology to respond specifically to data that does not exist in public. We received answers to most questions of the interview guide and what was desirable to get answers to, but still, there was a lack of practical numerical data concerning the price for producing adult salmon. These data are necessary to conduct the cost-benefit analysis and the production cost analysis, and we thus had to use existing estimated figures from public research reports. However, there is a lack of data, including the cost of production for SCCS technology. This was something the interviewee from FishGLOBE could not answer because it is still a lot of uncertainty associated with the technology, and thus it has not been documented yet. These factors lead to limitations on the thesis concerning evaluating the technologies for further potential growth in the aquaculture industry.

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Appendices

Appendix A

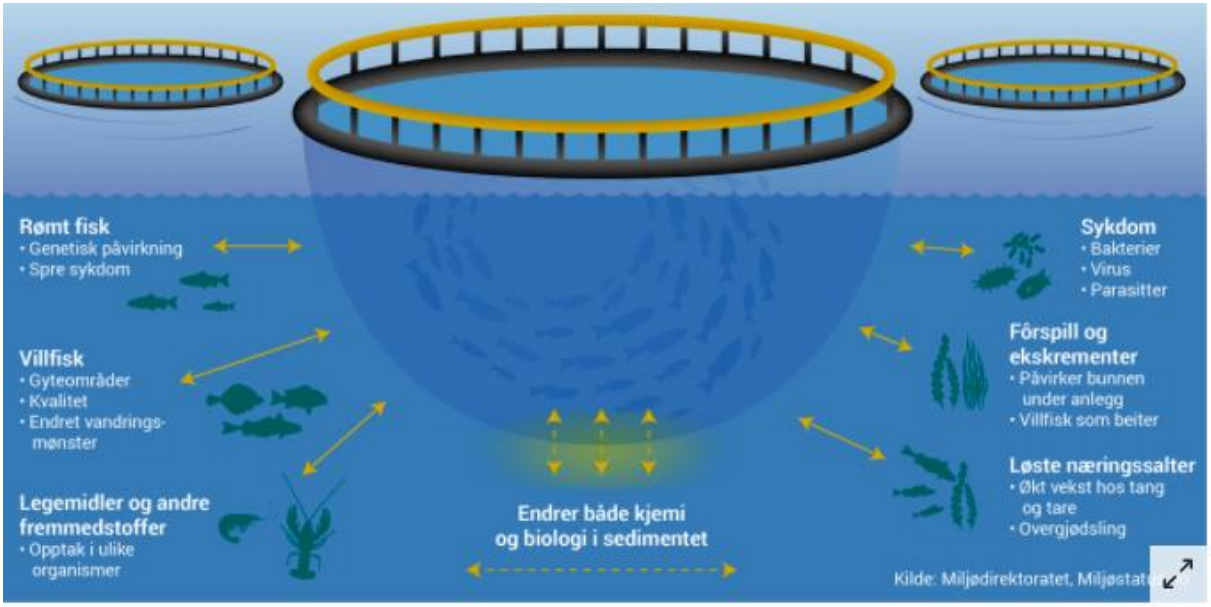

Figure A1: The Technology of Traditional Sea-Based Facilities. (Source: The Norwegian Environment Agency, n.d).

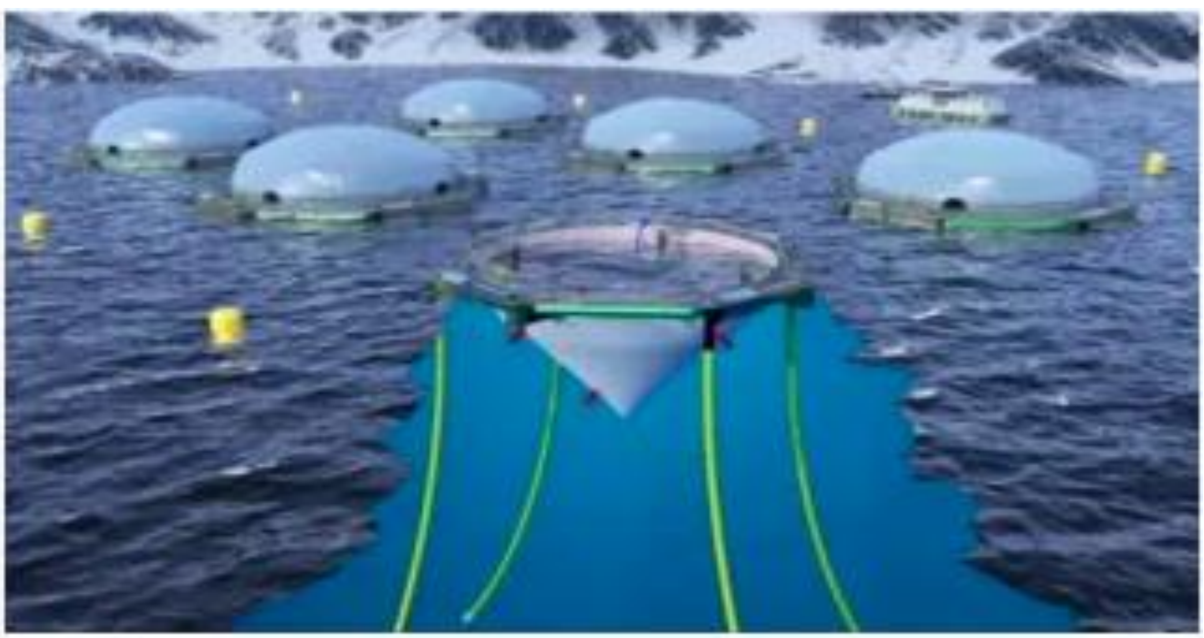

Figure A2: A fresh take on closed containment aquaculture (Source: The Fish site, 2017).

