



The Economic Attractiveness of Land-based Salmon Farming in Norway

A comprehensive presentation of an emerging industry

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This thesis was written in the fall of 2019 at Norwegian School of Economics, as an integral part of our Master of Science degree in Economics and Business Administration.

Despite extensive publicity on land-based salmon farming in the media, limited academic information on its economic attractiveness exist. The potential emergence of a new industry and sizeable investments being made, the need for robust economic information is considerable. This encouraged us to pursue the subject. We appreciate the opportunity to provide such information.

The process of writing this thesis has been challenging, yet educational and rewarding. We hope our work contributes to increased insight to the land-based salmon farming industry in Norway.

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Abstract

In this thesis we explore the economic attractiveness of land-based salmon farming in Norway, an entirely new industry with the potential of revolutionising fish farming. We will provide a comprehensive overview of the current status of the industry, as such information simply does not exist. Further, we will examine trends for both land-based and sea-based salmon farming in order to provide much needed insight on the possible future of these industries.

Planned land-based facilities with a total production equal to 32.3% of world production (2018), has been disclosed. As of such, our main focus is to investigate under which circumstances land-based farming is economically attractive. This is a prerequisite for understanding whether or not the industry can achieve the current expectations of success.

Despite massive interest of land-based farming there is a lack of both up-to-date and robust estimates of its economic attractiveness. We remedy this by being the first to examine the economic attractiveness avoiding unreliable estimates on cost components. Instead, we use two entirely new approaches for this industry: 1) we estimate the implicit maximum total cost per kg, and 2) we use the most up-to-date estimates and capture the uncertainty in our assumptions with a Monte Carlo simulation.

Our principal results implies that the land-based farming industry is currently not proven economically attractive. We find that the point of break-even is an implicit maximum total cost per kg (HOG) of NOK 50.1 when using a 20 year modelling period and the forward price. We also report that our modelled facility, with the same assumptions, has a negative value of equity of NOK -53.6 million. The Monte Carlo simulation find a 47.8% probability for positive net present value of equity.

However, small changes in assumptions may alter this conclusion. With recent developments in regulation and industry sentiment making sea-based farming less competitive, and the prediction that the performance/price ratio of land-based farming will increase as a function of effort invested, it is likely to see a shift towards land-based farming in the future.

Keywords – Land-based salmon farming, RAS, industry report, biological challenges

Contents

1	Introduction	1
1.1	Motivation and objective of the study	2
1.2	Limitations	3
1.3	Outline	3
2	Background	5
3	Literature Review	8
4	The Norwegian salmon farming regulatory regime	12
4.1	Historical developments	12
4.2	The traffic light system	14
4.3	Land based salmon farming	15
5	Salmon farming dynamics	17
5.1	The value chain of salmon farming	17
5.1.1	Terminology and ratios for Atlantic salmon	21
5.2	The biological situation in sea-based farming	21
5.2.1	Sea lice	21
5.2.2	Disease	22
5.2.3	Escape	23
5.2.4	Toxic algae	24
5.2.5	Mortality	24
5.2.6	Emissions	24
5.3	Political environment surrounding salmon farming	25
5.4	Land-based salmon farming technology	26
5.4.1	Flow through systems	26
5.4.2	Recirculating aquaculture systems	27
5.5	Risks in land-based salmon farming	28
5.6	Comparison of salmon farming in sea-based and land-based facilities . . .	31
5.7	Planned land-based production capacity	33
6	Theory	38
6.1	Economic profit in competitive markets	38
6.2	Negative externalities	39
6.3	Auctions	41
6.4	Tax in competitive markets	41
6.5	Development of technological performance	43
6.6	Patterns of technological evolution and change	45
7	Methodology	47
7.1	The price of Atlantic salmon	47
7.2	Sea-based salmon farming	51
7.2.1	Industry cost development	51
7.2.2	Development of industry operating margins	55
7.2.3	Development in MAB prices	56

7.3	Assumptions for the modelled land-based facility	59
7.3.1	Technical design	59
7.3.2	Capital structure	60
7.4	Comparison of capital expenditures	61
7.4.1	Land-based facilities	61
7.4.2	Comparing a land-based and sea-based facility	63
7.5	Capital asset pricing model	66
7.5.1	Beta estimate	67
7.5.2	CAPM estimate	69
7.6	Weighted average cost of capital	70
7.6.1	WACC estimate	71
7.7	Net present value	71
7.7.1	Implicit maximum total cost per kg	72
7.7.2	Base case NPV model	74
7.7.2.1	Biological assumptions	75
7.7.2.2	Roe	76
7.7.2.3	Feed	77
7.7.2.4	Vaccination	78
7.7.2.5	Labour	78
7.7.2.6	Insurance	79
7.7.2.7	Other operating costs	79
7.7.2.8	Depreciation	80
7.7.2.9	Net financial expense	80
7.7.2.10	Cost of harvesting	81
7.7.2.11	Total costs	81
7.7.2.12	Monte Carlo simulation	82
8	Analysis	85
8.1	Implicit maximum total cost per kg	85
8.1.1	Results when assuming 20-year lifetime	85
8.1.2	WACC sensitivities	86
8.1.3	Results when assuming an infinite lifetime	87
8.1.4	WACC sensitivities	87
8.2	NPV base case	88
8.3	Monte Carlo simulation	91
8.4	Comparison to previous studies	91
9	Implications and discussion of the findings	93
9.1	Implications of the findings	93
9.2	Discussion of the findings	94
10	Limitations and further research	97
10.1	Limitations	97
10.2	Suggestions for further research	98
11	Conclusion	99
	References	101

Appendix	108
A1 The thermal growth coefficient (TGC)	108
A2 Production plan	108

List of Figures

2.1	Volume in tonnes live weight (left axis) and price/kg NOK (HOG) (right axis) for Atlantic salmon adjusted for inflation, base year 1998, Source: Statistics Norway (2019)	6
2.2	Total production cost/kg and nominal price/kg, Source: Fiskeridirektoratet (2019)	7
4.1	Production zones in the traffic light system as clasfeied in 2017, Source: Norwegian Directorate of Fisheries (2018c)	15
5.1	Comparison of land-based and sea-based salmon farming value chains, Source: compiled by the authors	17
5.2	Graphical representation of the value chain in sea-based salmon farming, Source: Mowi ASA (2019)	19
5.3	Graphical representation of the value chain in land-based salmon farming, Source: The Conservation Fund (2019)	20
5.4	Complexity as a function of degree of recycling, Source: Billund Aquaculture Service A/S (2017)	28
5.5	Principle comparison of FTS and RAS, Source: Terjesen (2017)	28
6.1	Economic profit in a perfectly competitive market, Source: Goolsbee et al. (2013)	39
6.2	Externalities in a perfectly competetive market, Source: Goolsbee et al. (2013)	40
6.3	Who pays the tax?, Source: Goolsbee et al. (2013)	42
6.4	Normative development of technology performance/price ratio, Source: Schilling and Esmundo (2009)	44
6.5	Normative development in technology performance/price ratio, Source: Schilling and Esmundo (2009)	45
7.1	Historical nominal spot- and forward price in HOG, Source: Fish Pool (2019)	48
7.2	Average, high and low total expenses per kg (HOG) for Atlantic salmon in Norway, Source: Norwegian Directorate of Fisheries (2019b)	52
7.3	Historical average total operating cost per kg for Atlantic salmon produced in Norway, Source: Norwegian Directorate of Fisheries (2019c)	55
7.4	Average operating margin for sea-based salmon farmers in Norway 2008-2018, Source: Norwegian Directorate of Fisheries (2019c)	56
7.5	Capital expenditures per kg (HOG) of planned facilities in Norway, Atlantic Sapphire and previous studies, Sources: ilaks (2019f,a); Andfjord Salmon (2019); Kyst (2018, 2017a); ilaks (2019b); Kyst (2017b); ilaks (2019e,d, 2018a,b, 2016); Tekfisk (2019); Atlantic Sapphire (2019b); Liu et al. (2016); Bjørndal and Tusvik (2017); Bjørndal et al. (2018)	62
7.6	Weight development per fish (g)	76
7.7	Number of Atlantic Salmon per generation of roe	77
7.8	Development in total biomass for the first seven generations	78
7.9	Breakdown of other operating costs in NOK million	80
7.10	Total production cost per kg live weight in steady state	82
8.1	Sensitivity in the value of equity for changes in assumptions	89
8.2	Monte Carlo simulation of the value of equity using 1,000 simulations . .	91

List of Tables

5.1	Terminology and conversion ratios of Atlantic salmon, Source: Mowi ASA (2019)	21
5.2	Number of escaped farmed salmon in Norway, Source: Norwegian Directorate of Fisheries (2019d)	23
5.3	Mortality for completed production cycles in Norway, Source: Norwegian Veterinary Institute (2019)	24
5.4	Planned land-based salmon farming production capacity in Norway, *Government approval not granted, Source: Norsk Fiskerinæring (2019); ilaks (2019g,c)	35
5.5	Planned land-based salmon farming production capacity excluding Norway, Source: Norsk Fiskerinæring (2019)	36
5.6	Planned land-based salmon farming production capacity by continent . .	37
7.1	MAB prices from government licensing rounds in Norway (Finnmark), Source: Bjørndal and Asche (2011); Nofima (2014); Norwegian Directorate of Fisheries (2015)	57
7.2	MAB prices from government auction June 2018, Source: Norwegian Directorate of Fisheries (2019a)	57
7.3	MAB prices from government auction June 2018 (HOG), Source: Norwegian Directorate of Fisheries (2019a)	58
7.4	Capital expenditures for a 10,000 tonnes (live weight) land-based RAS facility, Source: Bjørndal et al. (2018); Billund Aquaculture Service A/S (2017)	60
7.5	Assumed price per MAB license, Source: Liu et al. (2016) and Bjørndal et al. (2018)	64
7.6	Capital expenditures for a 10,000 tonnes sea-based facility using two locations and average MAB-price, Source: Bjørndal et al. (2018); Norwegian Directorate of Fisheries (2019a)	64
7.7	Capital expenditures for a 10,000 tonnes sea-based facility using two locations and high MAB-price, Source: Bjørndal et al. (2018); Norwegian Directorate of Fisheries (2019a)	65
7.8	Comparison of capital expenditures for a 10.000 tonnes land-based RAS facility and sea-based facility. Capital expenditures per kg in HOG, Source: Bjørndal et al. (2018); Norwegian Directorate of Fisheries (2019a)	66
7.9	Beta estimate of modelled land-based project	69
7.10	Cost of equity estimate	70
7.11	WACC for land-based project	71
7.12	Estimates for price per kg (HOG) in NOK for different scenarios	73
7.13	Cost components the implicit maximum total cost per kg must cover . .	73
7.14	Growth from roe to 92 grams	75
7.15	Total cost in NOK million and total production cost per kg (HOG) for year 0, 1 and steady state	81
7.16	Assumptions for Monte Carlo simulation	84
8.1	Implicit maximum total cost per kg (HOG)	86
8.2	Implicit maximum total cost per kg (HOG) for changes in the real WACC	86
8.3	Implicit maximum total cost per kg (HOG)	87
8.4	Implicit maximum total cost per kg (HOG) for changes in the real WACC	88

8.5	Sensitivity for changes in unlevered β	89
8.6	Sensitivity in cost of feed as a result of changes in the BFCR (live weight)	90
8.7	Estimates of total production cost per kg in NOK (HOG) from previous studies	92

1 Introduction

Land-based farming of Atlantic salmon has gained significant attention over the last couple of years. This is demonstrated by 809,450 tonnes planned production capacity being publicly disclosed, equal to 32.3% of world production in 2018. Despite this, only limited amounts of academic information on the economics of land-based salmon farming exist.

Attractive fundamentals of conventional salmon farming may have formed the basis for the increased attention. The price of Atlantic Salmon is relatively high in a historical perspective and has strong future prospects. This is a result of increasing demand, while biological challenges for sea-based salmon limits production growth. In Norway, sea lice alone is estimated to have incurred direct costs for the industry in excess of NOK 15.0 bn over the last three years (DN, 2019b; Nodland, 2016).

Despite substantial costs related to biological challenges, the industry experience superprofits resulting in a strong desire for production growth (Ulltveit-Moe et al., 2019). In addition, the Norwegian government has large ambitions for the future of the salmon farming industry (Norwegian Ministry of Trade and Fisheries, 2015). Currently, potential growth options for Norwegian farmers are 1) higher utilization of existing licenses e.g. through post-smolt strategies, 2) increasing maximum allowable biomass (MAB) through acquisition of additional volumes in government auctions, and 3) new technology. New technology consist of a) modified net pens like snorkel net pens etc. which can be categorized as incremental technology changes addressing the current sea lice challenges (DN, 2019a), b) land-based farming, (c) offshore farming, and (d) floating, closed containment systems. Excluding a), all makes new areas available for industry growth.

In Norway, regulations are tied to biological conditions. This limits the volume available in MAB-auctions for conventional sea-based farmers. As a result, post-smolt strategies has become widespread, but may not offer the industry sufficient long-term growth potential. As a result, new technology has experienced increased attention and investments as a source of production growth. However, not all technology options presented are currently available, and some do not offer sustainable production growth. Modified net pens do not solve all challenges and externalities faced by conventional sea-based farming such, as

disease, emissions, escapes etc. Further, offshore farming and floating closed containment systems are currently held back by the absence of an established regulatory regime. Land-based farming has an established regulatory regime which makes it the only growth option available that can offer the industry sustainable long-term growth.

Land-based salmon farming may be profitable under the prevailing circumstances. Due to increasing operational expenses for sea-based farming, land-based farming has rapidly increased its competitiveness. In order to estimate its future development, we have to investigate under which circumstances land-based farming may be economically attractive.

1.1 Motivation and objective of the study

This thesis will focus on land-based salmon farming in Norway, as the competences and service clusters residing in Norway dominates the industry development. Our objective is to investigate whether or not land-based salmon farming is economically attractive and how this may change in the future. Further, our objective is to provide decision makers and stakeholders with comprehensive, reliable and up-to-date information on land-based salmon farming. This is highly relevant and valuable information which to date do not currently exist, and can have great impact on further development of this emerging industry, potentially revolutionising fish farming.

As a consequence of having limited robust information available, we apply two different approaches which aims to address this uncertainty. The first approach estimate the implicit maximum total cost per kg which yields a net present value of equity of zero. This method is considered robust as it does not include a view on each cost component associated with land-based salmon farming. The second approach use the latest cost estimates available and capture the uncertainty in these estimates using a Monte Carlo simulation. To the best of our knowledge, we are the first to apply these methods to a land-based farming facility. The results are compared to previous studies on the subject in order to provide a holistic picture of the industry.

Lastly, we draw the information presented and our findings to predict the potential future developments of land-based salmon farming and compare this with the outlooks for sea-based salmon farming.

The process of writing this thesis has been challenging, as a large amount of effort has gone into compiling information from an extensive amount of different sources to create a complete picture of this new industry. Furthermore, as the industry is only in its beginning stages it has required substantial effort to understand and predict the future of this industry. We hope our work contributes to increased insight to the land-based salmon farming industry.

1.2 Limitations

The lack of reliable information, the exclusion of other growth options and limiting the study to farming facilities in Norway are the three main limitations of this thesis.

The land-based salmon farming industry is entirely new and no companies have harvested significant volumes to date. Thus, verified estimates for land-based salmon farming do not exist. Although we address this by using robust methods, we have to base our assumptions on non-verified estimates.

Further, we have chosen to limit our study to Norway. This makes us exclude any potential benefits of locating a land-based facility closer to product markets. An example of which is the potential cost advantage from avoiding air freight. If a company is able to achieve such advantages, it may result in a larger margin and affect our results. However, by excluding such advantages we view our estimates to be more robust.

Lastly, we do not study the economic attractiveness of other growth options like offshore farming, post-smolt strategies and floating closed containment systems. As such, we can not compare the economic attractiveness of land-based salmon farming with these options, and some may be more economically attractive.

1.3 Outline

The thesis has the following structure. We start by providing information on the long-term drivers for seafood demand. This is followed by a review of the previous research on the economic aspects of land-based salmon farming. Next, we present the Norwegian regulatory regime for both sea-based and land-based salmon farming. Subsequently, we give an introduction to the salmon farming industry, provide information on the current

biological situation as well as a thorough presentation of land-based salmon farming. In the following section, we present a selection of theoretical concepts which forms the theoretical basis for the rest of the thesis. We then present two different methods for handling the lack of reliable information, as well as assumptions used when modelling a 10,000 tonnes land-based salmon farming facility. This is followed by a presentation of our results in addition to corresponding sensitivities. Consequently, we discuss our findings and the implications drawn from these. Finally, we present the conclusion and provide suggestions for further research on the topic.

2 Background

There are several trends suggesting that seafood production will increase in the future. The world's population is expected to grow from 7.7 billion in 2019 to 9.7 billion in 2050 according to the UN (2019). This suggests that more food must be produced, including seafood. Further, increased focus on health and climate change support a positive development for seafood.

Consumption of seafood are associated with health benefits which are increasingly being promoted by global health authorities. Further, healthy eating is expected to be one of the dominant trends within food consumption over the coming decades (Bjørndal et al., 2014). This trend is supported by the demographic development where staying healthy becomes increasingly important for ageing populations. In addition, a growing middle class will increase purchasing power which allows people to eat more nutritious.

Farmed Atlantic salmon is an efficient way to produce animal protein. In order to handle climate change and adapt to a more sustainable future, global CO₂ emissions must be reduced. Thus, animal protein must be produced more efficiently. The carbon footprint from different sources of animal protein varies considerably. Farmed Atlantic salmon has a carbon footprint of 2.9 kg CO₂ equivalents per kg edible product compared to 2.7 for chicken, 5.9 for pork and 30 for cattle (Mowi ASA, 2019). Based on this increased consumption of Atlantic salmon seems to be desirable.

Global seafood production consist of capture fishery and aquaculture. Atlantic salmon made up 4.0% of total aquaculture supply in 2016 (FAO, 2018a). Global growth in seafood production must in principle come from aquaculture. This is suggested as the global capture fishery supply is to a large extent fully exploited (Mowi ASA, 2019). Supply from aquaculture overtook capture fisheries in terms of volume available for human consumption for the first time in 2013 (FAO, 2018a). FAO (2018b) estimate that aquaculture production will grow 37.0% within 2030, compared to the 2016 level.

Norway is the world's largest producer of Atlantic salmon with production of approximately 1.3 million tonnes in 2018 (Statistics Norway, 2019). This corresponds to 52.0% of the global market (FAO, 2019). Norwegian production has grown significantly from the 1980s when salmon farming was considered a subsidiary income industry. The large market share

and high growth can, to a large extent, be attributed to optimal production conditions such as many fjords, inlets and suitable water temperature (Bjørndal and Asche, 2011). In addition, several liberalizing changes to the regulatory regime during the 1990s and 2000s facilitated increased growth. The development in produced volume and price per kg head on gutted (HOG) are shown in figure 2.1.

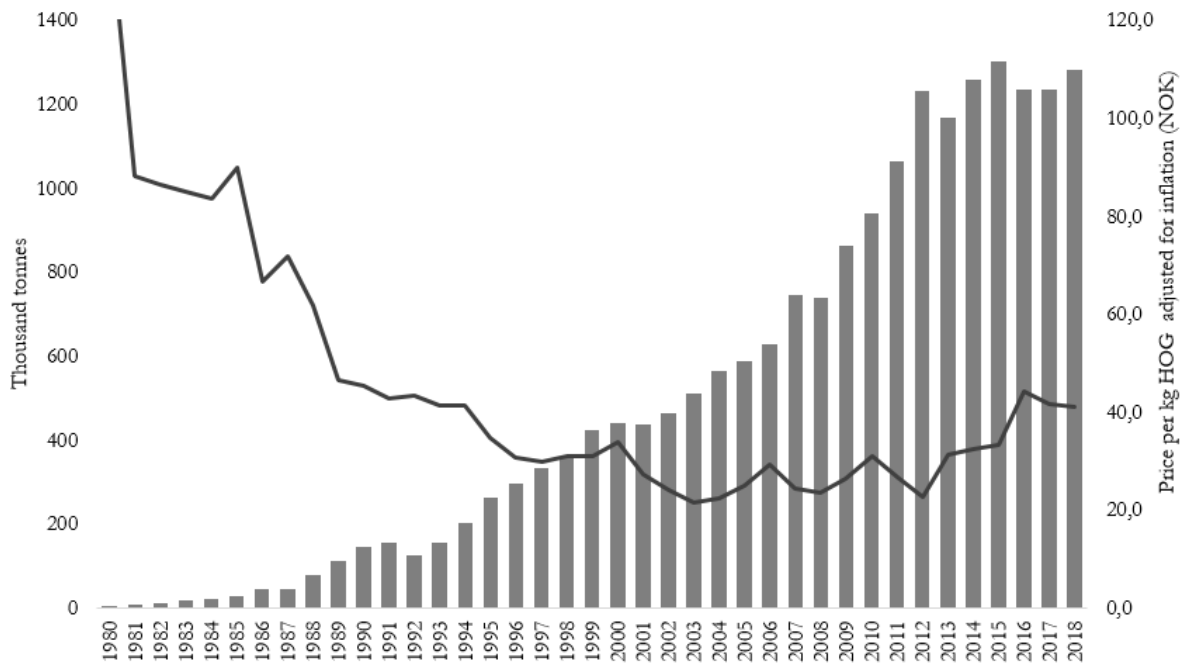


Figure 2.1: Volume in tonnes live weight (left axis) and price/kg NOK (HOG) (right axis) for Atlantic salmon adjusted for inflation, base year 1998, Source: Statistics Norway (2019)

Since 2012, the growth in production has stagnated due to a more challenging biological situation. As a consequence, a more conservative regulatory regime, nicknamed the "traffic light system", was implemented in 2017 (Norwegian Ministry of Trade, Industry and Fisheries, 2015). In this system the biological situation dictates production growth. Considering that Norway is the leading salmon producer, the stagnated production has contributed to reduced global growth. Further, prices has increased during the same period indicating that demand growth is outpacing supply growth.

Figure 2.2 illustrates the relationship between price per kg and total production cost, showing an increasing operating margin since 2013. The increase in total production cost is to a large extent due to a worsened biological situation (Iversen et al., 2015; Hjeltnes et al., 2017; Abolofia et al., 2017). Prices have also increased substantially and have since

2012 more than doubled in nominal terms, resulting in record high operating margins across the industry.

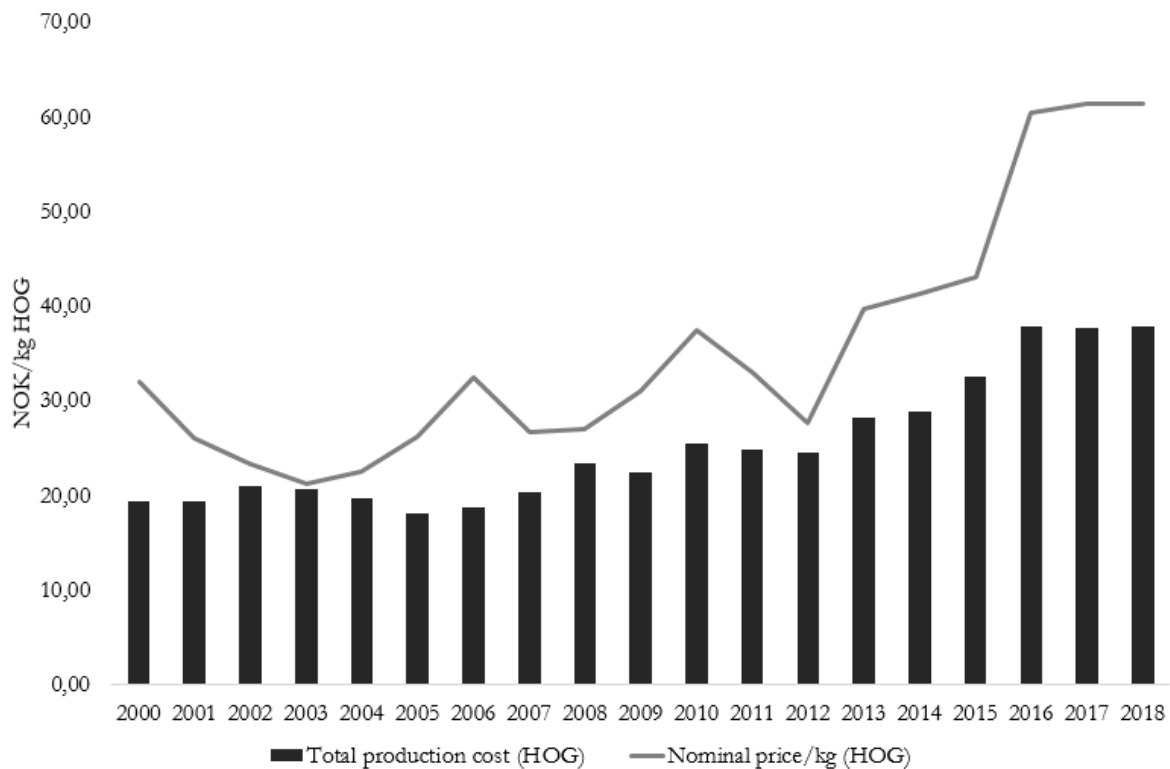


Figure 2.2: Total production cost/kg and nominal price/kg, Source: Fiskeridirektoratet (2019)

In sum, the trends outlined may contribute to increased demand for seafood in the future where growth must come from aquaculture production. This, together with the current high profitability within the salmon farming industry, makes it attractive to increase production. As sea-based farming currently has few options to grow production by significant volumes, the option to grow production on land has started to look increasingly attractive. This is demonstrated by a total planned global production capacity of 809,450 tonnes being publicly disclosed, corresponding to 32.3% of global production in 2018. Despite large production plans and considerable investments, the information available is limited and previous studies are conducted under varying assumptions. Thus, *robust* information about the industry and its economic attractiveness is of high value and importance for decision makers and stakeholders. This thesis aim to provide such information.

3 Literature Review

The pioneering work on economic analysis of salmon aquaculture was done by Bjørndal (1990) and was later updated by Bjørndal and Asche (2011) to reflect the significant transformation experienced by the industry. They systematically analysed the industry from a production and market perspective, on both the firm and industry level (Bjørndal and Asche, 2011). Of particular interest to this thesis is the research presented on how to analyse and model a prospective investment in a sea-based fish farm. Bjørndal was the first to derive the optimal harvesting models for aquaculture, applying mathematical models previously developed in the forestry industry (Bjørndal and Asche, 2011). The key was to optimize production when faced by a biologic growth function, limited production space and the rotation problem. The rotation problem arises from the opportunity cost of letting grown-out fish grow bigger compared to harvesting and releasing a new generation.

Henriksen and Gjendemsjø (2015) were the first, to our knowledge, to point out that there were only minor differences in required capital expenditures when comparing the establishment of a sea-based and a land-based salmon farming facility. This was mainly due to the inclusion of farming licences which constituted 68.0% of total investments. The cost per license had appreciated significantly compared to previous years and were estimated to NOK 80.0 million each. On the other hand, land-based farming facilities would receive licenses free of charge, levelling the total capital expenditures between the two production models.

When analysing a facility in Norway with an annual production of 5,000 tonnes, they estimated that there was a relatively small difference in operating expenses less interest and depreciation, between the two farming models. However, estimates provided had large uncertainty and did not include detailed information on assumptions, making the validity and robustness of their calculations questionable. Nevertheless, their estimates illustrated the economic competitiveness of land-based salmon farming under the proposed legal regime for farming licenses.

Liu et al. (2016) was the first to compare the economic performance of two farming models producing Atlantic salmon, modelling a US land-based recirculating aquaculture system (RAS) using freshwater and a conventional Norwegian open net pen facility in

sea. This analysis was a result of technological improvements which had demonstrated the full life-cycle production of Atlantic salmon in land-based RAS as a viable production technology (Liu et al., 2016).

The analysis assumed the same annual production capacity of 3,300 tonnes (HOG), equivalent to 4,000 tonnes live weight, for both farming models. It is noted that the yearly production used in the analysis imply a smaller scale of operation for the open net pen system compared to the average in Norway. By scaling up both systems, cost reductions due to scale economy can be obtained (Liu et al., 2016). In contrast, our model assumes that the facility is capable of producing 10,000 live weight annually as it is more representative of current industry plans.

The analysis estimated investments, production costs and profitability in the two farming models using a nominal cost of capital of 7.0% and a modelling period of 15 years. The investment for the land-based RAS facility was estimated to be approximately USD 54.0 million compared to approximately USD 30.0 million for the corresponding open net pen facility. For the latter, this includes three farming licenses of NOK 55.0 million each, approximately equal to the market price at the time. There are however no comparable license costs associated with a land-based RAS facility in the US (Liu et al., 2016).

Operating expenses was estimated to NOK 39.3 per kg (HOG) in the RAS facility. The operating expenses were modelled with an annual increase of 2.0% for the first five years and 3.0% for the remaining years. This accounts for estimate uncertainties and a general trend of increasing operating expenses over the last several years (Liu et al., 2016). In contrast, we estimate production cost to NOK 50.1 and a flat path.

In terms of economic attractiveness, the open net pen system is estimated to be financially superior compared to RAS facility. The former had an estimated net present value (NPV) of USD 3.5 million and an internal rate of return (IRR) of 7.9%, while the latter had an estimated NPV of USD -120.2 million and a negative IRR. The calculations used a salmon price of NOK 41.8 per kg (HOG), increasing 2.0% annually for the first five years and 3.0% thereafter. This implies expanding operating margins over the modelling period. Further, when incorporating a price premium of 30.0% for Atlantic salmon farmed in land-based RAS facilities, NPV are estimated to USD -20.4 million and IRR to 2.7% (Liu et al., 2016).

Bjørndal and Tusvik (2017) analysed the economic competitiveness of a RAS facility from a Norwegian perspective. Using the methodology laid out by Bjørndal (1990), they calculated the NPV and IRR of a facility with total annual production of 5,000 tonnes live weight. Bjørndal and Tusvik (2017) estimated operating expenses to NOK 38.7 per kg whole fish equivalents (WFE). In the calculations of IRR and NPV they assumed a price of NOK 49.2 per kg live weight, equal to NOK 59.0 per kg (HOG), for the entire modelling period. The analysis applied two alternative time horizons, the first used 20 years while the other infinity. We apply the same time horizons in this thesis. The 20 year scenario used a real cost of capital of 4.0%, while the infinite scenario used a real cost of capital of 4.0% in year 0 to 40, 3.0% in year 41 to 75 and 2.0% from year 75 to infinity. This thesis use a real WACC of 5.0%. The 20 year project scenario estimated an initial investment of NOK 429.6 million and a maintenance reinvestment of NOK 6.0 million in year nine. The infinite scenario used the same initial investment, but included continuous re-investments until year 60 (Bjørndal and Tusvik, 2017).

The results of the 20 year scenario was a NPV of NOK 745.4 million and IRR of 17.0%. Corresponding estimates for the infinite scenario was a NPV of NOK 1580.8 million and IRR of 19.0%. Bjørndal and Tusvik highlighted that the outlook for increased sea-based production is constrained by biological challenges and regulations, suggesting that the expected NPV in a land-based project may look attractive enough for many to take the risk, even when including some biological challenges (Bjørndal and Tusvik, 2017).

In 2018, Bjørndal, Tusvik, Holte and Hilmarson published a research report from the project; *Analyse av lukka oppdrett av laks – landbasert og i sjø: Produksjon, økonomi og risiko*. The first part of the research paper contains an extensive analysis of risks associated with land-based salmon farming, as well as suggested measures to avoid and mitigate operational incidents. Further, a compilation of current industry experiences, primarily from RAS smolt facilities, are presented together with suggested knowledge-enhancing measures. This was done in order to accelerate the development of the land-based salmon farming industry in Norway. The second part of the research paper contained an analysis comparing the economic competitiveness between different farming models, including both RAS and sea-based farming. This part of the research paper was conducted by Bjørndal and Tusvik and have many similarities with their report from 2017. However,

they provided more details and in-depth information on estimates, in addition to more extensive calculations.

The report estimated total investments of NOK 580.4 million and operating expenses of NOK 43.6 per/kg (WFE) associated with the establishment and operation of a RAS facility with an annual production capacity of 6,000 tonnes live weight. In contrast to their report from 2017, it did not include estimates of NPV or IRR (Bjørndal et al., 2018).

Further, the report included an estimate of the investments and operating expenses associated with a conventional facility operating nine licences of 780 tonnes, equal to an annual production of 14,000-15,000 tonnes live weight. The total investments were estimated to NOK 1.1 billion, where the price per license was NOK 93.6 million. This was based on the price offered by the Norwegian government to acquire MAB within the traffic light system in 2018. When using smolt of 100.0 grams and excluding any treatment related to sea lice, the estimated production cost was NOK 28.0 per kg (WFE), corresponding to 26.3 NOK per kg live weight. The report estimates that the production cost in sea increased to NOK 31.3 per kg (WFE) and NOK 33.8 per kg (WFE) under scenarios where five and 10 treatments for sea lice are conducted. The cost increase arises from direct costs incurred, mortality, adverse impact on fish growth and lower harvest weight. In addition, a potential loss of revenue due to quality downgrading can occur, however this is not included in the calculations (Bjørndal et al., 2018).

4 The Norwegian salmon farming regulatory regime

This section will 1) briefly explain the trend in the regulatory regime in Norway since 1980, 2) explain the newly adopted regulatory regime for conventional sea-based farming and 3) explain the regulatory regime in land-based salmon farming.

4.1 Historical developments

The first permanent bill to regulate the aquaculture industry was passed in 1981, although a temporary initiative was appointed in 1973 (Bjørnar Michaelsen-Svendsen, 2019). The bill from 1981 differed from the earlier regime as it stated that fish farming was an independent industry and not a subsidiary income for other industries (Bjørnar Michaelsen-Svendsen, 2019). In addition, the law opened for regulation of growth through licensing rounds (Bjørnar Michaelsen-Svendsen, 2019). In 1985, a more liberal regulation enabling farmers to hold several licences at several locations was passed (Bjørnar Michaelsen-Svendsen, 2019). However, they could only hold majority interest in one licence (Bjørnar Michaelsen-Svendsen, 2019).

This regulation change was one of the main factors leading to high production growth into the 1990s along with expansion in production capacity and improvements in production efficiency (Hovland et al., 2014). The industry consolidated from single-person operations into several large industrialized corporations. This was facilitated by two factors. Firstly, a regulatory change removed the law regarding local ownership (Bjørnar Michaelsen-Svendsen, 2019). Secondly, widespread bankruptcies led major consolidation through acquisitions.

During the 2000s, there was another major shift in the regulatory environment. Detailed technical management based on scientific knowledge, equitability, predictability and sustainability became areas of focus. In 2005, the MAB term was introduced. It is defined as the maximum amount (tonnes) of fish a company or location can hold in the sea at all times (Mowi ASA, 2019). Further, a bill adopted in 2006, shed more light on fish health and disease prevention (Bjørnar Michaelsen-Svendsen, 2019).

In 2010, the Gullestad committee was appointed by the Norwegian Ministry of Trade, Industry and Fisheries with a mandate to come up with solutions to the main problems faced by the industry. Firstly, the committee were to suggest how the government could secure enough space for the aquaculture industry within the coastal zone, as lack of space was becoming an increasing problem. Secondly, they reviewed a new management system with the aim to create a more sustainable industry. The final report in 2011 had three suggestions. Firstly, the committee suggested to divide the Norwegian coast into 13 different geographical zones. Secondly, they recommended the use of indicators and rules based on the most important challenges faced by the industry, to determine production growth. Lastly, they recommended that there should not be allocated new licences until the new system was adopted (Fiskeri- og kystdepartementet, 2011).

Biological sustainability has become an increasingly important factor for managing the industry. The Gullestad committee highlighted an average production loss of 25.2% on average between 1987 and 2007 (Fiskeri- og kystdepartementet, 2011). The main reasons being problems related to escape, disease and sea lice. The maximum amount of sea lice allowed is regulated to an average of 0,5 female lice per salmon (Mattilsynet, 2019). This results in continuous counting of lice to ensure compliance with these regulations. In 2013 and 2015, measures towards a more sustainable industry in the form of “special” licensing rounds was introduced. The first was a “green” licence round in 2013, targeting the sea lice issue by incorporating stricter allowable levels for female lice per salmon and reducing the use of medical treatments (Bjørnar Michaelsen-Svendsen, 2019). The companies that fulfilled these requirements were granted licenses at a price of NOK 10.0 million per licence, substantially less than the price of ordinary licenses, which ranged from NOK 55.0-66.0 million (Bjørndal and Tusvik, 2017). The second round, in 2015, focused on innovative projects with substantial investments to solve industry problems (Norwegian Ministry of Trade, Industry and Fisheries, 2018a). The development licences could later be converted into ordinary licences for NOK 10.0 million (Norwegian Directorate of Fisheries, 2018d).

There has been four ordinary licensing rounds for production of Atlantic salmon since 2000 (Norwegian Ministry of Trade, Industry and Fisheries, 2018a). The rounds were held in 2002/2003, 2009, 2013 and 2018. In addition, 10 licences were awarded in 2006, to locations in Finnmark. Lastly, a regulatory change opened for increasing capacity for

existing licenses in 2011 and 2015.

In 2017 a new management system based on suggestions from the Gullestad Committee was approved and implemented (Norwegian Ministry of Trade, Industry and Fisheries, 2015). This management system has been nicknamed the “traffic light system”.

4.2 The traffic light system

The traffic light system, implemented in 2017, is the management system that currently regulates the aquaculture industry. The system intends to provide sustainable growth, based on a set of biological and environmental indicators as constraint. However, as of now the only environmental indicator regulated is the sea lice impact on the mortality of the wild salmon stock. Further, the system aims to increase predictability for the industry (Norwegian Ministry of Trade, Industry and Fisheries, 2018a).

The system has adopted the division of the Norwegian coastline into 13 different production zones, as proposed by the Gullestad committee. The division is based on scientific research analyzing the ocean currents and the spread of sea lice along the coast line (Norwegian Ministry of Trade, Industry and Fisheries, 2018a). Each zone is assigned either the code *green*, *yellow* or *red*. Based on the assigned code, the production zone may be allowed to increase by 6.0%, maintain current production or reduce production by 6.0%, respectively. The growth is offered through a combination of fixed price and auctions, where the split between these are determined semiannually (Norwegian Ministry of Trade, Industry and Fisheries, 2018b).

In addition, companies with existing operations, regardless of zone code, can apply for up to 6.0% growth every other year (Norwegian Directorate of Fisheries, 2018b). This regulatory exception is based on fulfilling specific criteria regarding sea lice (Norwegian Ministry of Trade, Industry and Fisheries, 2017).