Appendix B

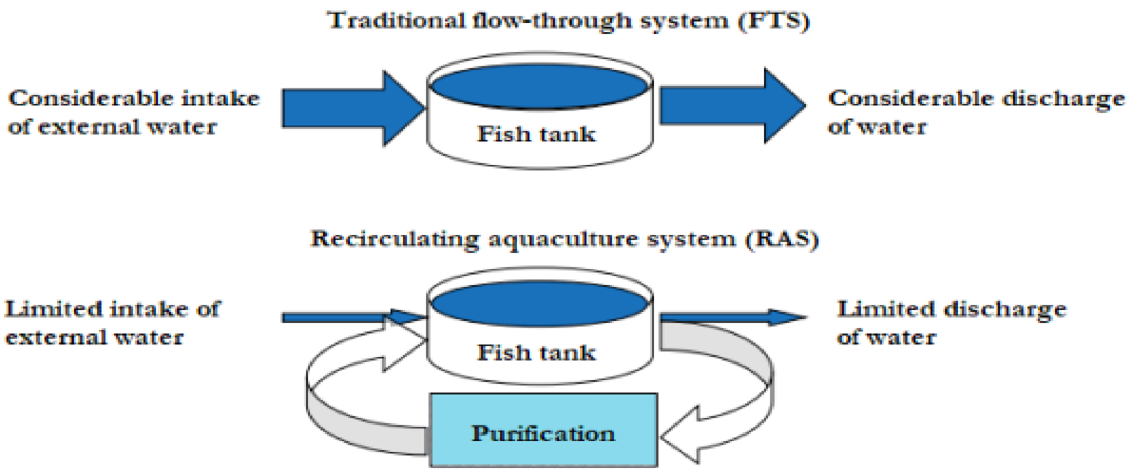

Figure: B1 Principle comparison of FTS and RAS, Source: (Terjensen, 2017)

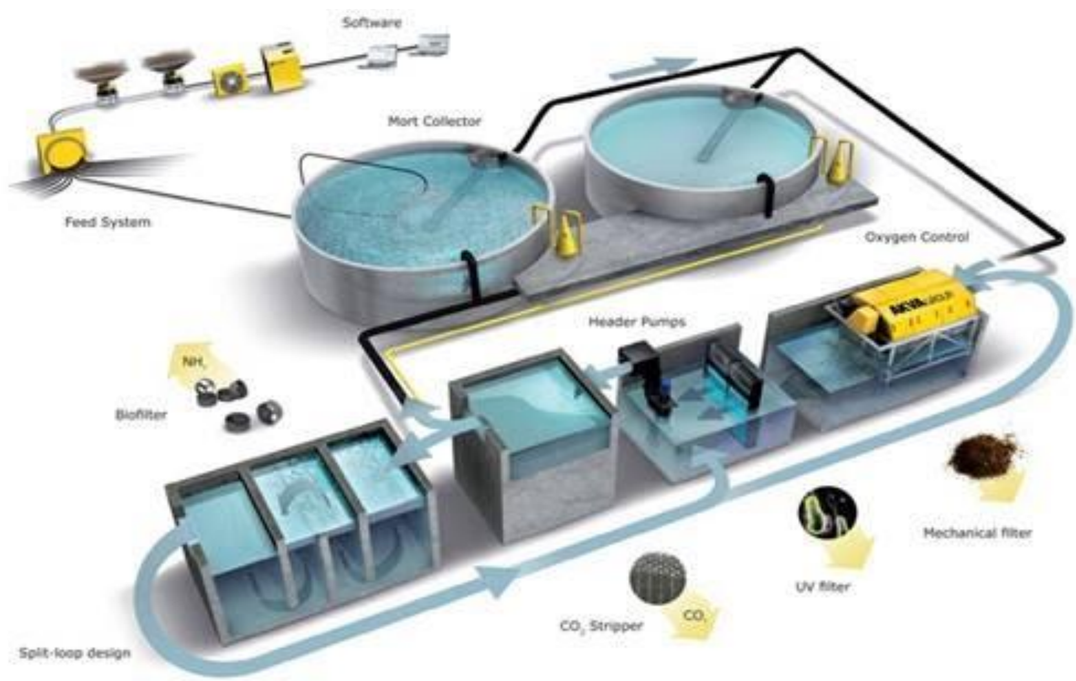

Figure:B2 Land-based facility based on RAS-technology (Source: Epic Aqua, n.d.).