The outcome from the 2017 classification of production zones is shown in figure 4.1. The environmental and biological conditions for each production zone is evaluated semiannually (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

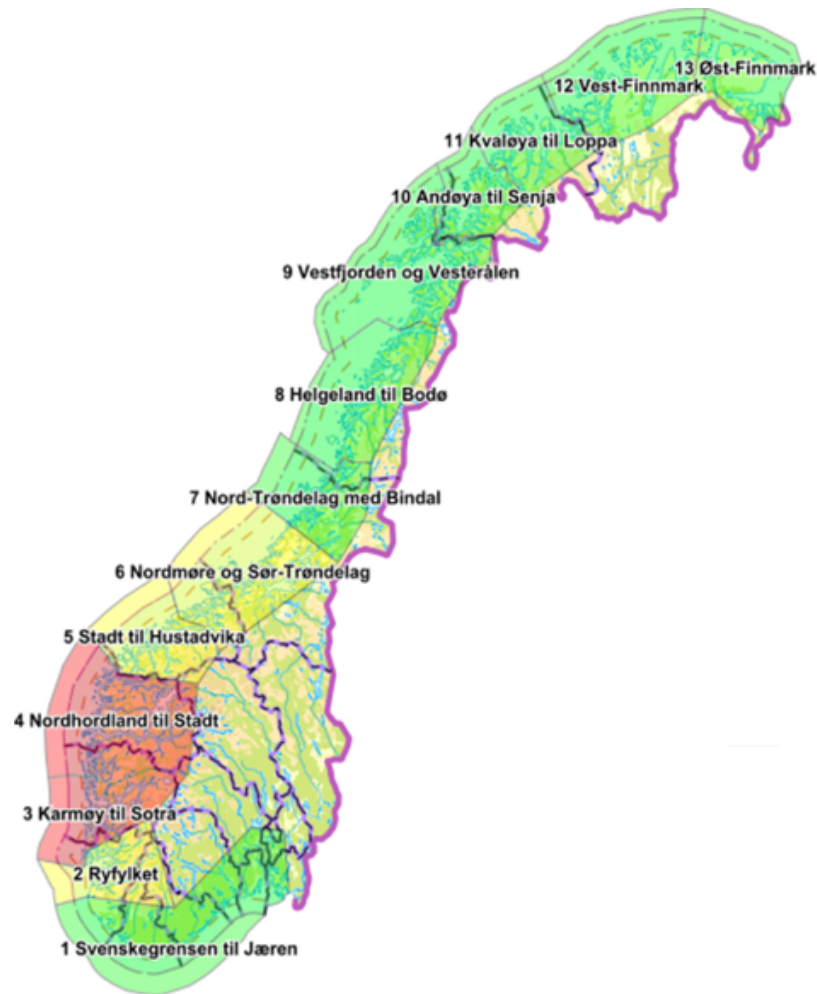


Figure 4.1: Production zones in the traffic light system as clasefied in 2017, Source: Norwegian Directorate of Fisheries (2018c)

In 2018, 2.0% growth was offered through a fixed price of NOK 120.000 per tonne. This implies a cost of NOK 93.6 million for a standard licence of 780 tonnes (Norwegian Ministry of Trade, Industry and Fisheries, 2017).

In June 2018, new licences were awarded through an ordinary auction round. The prices varied in the range of NOK 132,000-252,000 per tonne, equal to NOK 103.0-196.6 million per standard licence of 780.0 tonnes (Norwegian Directorate of Fisheries, 2019a).

4.3 Land based salmon farming

Prior to 2016, the regulatory regime for land-based salmon farming was covered by the same requirements associated with acquiring licenses as sea-based farming. This included a limited number of licences available through auction. The old regime favored sea-based

farming over land-based farming, as total investments for land-based farming significantly exceeded those of sea-based farming (Holm et al., 2015).

As the terms for land-based farming seemed unfavorable and noncompetitive compared to sea-based farming, a committee was appointed to look at the implications of land-based farming with the use of sea water (Holm et al., 2015; Norwegian Ministry of Trade, Industry and Fisheries, 2016). As of June 2016, the barriers to entry for land-based farming was reduced, opening for operating licenses to be issued on a continuous basis. This led to the elimination of both restrictions on number of licences available and the cost associated with buying licenses (Norwegian Ministry of Trade, Industry and Fisheries, 2016). The committee found that land-based farming should be exempted from the license fee as the cost would dampen the profitability and therefore also the competitiveness of the industry (Holm et al., 2015). The Norwegian regulatory regime for land-based salmon farming is therefore currently more liberal compared to the sea-based system.

The change in regulation is mainly caused by the notion that land-based farming can solve or reduce several of the challenges associated with sea-based farming. Production on land would eliminate the use of common coastal resources, and no longer interfere with fishing and emigration routes for wild salmon. It will also reduce the sea lice infection on wild salmon, thus increasing welfare for the fish. However, this would not apply if land-based farming came on top of the production in sea. In contrast, land-based farming might reduce fish welfare because fish in land-based tanks is held more dense compared to the 25.0 kg/m³ rule that applies for sea-based farming (Holm et al., 2015). This is allowed through an exception rule for land-based farming (Holm et al., 2015).

5 Salmon farming dynamics

5.1 The value chain of salmon farming

The value chain of both sea-based and land-based salmon farming are presented in 5.1. Although the value chain necessarily must cover the same phases of the salmon life cycle, the two salmon farming techniques differs as land-based salmon farming has a more compact value chain.

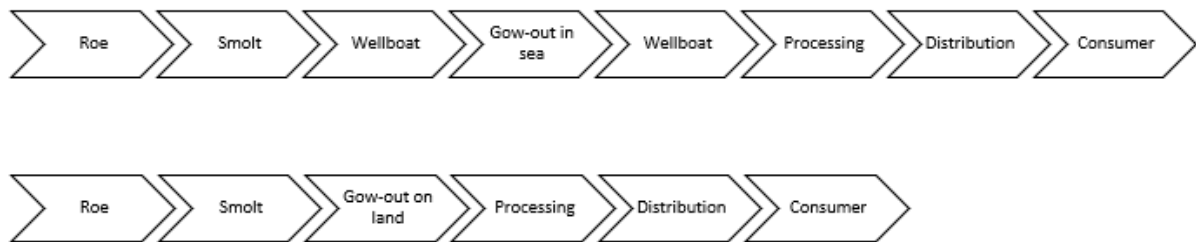


Figure 5.1: Comparison of land-based and sea-based salmon farming value chains, Source: compiled by the authors

Both sea-based and land-based salmon farming start by producing smolt. Salmon roe is stripped from broodstock, which is the best performing fish from a selection of parameters from previous generations that has been kept for breeding (Trodal and Risnes, 2017). The roe is fertilized and placed inside an incubator for six to eight weeks (The Conservation Fund, 2019). During the stay in the incubator, eggs become alevin and alevin then becomes fry. When the eggs hatch, the alevin has a yolk sac attached on its stomach which provides nourishment for the first 40 days of its life. From this point the growth and development of the fish will depend on temperature (SalMar ASA, 2018).

When most of the yolk sac is consumed, the fry is moved from the incubator to freshwater fry tanks. Here the initial feeding with pellets takes place. As the fry grows, they are sorted and transferred to larger tanks, as well as being vaccinated (SalMar ASA, 2018). The fry is kept in the fry tanks for seven months, and it typically weighs 80-120 grams the smoltification process takes place (The Norwegian Seafood Council, 2019). This process results in physiological, biochemical and morphological changes to the fish, preparing it for a life in sea (The Conservation Fund, 2019). Once this process is completed the fish is referred to as smolt.

For sea-based farming a wellboat is used for transportation of smolt. Smolt is transported from the smolt facility to the sea farm for its grow-out phase. In contrast, land-based farming use a transfer system at the facility to transfer the smolt from fry fish tanks to post-smolt fish tanks.

After being transported by wellboat, the smolt is released into open net pens in sea. Here, they are farmed in 12-18 months until they reach the desired harvest size of 4-8 kg. The duration of the grow-out phase in sea is affected by parameters such as sea temperature, feeding, light conditions, water quality and sea lice as well as the size of the released smolt. During the grow-out phase the salmons are sorted as they grow and develop (SalMar ASA, 2018).

After 12 months of growth, the first salmons are ready for harvesting. A wellboat transports the salmon from the sea farm to the processing plant where they are placed in holding pens. From the holding pens the salmons are transported into the processing plant where they are gutted, packed and distributed fresh or frozen. After a site is fully harvested it will be fallowed for 2-6 months before a new generation of smolt is released (Mowi ASA, 2019). In total, the sea-based farming cycle is approximately 24 months.

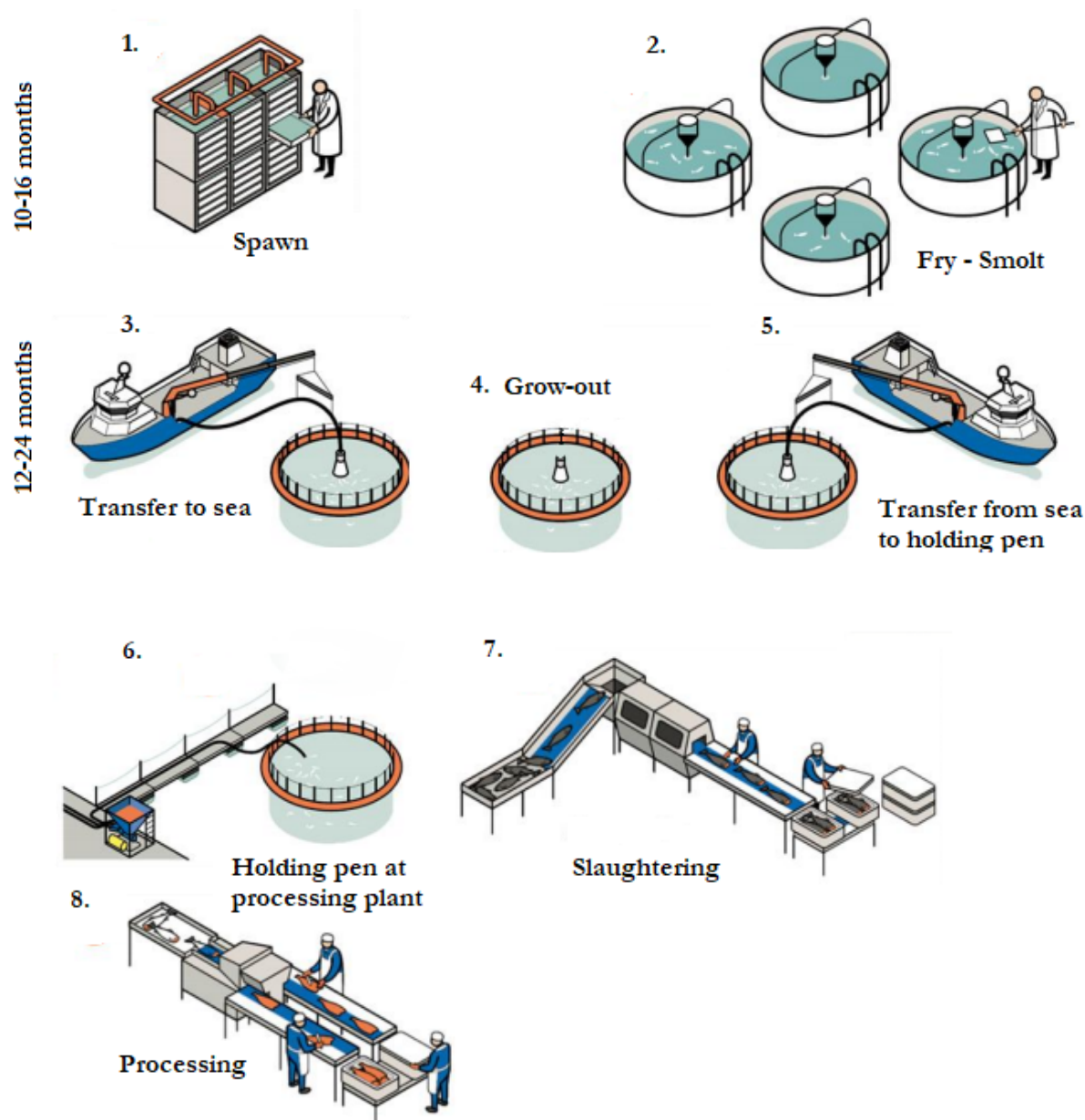


Figure 5.2: Graphical representation of the value chain in sea-based salmon farming, Source: Mowi ASA (2019)

In land-based farming, the fish stays in the post-smolt system for five months. At one year and approximately 700 grams, the fish is transferred to the grow-out tank where it stay for 12 months or more, depending on desired harvest size. When reaching desired harvest size of typically 4.5-5.5 kg, harvesting begins. The fish are sorted in order to separate the larger and smaller fish, and the larger fish is sent to the finishing tank where it goes through a six-day purge. On the sixth day the fish is gutted, packed and distributed. After a generation is harvested, the fish tanks will be thoroughly cleaned before the release of next generation post-smolt. In total, the land-based farming cycle is approximately 20

months (The Conservation Fund, 2019).

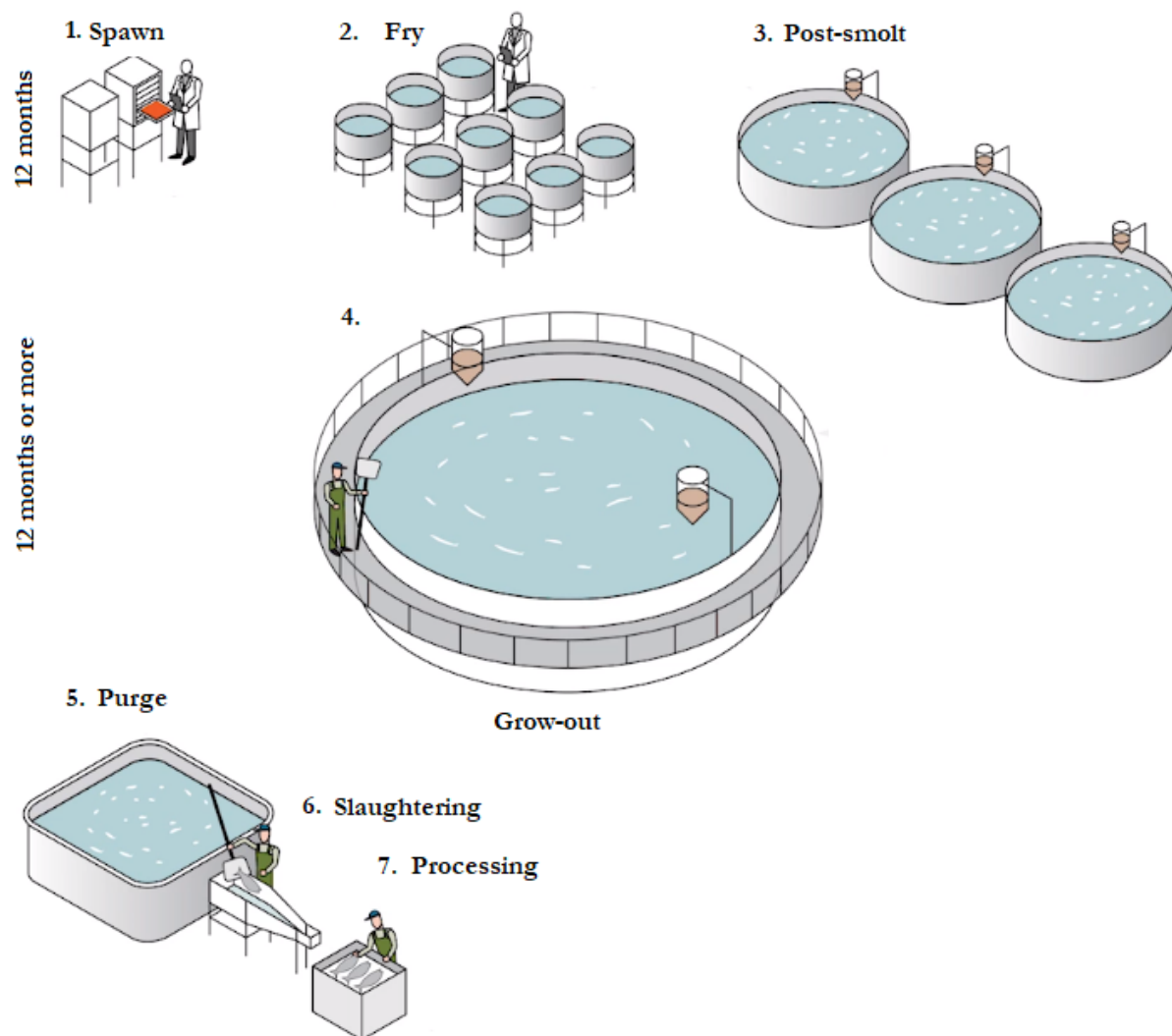


Figure 5.3: Graphical representation of the value chain in land-based salmon farming, Source: The Conservation Fund (2019)

Land-based salmon farming facilities can choose the degree of vertical integration. Based on available information, it seems like the majority of planned facilities aim to buy roe externally, while focusing on the smolt and grow-out phase. However, some facilities plan to buy smolt externally, which requires the facility to be located within reach of wellboats. This may transfer some of the disadvantages of sea-based farming like increased mortality, stress and risk of infection, to land-based farming. Thus, it may reduce some of the benefits of land-based farming, even though it will reduce the total capital expenditure required. Further, some facilities plan to include a processing plant. This may offer improved logistics, avoid mortality from wellboat handling as well as improved animal

welfare. As such, it may result in better economic performance. On the other hand it requires increased capital expenditures. In the following we will assume that land-based farming facilities includes both a smolt facility and a processing plant, while buying roe externally. This will highlight the differences between the two farming methods.

5.1.1 Terminology and ratios for Atlantic salmon

Table 5.1 provides an overview of terminology and conversion ratios used for Atlantic salmon at different stages of production. These ratios will be referred to in the subsequent parts of this thesis.

Table 5.1: Terminology and conversion ratios of Atlantic salmon, Source: Mowi ASA (2019)

Terminology	Conversion ratio
Live fish	100%
Loss of blood/starving	7.0%
Harvest weight (wfe)	93.0%
Offal	9%
Gutted fish (HOG)	84.0%

5.2 The biological situation in sea-based farming

In this section we give a comprehensive presentation of the current biological situation faced by the sea-based salmon farming industry in Norway. This will serve as a reference point throughout the rest of this thesis.

5.2.1 Sea lice

Sea lice has been a problem for sea-based farming since industry's inception. According to Norwegian regulations, the maximal allowed limit of sea lice is less than 0.5 female per fish for the majority of the year (Norwegian Ministry of Trade and Fisheries, 2012). During five weeks a year, this limit is lowered to 0.2 female sea lice per fish. In order to comply with these regulations, salmon farmers use several treatment methods.

From the late 1970s, medical treatments were used in order to control the parasite. Frequent medical treatments has however made the sea lice resistant, which has made

the industry adapt mainly non-medical treatments and the use of cleaning fish. The non-medical treatments typically either consist of thermal or mechanical treatments. Despite these methods being non-medical, they are associated with significant negative fish health consequences such as increased stress levels, injuries and mortality (Norwegian Veterinary Institute, 2019). Treatments also affect growth negatively through lost feeding days, which is due to starving prior to the treatment as well as subsequent restitution.

Recent research has found that the temperature used in thermal treatments is painful for fish (Norwegian Veterinary Institute, 2019). Further, mechanical treatments, which use water in order to remove sea lice from the fish, are associated with damages to fish skin and bleeding (Norwegian Veterinary Institute, 2019). Another aspect is the congestion that arises from getting the fish inside the de-licing systems. The congestion has proved to be great source of risk for fish welfare which comes in addition to the treatment itself. More research are expected on non-medical treatment methods in the coming years. We do not rule out tighter regulation on the use of these methods in the future.

Norwegian Veterinary Institute (2019) denotes *treatment* of sea lice as the greatest challenge for the health of Atlantic salmon in Norway. Over the last couple of years there has been extensive challenges related to treatment and prevention of sea lice. Paradoxically, despite the high direct and indirect mortality associated with treatment of sea lice, very few fish die as a direct consequence of sea-lice itself (Norwegian Veterinary Institute, 2019; Iversen et al., 2015). Iversen et al. (2015) states that the consideration of external effects on wild salmon, seems to outweigh fish welfare concerns for the farmed salmon.

The implementation of the traffic light system demonstrates the importance of sea lice as a determinant for future growth in conventional sea-based farming (Norwegian Veterinary Institute, 2019).

5.2.2 Disease

In addition to sea lice, viral diseases is a major concern for farmed salmon (Norwegian Veterinary Institute, 2019). Diseases like cardio myopathy syndrome (CMS), pancreas disease (PD) and infectious salmon anemia (ISA) are the most challenging. CMS was considered to be the most concerning viral disease in 2018 due to high growth (Norwegian Veterinary Institute, 2019). For both PD and ISA the number of infected localities in

2018 are on comparable levels to 2017 (Norwegian Veterinary Institute, 2019).

The current disease status in Norway affects sea-based production for farmed salmon negatively. CMS is a serious and contagious heart disease which causes changes to the heart of the farmed salmon (Norwegian Veterinary Institute, 2019). Under stressful situations like treatment for sea-lice, sorting, transportation and other handling of the fish, the level of stress can be so high that the heart breaks (Norwegian Veterinary Institute, 2019). Thus, infected fish may be particular vulnerable and cause increased mortality.

Consequences of PD infection may be increased production time caused by reduced appetite, as well as loss of fish due to inferior quality at harvesting. ILA may cause damages to the internal organs of the fish due to circulation problems. Mortality typically increase among infected fish, but are relatively modest at 0.5‰ to 1‰ per day (Norwegian Veterinary Institute, 2019). Outbreaks of ILA are regulated by strict measures like formation of combat zones and observation zones around the infected locations, which affect production negatively (Norwegian Veterinary Institute, 2019).

5.2.3 Escape

Escape of salmon from sea-based farming facilities impacts wild salmon negatively. Sexually mature salmon find its way up the salmon rivers to spawn. If successful, it may cause genetically intervention between farmed and wild salmon. Genetic intervention is harmful because it affects the wild salmon's ability to further reproduce. This constitutes an externality for the Norwegian society and is in general strongly undesirable. The scope of escapes is outlined in table 5.2. However, its relative proportion of production is hard to estimate due to the lack of reliable weight estimates of the escaped fish. For 2018, Norwegian Veterinary Institute (2019) estimated it to be 0.02%.

Table 5.2: Number of escaped farmed salmon in Norway, Source: Norwegian Directorate of Fisheries (2019d)

	2014	2015	2016	2017	2018	2019
Escaped fish	286,920	156,993	127,815	17,187	159,105	286,911

5.2.4 Toxic algae

During the spring and summer of 2019, several sea-based salmon farmers in northern parts of Norway were affected by an outbreak of the toxic algae *Chrysochromulina leadbeateri*. This caused widespread mortality over a limited period of time. Production of 13,400 tonnes live weight salmon were lost due to the algae (Norwegian Directorate of Fisheries, 2019e). This highlights the risk of operating in sea, although toxic algae outbreaks are considered to be a relatively rare event. For a land-based facility, the algae may be neutralized in the intake water treatment system which would reduce the risk of this kind of mortality considerably.

5.2.5 Mortality

The biological challenges in sea-based farming result in increased mortality and reduced fish welfare. Table 5.3 outlines median mortality as well as mortality in the 1st to 3rd quartile in Norway since 2015. The latter captures 50% of the observations for these years. The median and the 1st to 3rd quartile mortality increased from 2015 to 2016 and seem to have stabilised around 15-16%. However, according to Iversen et al. (2017) an increasing proportion of mortality is caused by sea lice treatment of larger fish. Thus, the biomass of dead fish has increased despite the mortality in percent being stable. The increased mortality among large fish have a particularly negative cost effect for farmers, as large fish has incurred a larger proportion of costs.

Table 5.3: Mortality for completed production cycles in Norway, Source: Norwegian Veterinary Institute (2019)

In percent	2015	2016	2017	2018
Mortality, median	12.3	15.7	16.1	15.0
Mortality, 1 st -3 rd quartile	7.1-22.5	9.4-26.2	8.3-25.0	9.0-23.1

5.2.6 Emissions

Sea-based salmon farming leads to considerable emissions of organic material and nutrients. These emissions affects the locations and surrounding waters to a varying degree, depending on conditions like water flow, topography and biology. The emissions of nutrients from

salmon farming in Norway are considerable, however the risk of eutrophication is considered to be low at the current production level. The majority of emissions of biological material will gather on the seabed close to the location, and primarily affect the seabed ecosystem negatively. Further, as bacteria process the organic material, there may be a risk of H₂S and methane gas occurring as well as oxygen deficiency in the surrounding water. The risk of the negative consequences may be highest at locations with limited water exchange. In a land-based facility, there will be limited negative consequences from emissions as it is collected and processed responsibly. Thus, the impact on the local ecosystem is significantly reduced (Hansen et al., 2017).

5.3 Political environment surrounding salmon farming

The Norwegian government has ambitions to increase value creation from aquaculture production considerably over the coming decades. In order to realize these ambitions, growth has to be predictable, sustainable and with reduced environmental impact. With the current production technology, nature sets the premises for the form and scope of aquaculture production. Research and development in addition to technological improvements, are crucial to unleash the full growth potential of the Norwegian aquaculture industry. The industry administration will protect the environment so that it enables the industry to develop long-term. Should the industry be offered a predictable growth regime, society has to decide on the acceptable level of environmental impact (Norwegian Ministry of Trade and Fisheries, 2015).

Civil organizations, media and social media may increase the political pressure to lower the acceptable level of environmental impact from sea-based salmon farming. In addition, increased focus on fish welfare and thereby reduced acceptance for the current operational practices in sea-based farming may be expected. This may increase additionally if land-based salmon farming becomes a real alternative to sea-based farming. This may influence the political opposition and government, and may lead to increased regulation of the sea-based industry.

Increased focus on fish health and welfare may lead to increased regulation for sea-based farmers and reduce the use of the current non-medical treatments for sea lice. Further, reduced acceptance for escape may lead to increased requirements for equipment used

in farming operations. This may lead to increased cost of compliance both in terms of operational and capital expenditures for conventional farmers.

In November 2019, a government appointed committee presented an Official Norwegian Report on taxation of the aquaculture industry. The committee recommend implementation of a profit based, accrued resource tax on 40.0% which comes in addition to the ordinary Norwegian tax rate of 22.0% (Ulltveit-Moe et al., 2019). Thus, if implemented, this gives total tax rate of 62% for the Norwegian sea-based aquaculture industry. The proposed resource tax do not apply to land-based salmon farming.

5.4 Land-based salmon farming technology

There are two main production technologies available for land-based production. These are flow-through systems (FTS) and recirculating aquaculture systems (RAS), and differ with respect to degree of water recycling.

5.4.1 Flow through systems

FTS is based on pumping water from a water intake to the fish tanks where it is used only once before being disposed (Holm et al., 2015). Therefore, conventional FTS has 0% water recycling. Conventional FTS do not have any treatment of the intake water or wastewater. Based on this, such systems are viewed to involve a low degree of complexity (Bjørndal et al., 2018).

The technological development over the last decades has resulted in modern facilities with both water reuse technology as well as treatment systems for the intake and wastewater (Bjørndal et al., 2018). In addition, FTS can include water temperature regulating systems to continuously secure optimal water temperatures for fish growth (Salmon Evolution, 2019). As such, the technological development has increased the degree of complexity involved in a modern FTS and making it a hybrid between RAS and conventional FTS.

However, by using proven technology with high reliability FTS are perceived to involve considerably less risk than RAS. This is caused by FTS having a greater availability of verified operating parameters with respect to water quality (Bjørndal et al., 2018). Risk will be further elaborated on in the separate risk section.

The reuse technology used in FTS adds oxygen and removes CO₂ from the water, resulting in a 30.0-70.0% degree of water recycling. Being able to reuse 30.0-70.0% of the water yields significant energy savings reductions for modern facilities due to reduced pumping of water, in addition to reduced need for temperature adjustments. Also, facilities using FTS do not include a biological filter in the water treatment system which offers lower complexity than corresponding RAS facilities (Bjørndal et al., 2018). This is illustrated in figure 5.4.

5.4.2 Recirculating aquaculture systems

Over the last 20 years RAS has seen a considerable technological development. In RAS facilities the water provides the fish with oxygen, removes waste and pathogens before being filtrated, oxygenated and returned to the fish. The water treatment process uses mechanic removal of particles and biological filters containing bacteria to remove, transform and defuse waste materials. Further, carbon dioxide is removed, oxygen added, and the water disinfected and controlled for parameters such as PH-level and salinity (Holm et al., 2015). Depending on the scope, this extensive water treatment yields a degree of water recycling of 95.0-99.0% (Holm et al., 2015).

The majority of facilities using RAS grow the fish in brackish water holding a salinity of 12-14‰, although some use a mix of freshwater and seawater holding a salinity of 2.0-3.0‰ (Bjørndal et al., 2018)). Further, the water temperature is regulated to ensure an optimal growth environment for the fish. Compared to conventional FTS, this technology offers a significant reduction in the need for external water and provides greater control over the production environment and the production itself. By recycling 95-99% of the water, the technology is more complex and increases operational risk (Holm et al., 2015). An illustration of this is found in figure 5.4.

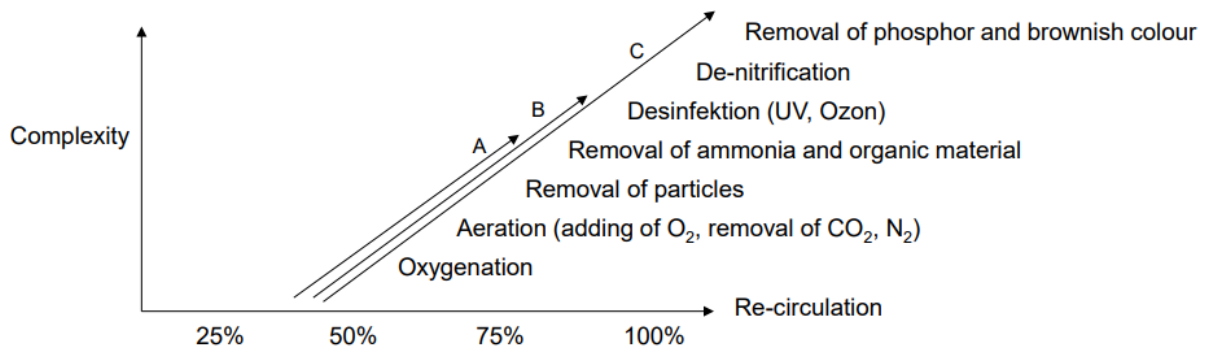


Figure 5.4: Complexity as a function of degree of recycling, Source: Billund Aquaculture Service A/S (2017)

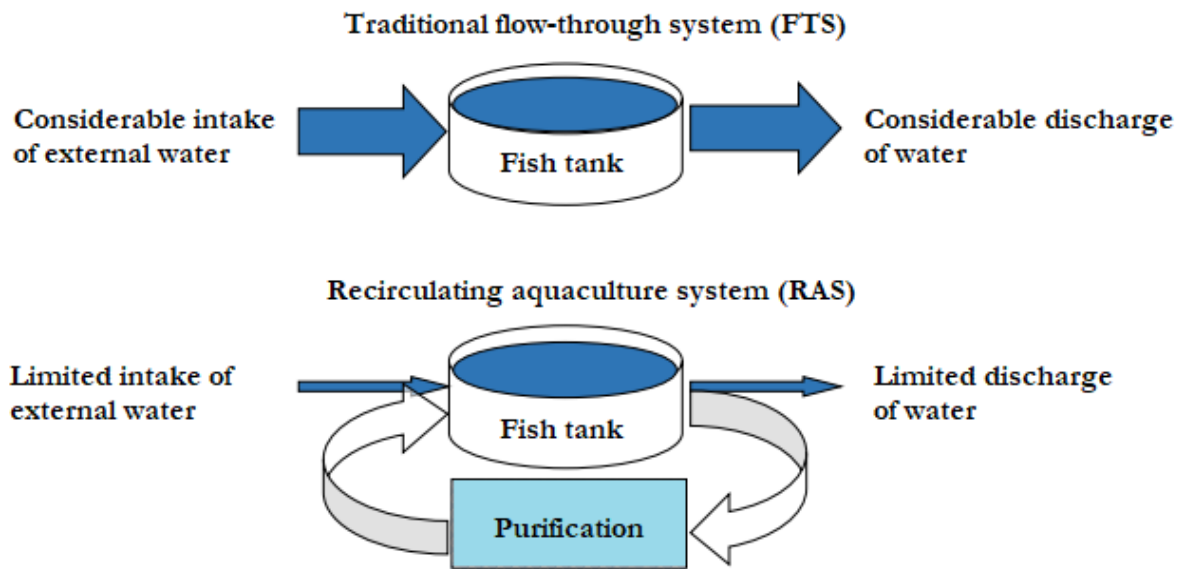


Figure 5.5: Principle comparison of FTS and RAS, Source: Terjesen (2017)

5.5 Risks in land-based salmon farming

There is a chance that disease can occur in land-based facilities. Introduction of biological material like roe, smolt and fish to the plant, in addition to the intake water, represents the largest potential source of infection (Norwegian Veterinary Institute, 2019). The roe, which is produced externally, may already be infected when entering the facility. Further, technical problems with the water treatment may result in infected water entering the facility. The increased control over the production environment and water recycling may be negative under such circumstances (Norwegian Veterinary Institute, 2019).

Further, for RAS facilities, pathogens can be established in the biological filter and

neutralizing these can be problematic as it impacts its function (Norwegian Veterinary Institute, 2019). It may take up to six months to clean and reestablish the biological filter if this occurs (Bjørndal et al., 2018). In this period the RAS will have to be without fish, representing lost production (Bjørndal et al., 2018). It may be significantly more costly and complex to get rid of these biological challenges compared with what would be the case for a sea-based facility.

Technological risk is present in land-based facilities, and may be comparatively higher than that in sea-based facilities. This may be due to the scarce experience from such facilities and the fact that the technology is not fully understood. One aspect of this relates to risk of the facility not being able to achieve the planned biomass growth rate, production volume, desired quality or planned total production expense per kg (Bjørndal et al., 2018). Further, there is a risk of problems with fish health and welfare which in turn may negatively affect the aforementioned factors. Being able to reach planned production and utilisation of the facility depends on comprehensive planning and risk management (Bjørndal et al., 2018). According to Bjørndal et al. (2018), there has been difficulty to realise the planned growth rate from 1.5 to 5.0 kg. This has had a negative effect on harvest weights which is estimated to be closer to 4.0 kg (Bjørndal et al., 2018).

Another aspect of technological risk is related to the technical components in land-based facilities. The toxic gas H_2S occurs when biological material decomposes and may result in widespread mortality (Norwegian Veterinary Institute, 2019). It is vital to avoid accumulation of biological material and excessive feeding in the facility. Further, the biological filter in RAS facilities are especially vulnerable with respect to H_2S (Norwegian Veterinary Institute, 2019). Several RAS facilities in operation have experienced problems with this, which is assumed to have caused widespread mortality (Norwegian Veterinary Institute, 2019). Preventive measures may be using feed specially developed for RAS facilities (Norwegian Veterinary Institute, 2019).

Risk may also be associated with facility design. RAS facilities using seawater have experienced problems with too high levels of CO_2 (Norwegian Veterinary Institute, 2019). Designing pipe, pumping and water treatment systems in a way which ensure continuous flow and prevents the water from being stationary is vital in this respect (Bjørndal et al., 2018). In other words, the facility depends on continuous and steady circulation of water.

Further, the use of sea water in RAS increase the risk of bacterial infections which causes skin infections and wounds on the fish. This problem has been experienced by several facilities in 2017 and 2018 (Norwegian Veterinary Institute, 2019).

Designing facilities correctly with respect to biosecurity is a prerequisite to achieve good risk management in production (Bjørndal et al., 2018). Bjørndal et al. (2018) suggest initiatives like over-sizing the capacity of the biological filter, having several separate water treatment systems and biological filters in order to reduce the operational risk.

The operational risk is another aspect which may be comparatively higher in land-based farming facilities. One relates to the need for off-tasting in RAS facilities before the fish is harvested (Bjørndal and Tusvik, 2017). If this fails the fish may get an undesirable taste which affects its value. Further, early maturation must be avoided as this reduces the product quality significantly (Bjørndal and Tusvik, 2017). Damage to the fish skin as a consequence of too high density may also be avoided as this affects fish health and thereby farming performance negatively (Bjørndal and Tusvik, 2017).

Water is a critical input in production of salmon. For both RAS and FTS facilities, reliable access to water and systems providing it may be crucial (Bjørndal et al., 2018). In order to secure this under any circumstance, backup power reserves and a trained workforce will be vital to reduce the risk of unplanned downtime or outbreak of disease and thereby loss of fish (Bjørndal et al., 2018).

Good water quality is essential for growth, quality and welfare of the fish, and thereby the facility's economic performance. The water quality is determined by factors like water source, facility design, water treatment system and operating strategy (Bjørndal et al., 2018). Further, according to Norwegian Veterinary Institute (2019), the biological filter may be extra vulnerable in the production ramp-up phase as well as in facilities using seawater. Thus, for land-based facilities there may be a larger risk of getting insufficient water quality as it depends on a larger number of controllable and non-controllable factors compared to sea-based farming. However, due to more operational experience with FTS facilities there exists more verified water quality parameters for this technology compared to RAS (Bjørndal et al., 2018). This reduce the operational risk for facilities using FTS.

5.6 Comparison of salmon farming in sea-based and land-based facilities

There are substantial differences between farming salmon in a sea-based facility and in a land-based facility. Many of these originates from increased control of the production environment as well as separation from its external environment, which a land-based facilities offers. In the following, we will give a comprehensive presentation of these differences.

One of the most fundamental differences is the production intensity. Sea-based farmers can maximally have 25 kg fish per 1000 litres of water (Holm et al., 2015). Land-based farming are exempt from this maximum limit. Research shows that production with density of 75 kg fish per 1000 litres of water is possible, while using a density of 100 kg per 1000 litres of water or more, negatively effects growth and stress occur (Bjørndal et al., 2018). The increased production intensity on land is key to achieving profitability (Bjørndal and Tusvik, 2017; Holm et al., 2015).

A land-based facility can utilize water treatment methods on its intake water. This ensures that potential pathogens and sea lice will be neutralized before the water enters the facility (Bjørndal and Tusvik, 2017). Being able to farm salmon without facing any issues with sea lice and other diseases represents a significant advantage over sea-based farming. The absence of treatments for sea lice may result in significantly improved fish health, improved biological growth and reduced loss of fish. Further, large direct costs like cost of treatment, sea lice counting, monitoring and preventive measures are omitted. Avoiding diseases also represent significant benefits making medicine and chemicals used in treatments obsolete.

A more stable production environment in land-based facilities also improve fish welfare. A more stable supply of oxygen has a positive impact. Further, land-based facilities can keep the optimal water temperatures of 12-14 Celsius under the entire production cycle. This results in improved growth conditions compared to sea-based farming.

Increased control over the production environment may improve product characteristics compared to conventional farming. Further, it allows for increased customization of the

product to what is demand of the customers. By having an optimal temperature of 12-14 Celsius over the entire production cycle, the fish grows more steadily. Also, by using different tanks under different life stages, the salmon can be exposed for optimal flow conditions throughout its entire life. Both these properties of land-based farming may improve the quality of the fish meat compared to fish farmed in the sea. In addition, it is possible to farm the fish to get the precise colour demanded by the customer. This may contribute to achievement of higher prices for land-based salmon. Land-based salmon farming also allows for full traceability of individuals, which may be valued by consumers.

A more controlled production environment may also reduce loss of fish during production. Due to the optimal and stable water temperature, mortality related to release of smolt may be reduced. Further, no need for transportation using wellboat may also reduce loss. Loss are further reduced by the absence of lice treatments, as previously mentioned. The reduced amount of fish lost in production may represent significant economic and fish welfare benefits, and address a large problem for the industry (Norwegian Veterinary Institute, 2019).

Land-based salmon farming also offers safer working conditions than sea-based farming (Bjørndal and Tusvik, 2017). Further, fewer employees may be needed in land-based farming given a comparable production volume, because the production processes may be more automated and of larger scale.

The stable water temperatures makes it possible for land-based facilities to produce more steadily than in sea. This may lead to better utilization of the MAB. Sea-based farmers have a production environment determined by natural conditions, which makes the water temperature fluctuate considerably over the year. Production in sea follows this temperature cycle, which gives rise to a seasonal pattern for supply of salmon. This is avoided in land-based farming, which can offer a steady production and thereby steady supply of salmon throughout the year.

Another benefit is that land-based facilities has fewer constraints in terms of its operating environment compared to sea-based farming facilities. This opens up entirely new areas for salmon farming and threatens the natural competitive advantage for salmon farming in Norway in the long run. Land-based facilities can be located in closer proximity to their product markets. By doing so, locally produced salmon will compete with salmon

produced in Norway or Chile etc. that needs to be transported to the market. The difference in transportation costs will give the locally produced salmon a cost advantage. In addition, the locally produced salmon may have lower carbon emissions compared to conventional farmed salmon when transportation is included, as estimated by Liu et al. (2016). A case in point may be Atlantic Sapphire which aims to farm salmon in Miami.

Due to the benefits in terms of fish health, product improvements and more sustainable production associated with land-based farming, it may achieve a price premium in the market. Liu et al. (2016) used a price premium of 30%, while industry sources has suggested that a price premium in the range of 5-15% may be obtainable. Bjørndal and Tusvik (2017), on the other hand, challenge this. The actual price achievement remain to be seen, but it may represent a benefit for land-based salmon compared to sea-based salmon.

Land-based facilities have a significantly higher energy consumption than sea-based farms. The majority of the energy is needed for water pumping, water treatment, temperature adjustments, ventilation, pumping of air to vent CO₂ and pressurizing water to add oxygen (Bjørndal et al., 2018). In addition to this, energy is needed to handle and process sludge and other emissions from production, as well as the smolt and processing facility. Thus, energy cost is a significant cost component for land-based farming facilities and a comparative disadvantage to farming in sea.

Despite all the aforementioned advantages of land-based farming, the material available suggest a relatively high total production cost per kg (Liu et al., 2016; Bjørndal and Tusvik, 2017; Bjørndal et al., 2018). This may suggest that land-based farming is less competitive than sea-based farming. Further, due to the relatively high total production cost per kg and relatively high total investments required, this farming method seems to dependent on achieving relatively high prices in order to be profitable.

5.7 Planned land-based production capacity

Over the last couple of years, numerous plans for establishing land-based salmon farming facilities has been publicly disclosed. These planned projects make up a total production capacity of 809,450 tonnes, equal to 32.3 % of world production in 2018. The scope of these plans highlight the current interest of land-based salmon farming.

In the following we present an overview over facilities planned in Norway. This provides a comprehensive overview over the development of the industry. The planned facilities constitute 245,150 tonnes of capacity, corresponding to 19.1% of the Norwegian production in 2018. Further, all facilities except Salmon Evolution and Andfjord Salmon plan on using RAS technology. These projects plan on using FTS technology. The planned facilities also differ with respect to capacity. Some facilities seems to have a high capacity in order to realise economies of scale, while others are of more moderate size. However, the capacity used by Liu et al. (2016), Bjørndal and Tusvik (2017) and Bjørndal et al. (2018) of 4,000, 5,000 and 6,000 tonnes respectively, seems to be in the lower range compared to the current industry plans.

Planned land-based salmon farming facilities in Norway may be seen as an intermediate step before being located closer to the end markets. This represents a natural evolution originated from world-leading knowledge of salmon farming which resides in Norway, as well as proximity to world-leading suppliers and existing infrastructure. We find it likely that if the Norwegian concepts are proven, they may be exported closer to the end markets. This pattern is observed by industry players such as Atlantic Sapphire and Nordic Aquafarms. By doing this, land-based salmon farming get to exploit the inherent advantages it potentially possess over sea-based salmon farming, with respect to reduced transportation costs, improved freshness and extended product life.

Table 5.4: Planned land-based salmon farming production capacity in Norway,
 *Government approval not granted, Source: Norsk Fiskerinæring (2019); ilaks (2019g,c)

Company	Country	Planned capacity
Ecofisk AS*	Norway	40.000 tonnes
Salmon Evolution AS	Norway	28.800 tonnes
OFS Andenes AS*	Norway	20.000 tonnes
OFS Nordkapp AS*	Norway	20.000 tonnes
Erko Seafood AS*	Norway	15.000 tonnes
OFS Måløy AS	Norway	15.000 tonnes
Andfjord Salmon AS	Norway	10.000 tonnes
Havlandet RAS	Norway	10.000 tonnes
Tomren Fish AS	Norway	10.000 tonnes
Aquaculture Innovation AS*	Norway	10.000 tonnes
Kobbervik og Furuholmen AS	Norway	10.000 tonnes
Salmofarms AS	Norway	8.500 tonnes
Salmo Terra AS	Norway	8.000 tonnes
Gaia Salmon AS	Norway	7.500 tonnes
Vadheim Akvapark AS	Norway	6.000 tonnes
Fredrikstad Seafood AS	Norway	5.500 tonnes
Bulandet Miljøfisk AS	Norway	5.500 tonnes
Smart Salmon AS*	Norway	5.000 tonnes
Oppdal Fjellmat og Fjellfisk AS*	Norway	3.250 tonnes
Lofoten Salmon AS	Norway	3.100 tonnes
Hjelvik Matfisk AS	Norway	2.000 tonnes
Ecomarin Seafarm AS	Norway	2.000 tonnes
Sum		245.150 tonnes

Total planned global capacity when excluding Norway amounts to 564,300 tonnes. Of this, 220,000 tonnes relates to a single company and project. Planned facilities seems to be located in a wide variety of countries. Further, planned capacity seems to be somewhat divided between large facilities with capacity exceeding 10,000 tonnes and smaller facilities with capacity below 6,000 tonnes.

Table 5.5: Planned land-based salmon farming production capacity excluding Norway,
Source: Norsk Fiskerinæring (2019)

Company	Country	Planned capacity
Atlantic Sapphire	USA	220.000 tonnes
Nordic Aquafarms	USA	33.000 tonnes
Whole Oceans	USA	25.000 tonnes
Pure Salmon	USA	20.000 tonnes
Aquabanq	USA	10.000 tonnes
AquaBounty	USA	1.450 tonnes
Hudson Valley Fish Farm	USA	1.000 tonnes
Inland Sea	USA	250 tonnes
Superior Fresh	USA	70 tonnes
Pure Salmon (5 facilities)	China	100.000 tonnes
Shandong Oriental	China	20.000 tonnes
Nordic Aquapartners	China	8.000 tonnes
Xinjiang E"he Construction	China	1.000 tonnes
Tianjin Changjiufada Comp.	China	250 tonnes
Cape d"Or	Canada	2.500 tonnes
Namgis Kuterra	Canada	2.000 tonnes
Golden Eagle Aquaculture	Canada	1.000 tonnes
Sustainable Blue	Canada	500 tonnes
Landeldi	Iceland	5.000 tonnes
Samherji	Iceland	3.000 tonnes
Matorka	Iceland	1.500 tonnes
Pure Salmon Japan	Japan	10.000 tonnes
Proximar	Japan	6.000 tonnes
FRD/Mitsui	Japan	1.500 tonnes
West Coast Salmon	South-Africa	4.800 tonnes
South African Salmon	South-Africa	2.500 tonnes
Nordic Corporation	South-Africa	1.800 tonnes
Global Fresh Fish	Russia	30.000 tonnes
Vologda	Russia	2.500 tonnes
Vikings Label	Dubai	10.000 tonnes
Fish Farm	Dubai	180 tonnes
Atlantic Sapphire Denmark	Denmark	3.000 tonnes
Danish Salmon AS	Denmark	2.000 tonnes
Jurrasic Salmon	Poland	1.000 tonnes
Global Fish	Poland	600 tonnes
Pure Salmon France	France	10.000 tonnes
Rodsel Group	Spain	8.000 tonnes
Newco	Latvia	5.000 tonnes
EFC Scotland	Scotland	4.000 tonnes
Fifax	Sweden	3.200 tonnes
Berliner Lachs	Germany	2.000 tonnes
Swiss Lachs	Switzerland	600 tonnes
BDV/SAS	France	100 tonnes
Sum		564.300 tonnes

One of the advantages of land-based salmon farming is the possibility to locate the facility closer to the end market. This may suggest an overweight of planned land-based capacity in markets remote from the conventional production. Studying the planned capacity by continent, we find that 40.4% is planned in Europe and 30.3% in Norway. Thus, planned Norwegian capacity makes up approximately $\frac{3}{4}$ of planned European capacity. The European market is traditionally well served from conventional farmers and transport costs are relatively small.

Table 5.6: Planned land-based salmon farming production capacity by continent

Continent	Planned capacity	Relative proportion
Africa	9.100 tonnes	1.1%
Asia	156.93 tonnes	19.4%
Europe	326.650 tonnes	40.4%
North-America	316.770 tonnes	39.1%
Oceania	- tonnes	- %
Sum	809.450 tonnes	100%

The aggregated capacity of planned facilities are undoubtedly significant for the supply of salmon. Further, it signals the interest and some of the future potential for land-based farming. In fact, if all this were to become operational land-based farming would be the 2nd largest producer of salmon in the world, exceeding Chile, with 32.3% of the world production in 2018.

However, there is large uncertainty related to how much of this capacity which actually ends up being realised. Further, financing seems to be the largest constraint as bank financing is scarce and investors seems to be selective in which projects they place their bets on.

6 Theory

This chapter provides theoretical frameworks and serves as the theoretical fundament for this thesis. Firstly, we present microeconomic theory under the assumption of perfect competition to analyse how superprofit can occur in a commodity industry. We then move on to present the economic theory behind auctions. This is used as the theoretical fundament when we return to analyse the extensive price appreciation witnessed in MAB auctions. Subsequently, we present theory on externalities, in order to analyse how choices undertaken by companies are affected by market failure. Finally, we present theory on technology S-curves in order to provide insight on how investments can be expected to affect performance for salmon farming technologies.

6.1 Economic profit in competitive markets

A market structure with perfect competition is characterized as a market with a large number of firms, identical products and no barriers to entry. Even though few markets are perfectly competitive, the study of perfect competition can give valuable insight into how these markets work (Goolsbee et al., 2013).

The economic implications of a market with perfect competition is that firms must consider the price as given, meaning they do not have the ability to affect the price by changing the quantity they produce. As such, firms are price takers. The market price is determined solely by the forces of supply (S) and demand (D). Further, producing firms are assumed to operate in a profit maximizing way.

In a perfectly competitive market, the marginal revenue (MR) generated by selling one extra unit is equal to the market price (P). Further, a firm will increase production if MR is larger than marginal cost (MC) associated with selling one extra unit. Since $P = MR$, this implies that firms will produce until $P = MC$ in order to maximise profit.

In the long-run all costs are assumed to be variable, and thus the firm's supply curve is the part of the MC curve above the average total cost curve (ATC). In the starting point, A, the industry is in equilibrium at a price of P_1 . Since the firms are price takers, they maximise profit where $P_1 = MC$. Price is also equal to the ATC so the firms earns zero

profit.

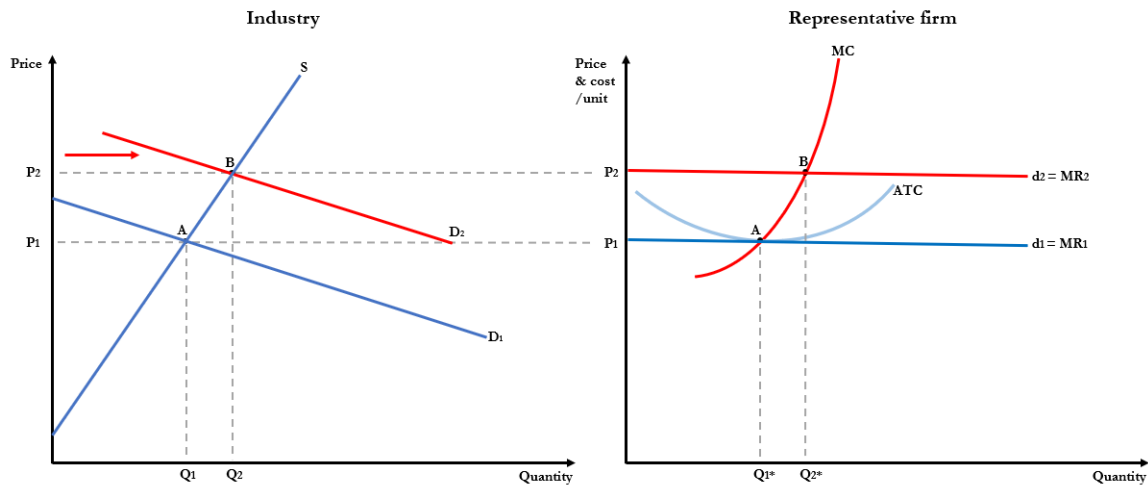


Figure 6.1: Economic profit in a perfectly competitive market, Source: Goolsbee et al. (2013)

In a situation where demand rises to D_2 , prices will rise to P_2 . This in turn will result in each firm moving upward its supply curve and produce a larger quantity where $P_2 = MC$. At an industry level, the increase in output would be reflected at the new intersection between S and D_2 , in point B . Even after the aggregated increase in output at the industry level, the price is above the ATC at firm level. This in turn, results in economic profit among existing firms. Further, the figure illustrates that as the price rises, firms are willing to take on additional costs in order to produce a higher quantum.

Theory behind perfectly competitive markets suggests that economic profit will not last in the long run. This is caused by an assumption of free entry, meaning the ability of a firm to enter an industry without encountering legal or technical barriers (Goolsbee et al., 2013). However, if such barriers affects a market, it implies that a favorable situation with economic profitability for already established firms occur.

6.2 Negative externalities

Goolsbee et al. (2013) defines negative externalities as "economic transactions which negatively impact third-parties not directly involved in the transaction". Negative externalities produces inefficient outcomes as the cost to the society is different from the

private cost between producers and consumers. A free market usually fails to produce the optimal quantity of a good when an externality is present. For negative externalities, too much tends to be produced.

External marginal cost (EMC) is the cost to society from producing or consuming an additional unit of output. When externalities exist, the social marginal cost (SMC) is equal to the private marginal cost plus the external marginal cost. In a free market with a negative externality, firms produce where $P = MC$, as seen in point B in the figure. However, this does not take into account the EMC. The SMC curve in the figure shows that if EMC is taken into account, the society as a whole has a higher marginal cost than the industry. When all costs are accounted for, total surplus is maximised in point A. In this equilibrium socially optimal price is higher and production quantity is lower. The inefficiency arises as the firms only pay for private costs and ignore the external costs that the society bears. In point A, consumers of the good value the good at least as much as it costs society to produce it, and between A and B consumers value the good less than it costs society to produce it. These consumers would not buy the product if the price reflected the full social cost of producing the good. If the market produces where $P = MC$ seen as point A, it results in a dead-weight loss represented by the shaded triangle in figure 6.2.

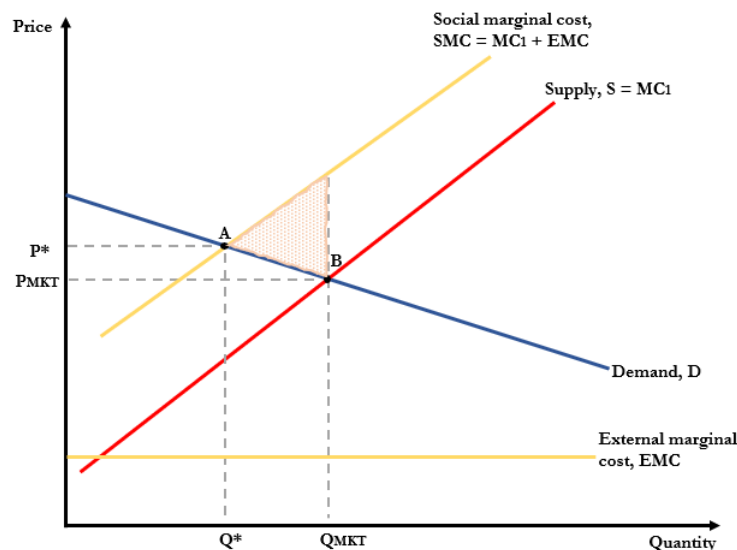


Figure 6.2: Externalities in a perfectly competitive market, Source: Goolsbee et al. (2013)

6.3 Auctions

Auctions is commonly used in economic transactions throughout society, and the outcome can be predicted using game theory under imperfect information (Klemperer, 1999). In this section, we will only cover the first-price sealed-bid auction. In this form of auction, the bidders submit a single bid independently, without knowing what others are bidding. Each bidder know their value of the object, but this information is private. This is referred to as the *private-value* model. The object is sold to the highest bidder at the highest price.

Despite this auction set-up, the *Revenue Equivalence Theorem* states that the expected revenue from an auction is independent of auction mechanism, as long as its assumptions are fulfilled (Klemperer, 1999). These being that bidders are risk-neutral and have private signals about the value. Further, the auction mechanism will always sell the object to the bidder with the highest signal, and the bidder with the lowest feasible signal expects zero surplus (Klemperer, 1999). According to Bulow and Roberts (1989), under the revenue equivalence theorem, the expected revenue from an auction is the expected marginal revenue of the winning bidder. Thus, in an optimal auction, assuming that the bidder with higher signals have higher marginal revenue, the bidder with the highest marginal revenue gets the object (Klemperer, 1999). However, if bidders have some information about other bidders' marginal revenue, the one with highest signal may only bid sufficiently to win the object, not the true marginal revenue.

6.4 Tax in competitive markets

In figure 6.3, an fictive example of the incorporation of NOK 1.0 in tax per quantity sold is shown. In this example the original price is NOK 5 per unit in point A. With the new tax imposed, the supply curve shifts up to the left, resulting in a new equilibrium in point B. Higher price result in lower demand, and the new price is estimated at NOK 5.6. The consumer pays $\text{NOK } 5.6 - \text{NOK } 5.0 = \text{NOK } 0.6$ of the tax. The producer receives $\text{NOK } 5.6 - \text{NOK } 1.0 = \text{NOK } 4.6$, which means that NOK 0.4 of the tax is payed by the producer. In the example, 60% of the tax is passed on to the consumer, but the split between the producer and consumer is decided by the elasticity of the supply and demand

curve within the industry.

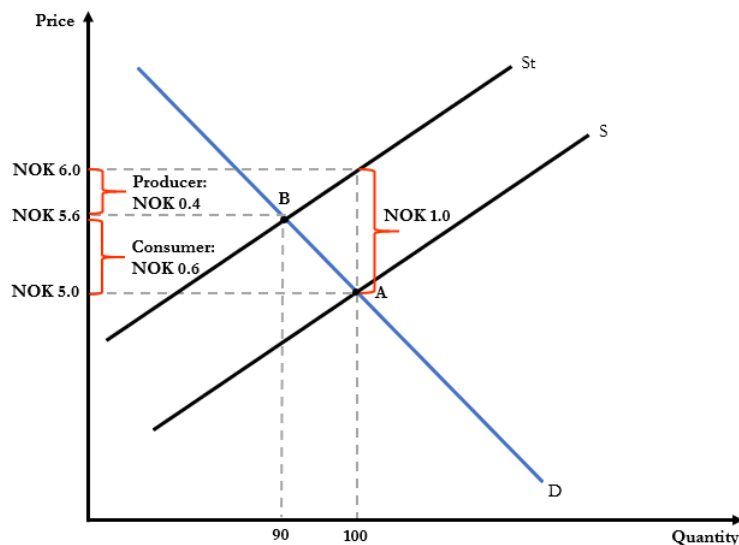


Figure 6.3: Who pays the tax?, Source: Goolsbee et al. (2013)

The intuition behind figure 6.3 can be shown following model: t is the tax per unit, P is the consumer price and p is the producer price. The model seeks to explain what happens to P and p when tax is incorporated. The consumer price is equal to the producer price plus the tax per unit, $P = p + t$. This can be rewritten to $p = P - t$, which means the producer price is equal to the consumer price minus tax per unit.

Equilibrium can be found where demand (D) is equal to supply (S). The effect tax has on the producer and consumer price is found by $\frac{\partial P}{\partial t}$ and $\frac{\partial p}{\partial t}$. We assume the usual properties of the supply and demand functions. That is $\frac{\partial S}{\partial p} = S'(p) > 0$, meaning supply will increase when prices increase and $\frac{\partial D}{\partial p} = D'(P) < 0$, meaning demand will fall as prices increase.

Equilibrium expressed in consumer price P , is $D(P) = S(P - t)$. Similarly, equilibrium expressed in producer price is $D(p + t) = S(p)$. In equation 6.1, we find the partially derivative of the producer price on taxes. In equation 6.2, the expression from equation 6.1 has been rearranged to separate $\frac{\partial p}{\partial t}$. In equation 6.3 and 6.4, we show the same steps as in equation 6.1 and 6.2 for the consumer price.

$$D(p + t) = S(p) \implies D'(P)\left(\frac{\partial p}{\partial t} + 1\right) = S'(p)\frac{\partial p}{\partial t} \quad (6.1)$$

$$\frac{\partial p}{\partial t} = \frac{D'(P)}{S'(p) - D'(P)} < 0 \quad (6.2)$$

$$D(P) = S(P - t) \implies D'(P)\left(\frac{\partial P}{\partial t} - 1\right) = S'(p)\frac{\partial P}{\partial t} \quad (6.3)$$

$$\frac{\partial P}{\partial t} = \frac{S'(p)}{S'(p) - D'(P)} > 0 \quad (6.4)$$

The implications of 6.2 and 6.4 is that the producer price falls and the consumer price increases when tax increases. If the supply or demand curve is either perfectly elastic or inelastic this implication is no longer valid, however this is outside the scope of this thesis.

6.5 Development of technological performance

It is well documented that for a wide range of technologies, the development in the performance/price ratio over their lifetimes can be graphically represented by an S-curve (Schilling and Esmundo, 2009). The relationship occurs when plotting the performance/price ratio of a technology against the effort invested in it. Effort typically consist of time and capital invested in research and development activities. Over its lifetime, a technology typically shows slow initial improvement, then it accelerates, before it faces diminishing improvement in performance when matured.

The slow initial improvements in performance/price ratio of a technology occurs because the fundamentals of the technology are poorly understood. Considerable work and investments may be undertaken exploring different paths of improvement or in exploring different drivers of improvement. The accumulation of knowledge results in a deeper understanding of the technology, which in turn leads to the performance/price ratio starting to accelerate. Research and development efforts of the technology are concentrated on activities with most promising prospects, yielding activities with the greatest improvement per unit of effort. This enables the performance/price ratio to improve rapidly which continues until, at some point, diminishing returns relative to effort materialise. As the technology approaches its intrinsic theoretical potential, the efforts associated with each marginal improvement in the performance/price ratio increases. Thus, the S-curve face a reduced

slope (Schilling and Esmundo, 2009).

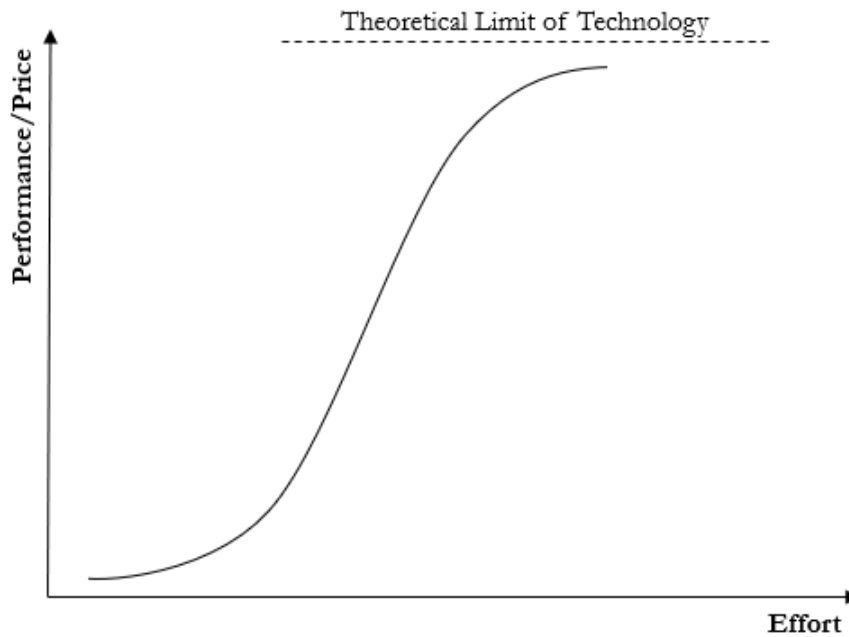


Figure 6.4: Normative development of technology performance/price ratio, Source: Schilling and Esmundo (2009)

Technologies can be made obsolete before reaching their limits. New innovations can represent discontinuous technology which is characterized by satisfying the same market need while building on an entirely new knowledge base (Schilling and Esmundo, 2009). Theoretically, when such innovation first appears, it typically has lower a performance/price ratio than the incumbent technology. Further, the increase in performance/price per unit of effort invested is typically lower compared to effort invested in the incumbent technology. Thus, firms continue to invest their efforts into the incumbent technology. However, at some point the positions may be reversed, and the new technology offers the highest increase in performance/price ratio per unit of effort invested. From this point, substitution occurs as firms entering the industry are likely to choose the disruptive technology (Schilling and Esmundo, 2009). Incumbent firms, on the other hand, needs to choose whether to invest in extending the life of the established technology currently employed, or invest in substituting to the new technology.

The greater the performance/price potential for a given amount of effort, which may be associated with a new technology, makes it likely that the new technology will displace the in the long run. However, there may be large variations in the pace of displacement

depending on individual context.

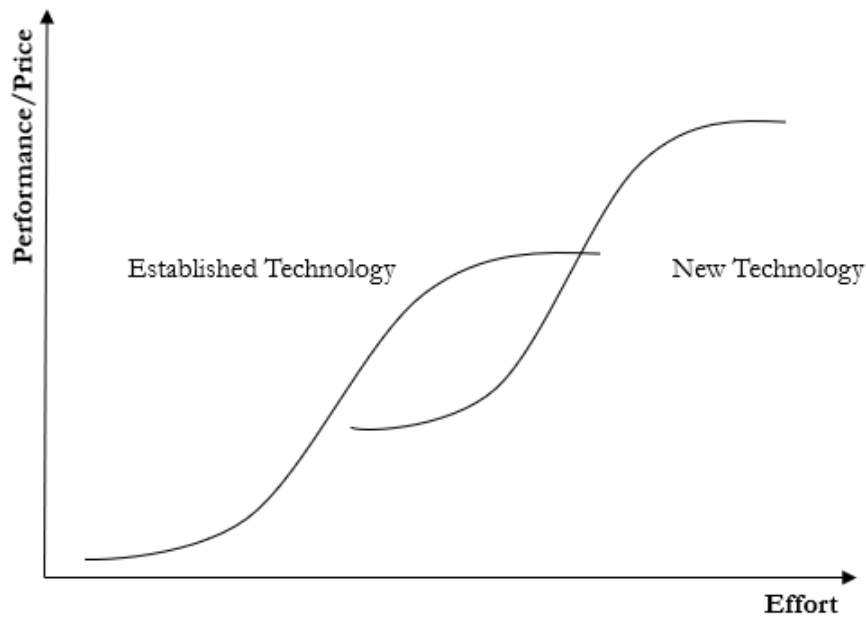


Figure 6.5: Normative development in technology performance/price ratio, Source: Schilling and Esmundo (2009)

There exist several limitations to the presented theory concerning development in technological performance/price ratio as a function of effort invested. One limitation relates to the fact that there is virtually impossible to estimate the true inherent potential of a technology ex ante. Further, firms in the same industry may have very different perceptions of a technology's future prospects. Another limitation relates to the shape of the technology S-curve and deviations from it. Unforeseen changes in the market, technologies applied in components used or in complementary technologies can affect the duration of a technology's lifecycle (Schilling and Esmundo, 2009). Limitations also exist due to the firms' ability to influence the shape of the S-curve through their own research and development efforts. Further, the length of an S-curve can be expanded due to new development approaches or revamping the architectural design of the technology (Schilling and Esmundo, 2009).

6.6 Patterns of technological evolution and change

Tushman and Anderson (1986) describes patterns of technological change and the impact of technological change on environmental conditions. They found that "technology tend to

develop through periods of incremental change punctuated by technological discontinuities” (Tushman and Anderson, 1986). The technological discontinuities either enhance or reduce the value of a firm’s resources and activities.

Initially, a new technological regime emerges as a result of a technological breakthrough or discontinuity. Technological discontinuities initiate by themselves a subsequent period of technological ferment. Due to the new technological regime opening a new product class, or stimulating substitution from previous products, a substantial amount of product variants emerge in this period (Tushman and Anderson, 1986). This is a result of the new technology not being fully understood, and because each firm has an incentive to differentiate its product to those already available. The emergence of a variety of product variants results in increased competition within the new technological regime as they compete for dominance. Competition further intensifies between the new and previous technological regimes as the new technology becomes a stronger substitute as it evolves. In terms of duration, the period of ferment tends to endure longer the more radical the substituting technology is compared to the established technology (Knudsen, 2019b).

The emergence of one or several dominant designs marks the end of the period of ferment and the start of the period of convergence. The number of product variations converge, and environmental uncertainty is reduced, as firms adopt the dominant design or industry standard (Tushman and Anderson, 1986). The majority of potential adopters will wait for an industry standard to emerge before adopting a new technology as this reduces the risks associated with switching. Thus, sales tend to peak after the emergence of an industry standard and it is often a prerequisite to reach mass adoption (Knudsen, 2019b).

Following the emergence of a dominant design, the technological progress takes place through various incremental improvements and innovations. Competition now shifts its focus from increased performance to lower costs or differentiation through minor variations in design. This continues until a new technological discontinuity emerge and marks another major technological advance (Tushman and Anderson, 1986).

7 Methodology

In this chapter we will present the methods and assumptions used to answer whether or not land-based salmon farming is economically attractive.

7.1 The price of Atlantic salmon

The price formation of Atlantic salmon is a result of supply and demand in the world market as Atlantic salmon is considered a commodity. Further, as the world market is intertwined, changes in supply from other parts of the world will affect the prices available for Norwegian farmers. This is mainly due to the fact that Norwegian and foreign salmon compete for the same buyers in the product market, although some price differences arise from different costs of transportation (Bjørndal and Asche, 2011).

Demand and supply of Atlantic salmon depends on multiple factors. As salmon is a food product, demand tend to be rather stable throughout the year. However, some seasonal demand effects exist. On an annual basis, demand for Atlantic salmon tend to increase, although at historically varying rates. Short-term supply depends on the aggregated timing of harvest between farmers. Also some seasonal patterns do exist relating to the natural cycle arising from the two main smolt releases in May and October every year.

Supply of salmon is inelastic in the short run, while being more elastic in a two to three year period. This is due to long lead times associated with the salmon life-cycle. Production increases today will hit the market in about two years time if there is available capacity and non-binding constraints. However, if there is binding constraints and additional investments in the value chain has to be undertaken, lead times will be longer.

Although much has been written about the price formation and market dynamics of Atlantic salmon, it is outside the scope of this thesis to go in any further depth on these subjects.

Figure 7.1 provides an overview of the historical development in the nominal spot price of Atlantic salmon from January 2006 to September 2019, as well as the current nominal forward price for the next five years. The price refers to fresh, gutted Atlantic salmon weighing 3-6 kg of Superior Quality delivered in Oslo.

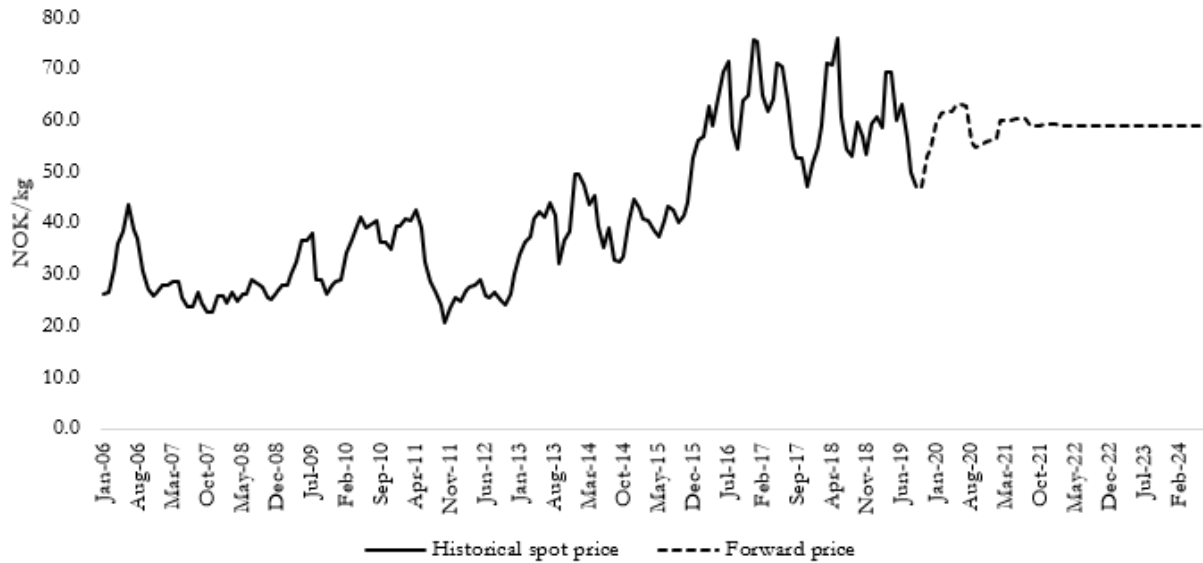


Figure 7.1: Historical nominal spot- and forward price in HOG, Source: Fish Pool (2019)

From 2006 through 2015, the price of Atlantic salmon fluctuated in the range of mid-20 NOK/kg to high-30 NOK/kg, with occasional peaks over NOK 40 per kg and troughs around NOK 20 per kg. From 2016, it increased significantly and established a new price level around NOK 60 per kg. However, the price has been close to NOK 80 per kg and mid-40 NOK/kg in the same period. This reflects the inherent volatility in the historical monthly prices of Atlantic salmon, having a standard deviation of NOK 14.5 per kg over the period. The forward price is in the range of mid-40 NOK/kg to NOK 60 per kg until April 2021, before stabilizing at 59 NOK/kg thereafter.

The period of historically high salmon prices beginning in 2016 primarily reflects the biological situation in Norway and other producing regions. As Norway accounts for 51.3% of total world production, changes in production affects the world supply significantly. Total annual production has been unable to grow satisfy to annual growth in demand, which is a prerequisite for keeping the price unchanged. Thus, demand has increased more than supply, which has resulted in a new market equilibrium at a higher price level in the range of NOK 50-60 per kg.

The implementation of the traffic light system in Norway established a causal relationship between production adjustments and the biological conditions in terms of sea lice. The current sea lice situation can be described as challenging in several of the production zones resulting in being categorized as *red* and *yellow*. Thus, growth opportunities in

terms of increased MAB in sea are constrained for significant parts of the Norwegian production. Further, biological challenges in terms of diseases, toxic algae outbreaks and sea lice has affected the current production negatively, as it has become more challenging to maintain production volumes and reach desired harvest weights. The sum of current constraints for future MAB growth, together with direct impacts on production resulting from the biological situation, have contributed significantly to the establishment of a new and higher price equilibrium for salmon over the current years, as well as providing the basis for high forward prices. At this price level the industry experience superprofits, but in lieu of current constraints prices should approach industry marginal cost.

In the following we assume salmon farmers to be price takers with no market power. We recognize that salmon farmers probably have market power in terms of volumes. However, we make this assumption in order to simplify our analysis and direct our focus on the economic attractiveness of land-based salmon farming in itself under the assumed prices. We assume that the modelled facility in this thesis will not influence the salmon price.

When modelling a land-based farming facility we will in the following assume three different price scenarios. Scenario 1 use the long-term forward price of NOK 59.0 per kg (HOG), corresponding to NOK 49.6 per kg live weight, over the entire modelling period. This may seem be too optimistic as such price may imply superprofits for the conventional sea-based industry over the entire facility lifetime. However, it is currently regular practice among industry practitioners to assume a price equal to the forward price as the market is considered to be efficient.

In scenario 2, we assume that land-based salmon farming overcome the technological challenges and become successful in commercial production. Consequently, we assume that the success of land-based salmon farming will enable enough growth in production volume over time as to shift the supply curve out and bring the price down towards industry marginal cost. However, such increase in production volumes on land will have significant lead times due to a construction time of approximately two to three years and the salmon life-cycle of 20 months. Thus, we try to capture this long-term movement in production volumes, and thereby price, when assuming a salmon price of NOK 59.0 per kg (HOG) for the first 7 years, NOK 50.0 per kg (HOG) for the following 7 years and NOK 45.0 per kg (HOG) for the last 6 years or infinity, depending on the modelling period.

This corresponds to prices of NOK 49.6 per kg, NOK 42.0 per kg and NOK 37.8 per kg in live weight, respectively.

Scenario 3 assume that land-based salmon will be able to achieve a price premium of 10% in the market. This is viewed as conservative compared to Liu et al. (2016) which estimated a price premium of 30%. The price premium may arise from customers having increased willingness to pay for land-based salmon due to the advantages of this production method compared to sea-based farming. In particular, these advantages consist of (1) better fish health due to absence of sea lice, (2) no sea lice induced mortality on the population of wild salmon, (3) absence of harmful sea lice treatment methods, (4) better fish health due to reduced risk for disease, (5) absence of harmful transportation methods, (6) no escapes that affects the population of wild salmon negatively, (7) responsible management of sludge and other waste from production, (8) better product quality in terms of the fish meat and colour due to a more controlled production environment and (9) the potential to be produced close to the end market.

Also potential certification schemes and the potential for organic production is mentioned by Bjørndal and Tusvik (2017) as potential factors to increase customers willingness to pay for the product. In order to possibly achieve a price premium, these attributes needs to be communicated to the customer through branding and marketing. Thus, it is dependant on companies being successful in their branding and marketing execution. However, independent certification schemes may reduce this risk.

On the other hand, some factors may suggest that a price premium on salmon farmed on land is too optimistic. Bjørndal and Tusvik (2017) argues that the ability to achieve the benefits of land-based salmon farming may be distinguished by producers and not the technology itself. Just like some sea-based farmers and countries are more successful in operational and biological performance than others, the same can be the case for land-based farmers. Thus, the price premium may be linked to the best land-based farmers rather than salmon farmed on land.

Liu et al. (2016) estimate the carbon emissions associated with land-based salmon farming in the US and compares it with estimates on sea-based production in Norway. When using average US electricity mix they found emissions of 7.0 kg CO₂-equivalents per kg for the salmon produced on land, compared to 3.4 kg CO₂-equivalents per kg for the salmon

produced in sea. However, when using an electricity mix of 90% hydro power and 10% coal power the land based salmon had an estimated emission of 3.7 kg CO₂-equivalents per kg. In that case, land based salmon farming have a slight disadvantage if the facility is located in proximity to the sea-based farm. On the contrary, when including emissions from transportation from the farmer to the retailer gate, the carbon emissions from a land-based facility can be lower compared to a sea-based facility if the transportation distance is sufficiently large. Liu et al. (2016) estimated that land-based salmon produced in US for delivery in Seattle had approximately 49.0% of the total carbon emissions compared to Norwegian sea-based farming, at 7.4 and 15.2 kg CO₂-equivalents per kg respectively.

7.2 Sea-based salmon farming

7.2.1 Industry cost development

The sea-based salmon farming industry has experienced a rising trend in total cost per kg produced over the last 10 years. From having an industry average total cost of NOK 23.3 per kg (HOG) in 2008, this had developed to NOK 37.5 per kg (HOG) in 2018. This represents a 61.5% nominal cost increase. Of this, 54.2% came in the period from 2012 to 2018. There also exist significant deviation from the Norwegian average. The *high and low* area in figure 7.2 illustrate the highest and lowest average total cost per kg among Norwegian farmers grouped after production county. In addition, the average total cost per kg from companies with production in multiple counties are included. This group typically consist of larger companies. Figure 7.2 compares the Norwegian average with the average in each county, as well as the average from the group with production in multiple counties.

Another point of interest is the development over the last two years of the spread compared to the country average. In these years the high-cost production group had an average total cost per kg significantly higher than the country average. In 2018, the high-cost group of producers, being producers with sole production in Hordaland county, had a total average production cost of NOK 43.4 per kg (HOG). This was 15.8% higher than the country average. On the other hand, the low-cost group had a total average cost per kg slightly

below the country average. In 2018, the low-cost group of producers was comprised of companies with production in multiple counties. Their average production cost was NOK 35.3 per kg (HOG), which was 6.4% lower than the country average. Further, the spread between the high-cost and low-cost group in 2018 was NOK 8.1 per kg (HOG). Although the spread has widened over the ten year period, it has actually been reduced relative to the country average over the same period. In 2008, the spread was NOK 5.8 per kg (HOG) making up 24.6% of the country average, while it made up 21.8% in 2018.

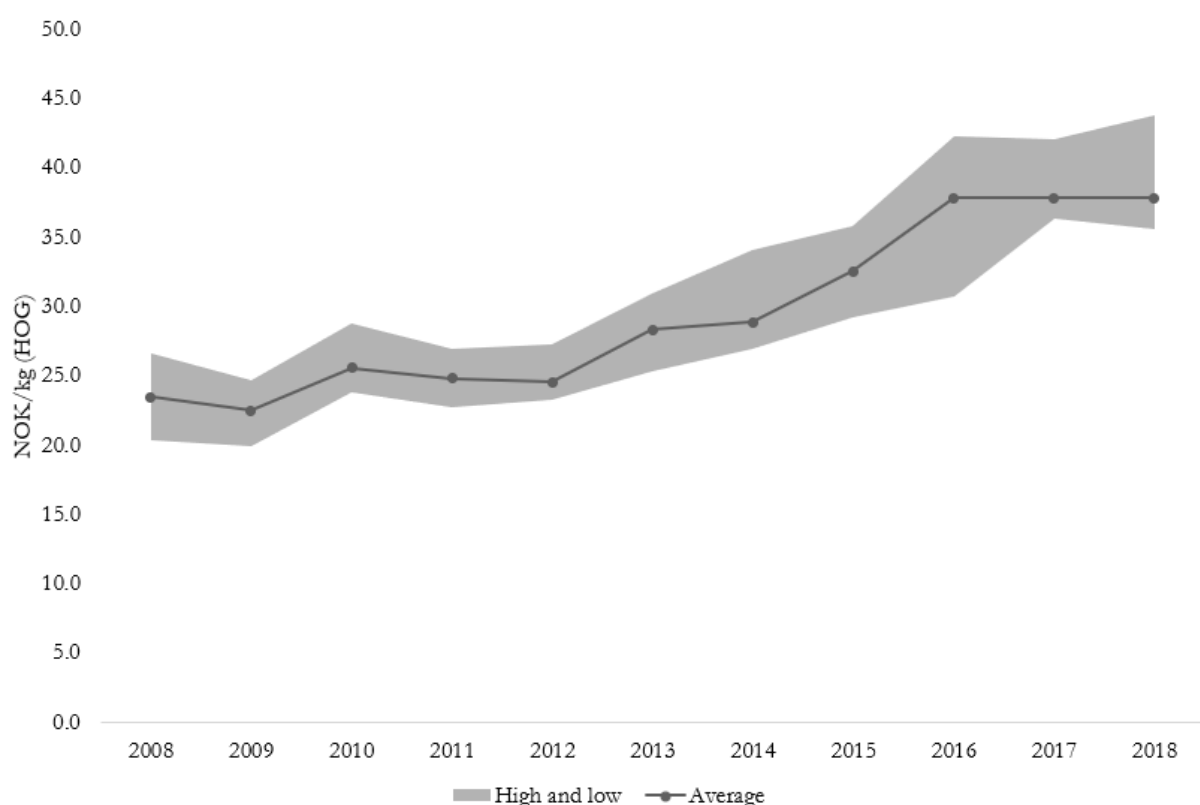


Figure 7.2: Average, high and low total expenses per kg (HOG) for Atlantic salmon in Norway, Source: Norwegian Directorate of Fisheries (2019b)

The cost increase can primarily be attributed to increased cost of feed together with increased direct and indirect cost associated with sea lice, reported as other operating costs per kg (Iversen et al., 2017). Sea lice and the general biological situation has increased other cost categories such as smolt, depreciation and labour. In 2018, the total direct costs related to sea lice for the industry amounted to NOK 5.2 bn, which marked a new record. Over the last three years the accumulated direct cost are estimated at NOK 15 bn (DN, 2019b; Nodland, 2016). However, the growth in these costs has been reduced during 2018 and seem to have stabilised around NOK 5 bn annually (Iversen et al., 2017). To

highlight the rapid cost increase related to sea lice, the corresponding number for 2011 was approximately NOK 1 bn (DN, 2019b). Further, considerable revenue loss and indirect costs arising from negative impact on growth, quality downgrading, negative reputation etc. come in addition to this.

Treatment to comply with sea lice regulation has affected the average harvest weight negatively. Lower average harvest weight, higher weight of dead fish and lower production has resulted in allocation of costs to fewer kilograms (Iversen et al., 2017). This impacts cost of smolt, feed, labour and depreciation per kg produced. Thus, the general biological situation, and especially the sea lice situation, have widespread impact on total costs per kg.

Costs of smolt and depreciation have increased significantly over the last couple of years. This can primarily be attributed to the shift towards larger smolt and corresponding investments made in smolt facilities using RAS (Iversen et al., 2018). The strategy of using larger smolt has come as a response to the biological situation as it reduces time in sea and thereby the exposure to pathogens and sea lice. Further, it is a way to increase production through higher utilisation of MAB when increase in MAB is limited and costly. Further, the cost of roe has increased by 8-10% annually since 2010 as genetic properties has become more important. This also reflected in increased cost of smolt.

Depreciation has increased as a result of the increased investment level throughout the industry. Investments in farming equipment to improve efficiency, monitoring and automation in farming operations have faced strong growth over the last couple of years. Further, the industry is investing substantially in feed barges and boats in addition to equipment used for prevention and treatment of sea lice. New technical requirements imposed by regulations, and a partial trend of using more exposed locations increases the technical requirements. Which also drives investments and thereby depreciation (Iversen et al., 2018).

Cost of feed is the largest single cost component when producing salmon, making up 41.8% of total production cost per kg in 2018. Although cost of feed per kg has increased significantly, its proportion to total costs per kg has been reduced over the last couple of years. Cost of feed per kg consist of two components, namely the price of feed per kg and the feed consumption necessary to produce one kilogram of harvested salmon. This is

called the economic feed conversion ratio (EFCR).

The cost of feed can be split into several components. The mix of high-value and low-value feed used, cost inflation, currency effects and developments in commodity prices. According to Iversen et al. (2017), the largest impact on changes in cost of feed in the period between 2010 and 2016 has been currency movements. Further, change in mix toward high-value feed has had a limited negative impact on cost of feed, while cost inflation among feed producers is more than offset by positive movements in commodity prices. The EFCR has increased during the period, which is mainly related to increased loss from production as well as lower average harvest weights (Iversen et al., 2017).

Cost of labour has increased rapidly since 2012, outgrowing inflation. In fact, inflation only explains about 20% of the increase in cost of labour over this period. This indicates that the labour intensity has increased, which partially can be explained by the sea lice situation. Considerable amounts of labour is used to monitor the lice situation through frequent counting of sea lice etc., undertake preventive measures and provide treatments. Also, widespread use of hiring external suppliers to conduct labour intensive operations hides the real increase in labour costs. This because these costs are reported as other operating costs per kg (Iversen et al., 2018).

Other operating costs mainly consist of costs related to sea lice and hiring of external service providers used in different parts of the production process. These costs have more than doubled since 2012 and has been a result of the current biological situation.

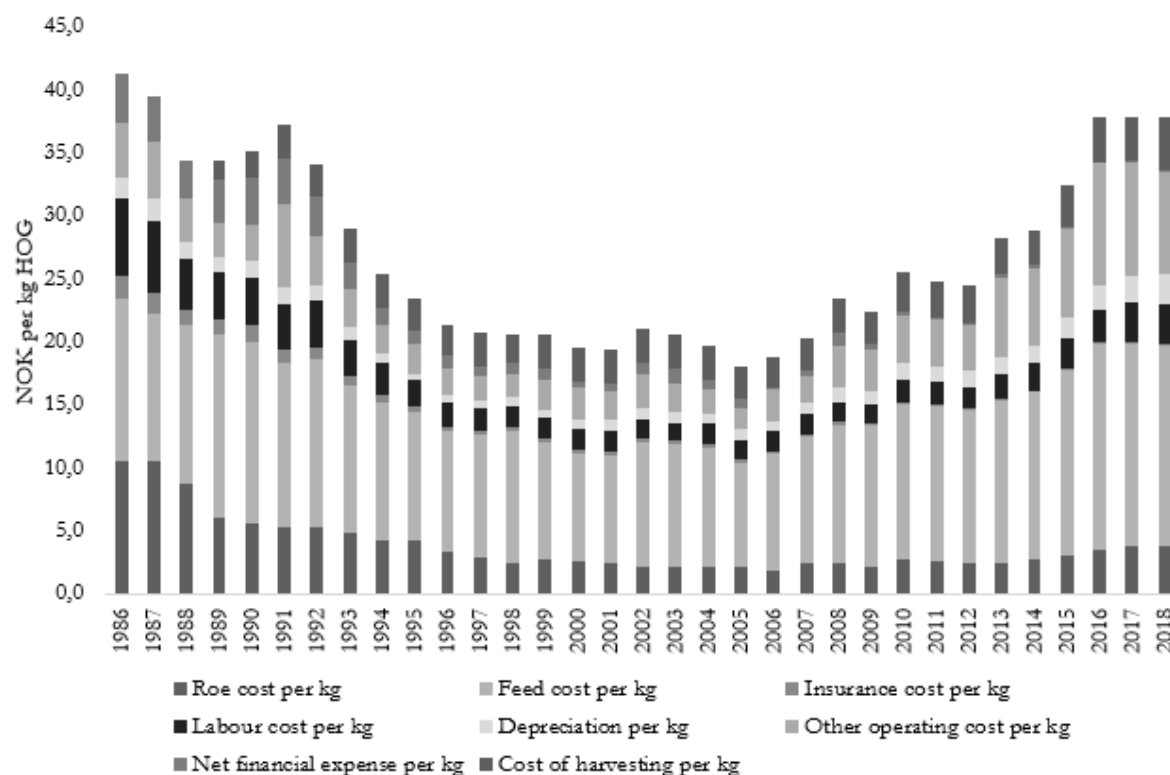


Figure 7.3: Historical average total operating cost per kg for Atlantic salmon produced in Norway, Source: Norwegian Directorate of Fisheries (2019c)

Over the last couple of years sea-based salmon farmers have experienced superprofits (Ulltveit-Moe et al., 2019). Under such profitable operating environment, companies respond by increasing their production. Previously unprofitable production will under these circumstances become profitable, and it will be profitable and desirable for companies to increase their production despite increasing their total cost per kg. This is because marginal revenue has increased to a new and higher level such that an increase in marginal cost may be profitable. Assuming perfect competition where salmon farmers are price takers, marginal revenue equals the price of Atlantic salmon. This effect is likely to have contributed to the increase in total production cost per kg witnessed from 2013.

7.2.2 Development of industry operating margins

The average industry operating margin have been solid and may have exceeded the industry weighted average cost of capital (WACC) in the majority of years during the last decade. Further, the average operating margin varied more in the period between 2008 and 2013. After 2013, the average operating margin have been somewhat more

stable at a high level. However, average operating margin increased considerably from 2015 to 2016 due to increased biological challenges and limited growth options. Thus, demand growth exceeded supply growth. Average operating margins has remained stable on a high level since 2016. In such a profitable environment, growth is desired by salmon farmers. Through the implementation of the traffic light system, growth becomes available semiannually given that certain criteria are met. The superprofit was reflected in the government auction for MAB in 2018.

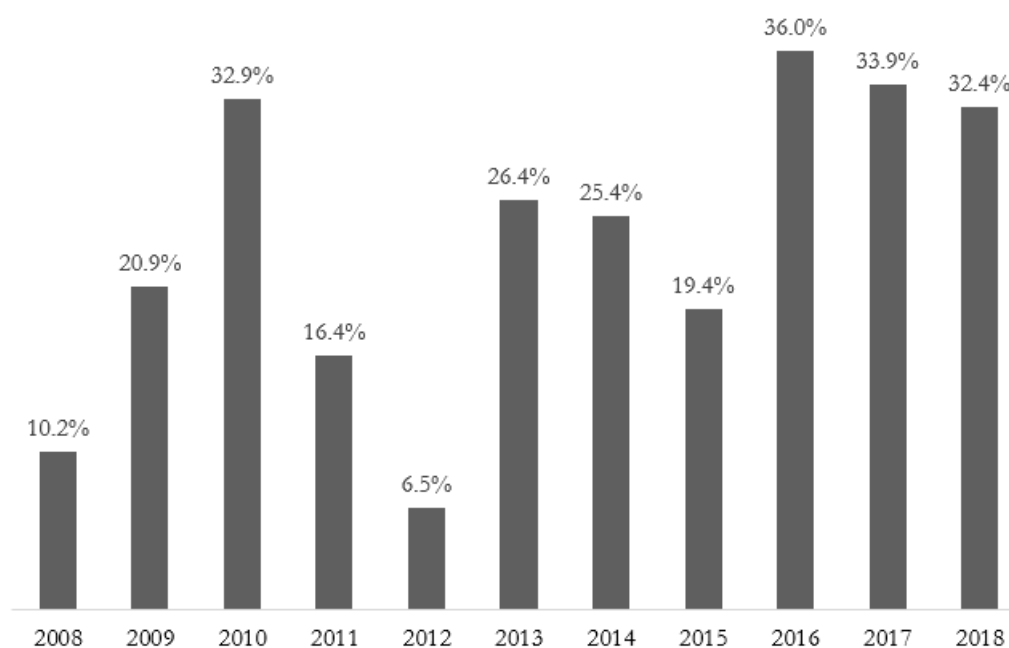


Figure 7.4: Average operating margin for sea-based salmon farmers in Norway 2008-2018, Source: Norwegian Directorate of Fisheries (2019c)

7.2.3 Development in MAB prices

There has been four licensing rounds for MAB in Norway after year 2000, with the latest in 2018. Pre 2002 licenses were free but had substantial regional policy considerations (Bjørndal and Asche, 2011). The licensing round in 2002/2003 was the first to charge a fixed consideration. The price of a license has increased in every of the following rounds, except for Finnmark. The price development is outlined in table 7.1. All rounds used a fixed price determined by the government until 2017 when auction were introduced with the traffic light system (Norwegian Ministry of Trade, Industry and Fisheries, 2018a).

Table 7.1: MAB prices from government licensing rounds in Norway (Finnmark), Source: Bjørndal and Asche (2011); Nofima (2014); Norwegian Directorate of Fisheries (2015)

Licensing round	Price per license NOK million	NOK/kg (live weight)
Pre 2002	Free	-
2002/2003	5 (4)	6.4
2009	8 (3)	10.3
2013 (<i>Green</i> licences)	10.7	13.7

A company is willing to bid equal to their marginal revenue when having imperfect information in first-price sealed-bid auctions (Klemperer, 1999). For conventional salmon farmers, this means that their maximum bid for MAB will be equal to their marginal revenue from the corresponding MAB. Their theoretical maximum bid will be that which equates marginal revenue and marginal cost in the long run, and therefore make net present value equal to zero. As a consequence, the regions and locations with highest marginal revenues associated with them, will fetch the highest bids.

However, net present value should theoretically be equal to zero for locations with low and high MAB price as the MAB will balance total capital expenditure and reflect different operating conditions. This is reflected in table 7.2, although only the averages for each production zone are presented. Further, as the MAB are allocated to the salmon farmers which have the highest marginal revenue from using it, and the government are the seller, society theoretically appropriates the entire marginal revenue associated with the production growth.

Table 7.2: MAB prices from government auction June 2018, Source: Norwegian Directorate of Fisheries (2019a)

Production zone	Average NOK/kg (live weight)	Implicit license price NOK million
1	132.0	103.0
2-6	-	-
7	214.7	167.4
8	249.5	194.6
9	230.3	179.6
10	164.6	128.4
11	162.3	126.6
12	165.0	128.7
13	153.5	119.7
Norway	186.5	145.5

In the June 2018 auction, the implicit price for a 780 tonne license using the Norwegian average price per tonne was equal to NOK 145.5 million. However, individual companies bid considerably higher. When using the highest price per tonne from the auction, the implicit price for a 780 tonne license equals NOK 194.6 million. The lowest price paid in the auction corresponds NOK 103.0 million per license.

In order to get comparable capital expenditure for land-based and sea-based facilities, we have to adjust MAB in capital expenditures. Firstly, MAB refers to live weight while capital expenditures per kg is normally stated in HOG. Secondly, we have to adjust for the fact that 1 unit of MAB gives approximately 2 units of output (Bjørndal et al., 2018). We have assumed that 1 unit of MAB gives 1.83 units of output in live weight to be conservative and better reflect the current sea-based production in Norway. When implementing these adjustments, the average capital expenditure per kg of output in HOG gives a comparable number to that used in land-based farming. The results of these adjustments for the June 2018 auction is outlined in table 7.3.

Table 7.3: MAB prices from government auction June 2018 (HOG), Source: Norwegian Directorate of Fisheries (2019a)

Production zone	Average NOK/kg MAB (HOG)	Average NOK/kg output (HOG)
1	157.1	85.9
2-6	-	-
7	255.6	139.7
8	297.0	162.3
9	274.2	149.8
10	196.0	107.1
11	193.2	105.6
12	196.4	107.3
13	182.7	99.8
Norway	222.0	121.3

Please note that capital expenditure per kg output in HOG is not a comparable number between land-based and sea-based production, as capital expenditure must be considered in relation to associated cash flow.

7.3 Assumptions for the modelled land-based facility

In the continuation of this section, we present all assumptions underlying our modelled land-based farming facility. We start off with the technical assumptions about the facility before discussing the appropriate capital structure.

Secondly, we explain the capital asset pricing model, our beta estimate and cost of equity calculation. Further, we explain the concept of WACC and our WACC estimate. We also explain the net present value method and how we estimate maximum implicit operational cost/kg.

Lastly, we explain the biological assumptions that forms the basis for a NPV base case and explain Monte Carlo simulation conducted on the base case.

7.3.1 Technical design

We model a RAS facility with a capacity of 10,000 tonnes live weight. We assume a facility that buys roe externally, but includes all remaining stages in the value chain until distribution. This capacity is chosen as it seems to be approximately the typical size of planned facilities in Norway. Our impression is that there is a trend towards larger facilities, trying to achieve scale economics. Further, there seems to be no research on the economic attractiveness of a 10,000 tonnes facility. For instance, Liu et al. (2016) used a capacity of 4,000 tonnes live weight, Bjørndal and Tusvik (2017) used a capacity of 5,000 tonnes live weight and Bjørndal et al. (2018) used a capacity of 6,000 tonnes live weight. Thus, we see a need for a new analysis using a capacity closer to the trend in the industry.

We have estimated total capital expenditures for the facility based on prices provided by Billund Aquaculture Service A/S (2017)¹. We base our estimate on the cost of a 5,000 tonnes facility, scaling it to 10,000 tonnes by doubling the cost of all facility components. This corresponds with the method used by Bjørndal et al. (2018). However, such approximation does not imply any economies of scale. We acknowledge this, but argue that our approach is conservative and robust. Further, prices from Billund Aquaculture Service A/S (2017) implies that the majority of benefits from economies of scale is achieved at 5,000 tonnes.

¹Prices converted using EUR = 10.16 NOK (Norges Bank, 2019b)

The estimate for cost of land as well as operating costs are based on estimates from Bjørndal et al. (2018). There are currently few robust analyses estimating the cost of production for land-based farming. Existing studies are based on engineering studies as currently, very limited volumes have been harvested. The estimates from Bjørndal et al. (2018) appears to be the most robust and up to date that currently exist.

Capital expenditures and economic lifetime for the different components are presented in table 7.4. All components are assumed to be depreciated linearly over their economic lifetime. Our estimate suggests that total capital expenditures is NOK 1,309.4 million, equal to capital expenditures per kg (HOG) of NOK 155.9.

Table 7.4: Capital expenditures for a 10,000 tonnes (live weight) land-based RAS facility, Source: Bjørndal et al. (2018); Billund Aquaculture Service A/S (2017)

Component	NOK million	Economic life
Land	45.0	∞
Buildings	347.9	20 years
Electrical installations	69.0	15 years
Other installations (Ventilation etc.)	48.4	15 years
RAS equipment	537.9	20 years
Concrete work (RAS and fish tanks)	237.6	20 years
Various	23.7	10 years
Total	1,309.4	
Capital expenditures/kg (HOG)	155.9	

Working capital requirement is estimated to NOK 166.1 million. This consist of all incurred costs from the facility start-up until the operations becomes self-sufficient with cash from sales.

7.3.2 Capital structure

The capital structure is assumed to consist of 89.0% equity and 11.0% debt. This is based on full equity financing of the investment of NOK 1,309.4 million, while the sum of working capital requirements from year 0 and year 1 of NOK 166.1 million is financed with debt. We argue that the high equity share of 100.0% on the investment is realistic and conservative as debt financing is currently only used as a very small fraction compared to market value of equity for similar projects. To compare, Atlantic Sapphire has 5.1% of debt compared to their market value of equity from November, 2019. Further, the director

for marine industries in DNB, Kristin Holth, stated in 2019 that land-based farming is in a early stage with high risk. Therefore it is normally equity financing that must take these projects to a certain level before debt financing becomes relevant (Knudsen, 2019a).

We assume that the project pay out all excess cash to shareholders in the form of dividends in line with weighted average cost of capital (WACC) assumptions regarding a constant debt-to-equity ratio. Some projects might be able to achieve some form of debt capital, either in the form of bonds or bank debt. In such a scenario, the cost of capital would theoretically be lower and the cost of equity higher. The overall effect would be a reduced cost capital as the interest tax shield obtained from increasing the debt share would more than make up for a higher cost of equity.

Liu et al. (2016) estimated the capital structure to consist of 40.0% equity and 60.0% debt in their NPV analysis. We argue that their choice of capital structure may not be realistic. Bjørndal and Tusvik (2017) modeled NPV before tax and thus argued that the NPV is independent from the choice of capital structure. This is based on the propositions by Modigliani-Miller for perfect capital markets. We argue that this is a simplistic and unrealistic way of modelling the profitability as taxes represent a true cost for salmon farmers and as the choice of capital structure matters. This is especially true for land-based salmon projects where there seems to be limited debt financing available.

7.4 Comparison of capital expenditures

7.4.1 Land-based facilities

In this section we present our estimate of capital expenditures required for the project, and compare this to other Norwegian land-based projects. We also compare the required capital expenditure to that of a corresponding sea-based facility.

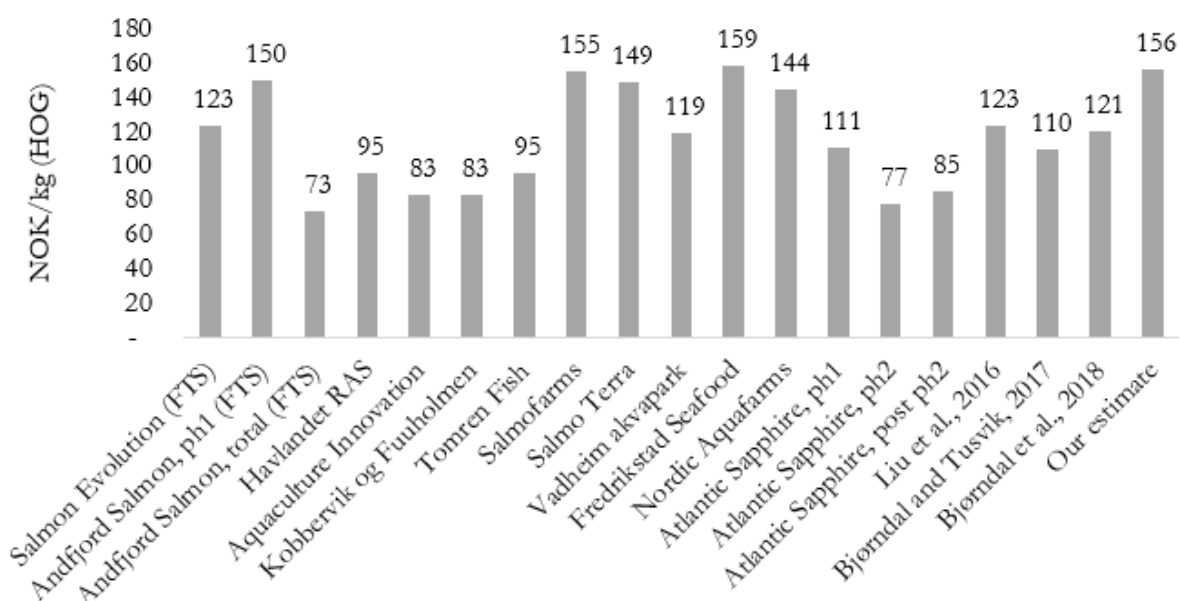


Figure 7.5: Capital expenditures per kg (HOG) of planned facilities in Norway, Atlantic Sapphire and previous studies, Sources: ilaks (2019f,a); Andfjord Salmon (2019); Kyst (2018, 2017a); ilaks (2019b); Kyst (2017b); ilaks (2019e,d, 2018a,b, 2016); Tekfisk (2019); Atlantic Sapphire (2019b); Liu et al. (2016); Bjørndal and Tusvik (2017); Bjørndal et al. (2018)

Figure 7.5 outlines capital expenditures per kg for all planned Norwegian land-based facilities with available information, as well as for Atlantic Sapphire² and previous studies. There seems to be considerable variations in capital expenditures per kg between the projects, with some at twice the level of others. Although economies of scale may be important, we find large projects (capacity over 20,000 tonnes) in both ends of the scale. Nordic Aquafarms has an estimated capital expenditure per kg of NOK 144.0, while Atlantic Sapphire is estimated to NOK 85.0 when fully developed.

Although scale may explain some of the variations, key design elements such as the ratio between the number of RAS and number of fish tanks will have a large impact on capital expenditure per kg (Atlantic Sapphire, 2019a). This is a choice made in the design phase and determines the biosecurity of the plant.

Multiple RAS systems increase capital expenditure per kg, while offering better biosecurity, as a smaller part of production is affected in case of operational problems like occurrence of H₂S. Contrary, a lower RAS density lowers capital expenditures per kg while increasing the risk of operational problems. The variation in capital expenditure per kg may reveal

²Capital expenditure converted using USD = 9.2 NOK (Norges Bank, 2019c)

differences in operational risk as well as scale.

Two FTS facilities are included in the figure. However, there seems to be insignificant differences in capital expenditures per kg when comparing them with RAS facilities. Salmon Evolution has an estimated capital expenditure per kg of NOK 123.0 while Andfjord Salmon has 73.0 when fully developed. This is on comparable levels with RAS facilities.

Our facility has estimated capital expenditures per kg (HOG) of NOK 155.9. This is well above both Liu et al. (2016), Bjørndal and Tusvik (2017) and Bjørndal et al. (2018). Note that Bjørndal et al. (2018) understates capital expenditures per kg as they used estimated capital expenditures for a 5,000 tonnes facility, however without scaling it to 6,000 tonnes which was the modelled capacity used throughout the study. Further, our estimate is in line with the most expensive projects disclosed. However, the disclosed capital expenditures for these projects are likely to be positively biased. This because these estimates are based on news articles for projects which typically lacks financing. We believe the news articles are part of marketing the projects in order to attract capital. This reduce the robustness of the numbers. Nevertheless, these are the best estimates currently available and serves to give an industry overview rather than precise numbers.

7.4.2 Comparing a land-based and sea-based facility

In order to compare total capital expenditure associated with a 10,000 tonnes RAS facility with a Norwegian sea-based facility, we have to estimate required capital expenditures for the latter. We assume a production capacity of 10,000 tonnes live weight using 7 licenses which equals 5,460 tonnes of MAB in total. As such, we assume that one unit of MAB produce 1.83 units of salmon in live weight. For the MAB we use both average and high estimates from the June 2018 auction in order to provide capital expenditure per kg estimates, however we place most weight on the Norwegian average price. This equals a license price of NOK 145.5 million and NOK 194.6 million respectively, and this differs considerably from that assumed by Liu et al. (2016) and Bjørndal et al. (2018). The different assumptions on MAB prices is presented in table 7.5.

Table 7.5: Assumed price per MAB license, Source: Liu et al. (2016) and Bjørndal et al. (2018)

Study	NOK million
Liu et al. (2016)	55.0
Bjørndal et al. (2018)	93.6
Our study	145.6

We assume the production to be split in two locations. This is based upon assumptions on locality MAB and that a large location according to Iversen et al. (2018) consist of seven licenses. We have estimated necessary equipment for the facility based on Bjørndal et al. (2018). The number of net pens are estimated using the volume of a net pen with a diameter of 130.0 meter, equal to 25,000 m³ and the density limit of 25.0 kg/m³ (Bjørndal et al., 2018). This results in a production per net pen of 625.0 tonne per cycle. However, due to two months fallowing we estimate a total production cycle in sea of 14 months. When adjusting for this, rounding to closest even number and add two net pens per locality as production buffer, we end up with 24 net pens for the sea-based facility. A more detailed overview of the components and prices assumed for the sea-based facility is presented in table 7.6 and 7.7. Please note that licences have an infinite life time and are therefore not subject to depreciation.

Table 7.6: Capital expenditures for a 10,000 tonnes sea-based facility using two locations and average MAB-price, Source: Bjørndal et al. (2018); Norwegian Directorate of Fisheries (2019a)

Component	Units	Unit price NOKm	Sum NOKm
Floating rings (incl. moorings)	24	1.375	33.0
Nets	24	0.300	7.2
Light, camera and feed systems	24	0.158	3.8
Feed barges	2	20.000	40.0
Small boat	2	0.450	0.9
Large boat	1	3.000	3.0
Office building	1	15.000	15.0
Land and quay	1	20.000	20.0
Electricity (shore power)	1	20.000	20.0
Licences, average June 2018	7	145.461	1,018.2
Total			1,161.1
Capital expenditures/kg (HOG)			138.2

When comparing total capital expenditure per kg from table 7.6 and 7.7, the effect of

different MAB assumptions becomes clear. Despite the fact that capital expenditure per kg is estimated to NOK 138.2 and NOK 179.2 when using average and high MAB prices respectively, both these farms should theoretically have net present value equal to zero all else equal.

Both facilities have capital expenditure per kg in a comparable range to that of a land-based facility. Thus, it takes significant amounts of capital to establish a sea-based farming facility in Norway as licences must be included. Note that licences makes up between 87.7% and 90.5% of total capital expenditure in our estimates, which makes capital expenditures for sea-based facilities sensitive to changes in MAB prices. Of the two estimates, the one using average MAB price from 2018 has a slightly lower capital expenditure kg compared to the modelled land-based facility, however the one using high MAB price exceeds the modelled land-based facility.

Table 7.7: Capital expenditures for a 10,000 tonnes sea-based facility using two locations and high MAB-price, Source: Bjørndal et al. (2018); Norwegian Directorate of Fisheries (2019a)

Component	Units	Unit price NOKm	Sum NOKm
Floating rings (incl. moorings)	24	1.375	33.0
Nets	24	0.300	7.2
Light, camera and feed systems	24	0.158	3.8
Feed barges	2	20.000	40.0
Small boat	2	0.450	0.9
Large boat	1	3.000	3.0
Office building	1	15.000	15.0
Land and quay	1	20.000	20.0
Electricity (shore power)	1	20.000	20.0
Licences, high June 2018	7	194.610	1,362.3
Total			1,505.2
Capital expenditures/kg (HOG)			179.2

In table 7.8 we present a comparison of capital expenditure for our modelled land-based facility and our estimate for a sea-based facility using average MAB price from 2018.

Table 7.8: Comparison of capital expenditures for a 10.000 tonnes land-based RAS facility and sea-based facility. Capital expenditures per kg in HOG, Source: Bjørndal et al. (2018); Norwegian Directorate of Fisheries (2019a)

Land-based	NOK million	Sea-based	NOK million
Land	45.0	Floating rings	33.0
Buildings	347.9	Nets	7.2
Electrical installations	69.0	Technical systems	3.8
Other installations	48.4	Feed barges	40.0
RAS equipment	537.9	Small boat	0.9
Concrete work	237.6	Large boat	3.0
Various	23.7	Office building	15.0
Total	1,309.4	Land and quay	20.0
Capital expenditures/kg	155.9	Electricity	20.0
		Licences	1,018.2
		Total	1,161.1
		Capital expenditures/kg	138.2

7.5 Capital asset pricing model

The capital asset pricing model (CAPM) is recognized to be one of the most efficient method for pricing risky assets in practice (Berk and DeMarzo, 2014). The focus of this chapter will be on the explanation, assumptions and insight the model provides rather than on the technicality of the model. The concept of CAPM provides a methodical framework on how to estimate the risk premium for risky assets over less risky ones. This estimate is a measure of how sensitive the asset is in relation to that of the market factor, known as β .

CAPM established the concept of systematic, which is non-diversifiable, and investors are compensated for bearing. The model do not compensate for firm-specific risk as such risk can be diversified. In the equation 7.1, the CAPM formula is shown while equation 7.2 shows the formula for calculation of β .

$$E[r_i] = E[r_f] + \beta_i \times (E[r_m] - E[r_f]) \quad (7.1)$$

$$\beta_i = \rho_{i,m} \times \frac{\sigma_i}{\sigma_m} \quad (7.2)$$

$E[r_i]$ = expected return on asset i

$E[r_f]$ = risk free rate

β_i = market sensitivity between asset i and the market factor

$\rho_{i,m}$ = correlation between asset i and market factor

σ_i = standard deviation of asset i

σ_m = standard deviation of market factor

The second part of equation 7.1 represents the market risk premium. The market risk premium captures the difference between the expected return of the market portfolio and the risk-free rate. In general, it represents the collective premium required by investors to hold market portfolio risk. The riskiness of an investment is determined by how sensitive it is to changes in the market portfolio, estimated by β in equation 7.2. An investment with higher systematic risk compared to the market require a higher premium as changes in the market portfolio change the value of the asset relatively more.

CAPM is based on three main assumptions, 1) investors can buy and sell securities in perfect capital markets with no taxes, 2) investors hold only efficient portfolios - yielding the maximum expected return for a given level of volatility and 3) it assumes investors have homogeneous expectations about expected returns, volatility and correlation between investments. The CAPM model has received criticism for being based on too strong assumptions (Berk and DeMarzo, 2014). However, economists find the qualitative intuition underlying the CAPM compelling (Berk and DeMarzo, 2014).

7.5.1 Beta estimate

The industry for land-based farming of Atlantic salmon is currently undeveloped and includes only one listed company, Atlantic Sapphire, with planned operations in Miami and Denmark. The US facility plans to harvest 23,000 tonnes (HOG) annually from 2023, scaling up to 90,000 tonnes from 2026. However, it has yet to harvest any significant volume. (Atlantic Sapphire, 2019a).

To find an appropriate beta for our modelled facility, we use the concept of unlevered beta. This a measure of the beta of a security without the impact of debt. We estimate

levered beta using public data from Atlantic Sapphire, and adjust for its capital structure. Companies with similar assets should have a similar unlevered beta and this can be used to re-lever a project with an appropriate capital structure.

Our facility will have operations in Norway, but we argue that the difference in location from Atlantic Sapphire is of little importance due the similarities of assets. Further, we notice that the assets that Atlantic Sapphire reports in their half year report from June 2019 is mostly property, plant equipment (PP&E), while currently only 4% is in the form of biological assets (Atlantic Sapphire, 2019c). However, the value of the biological assets has more than doubled compared to December, 2018 (Atlantic Sapphire, 2018). As most of asset values currently consist of PP&E, it could suggest that the assets Atlantic Sapphire hold has other characteristics compared to that of a land-based company with scaled up operations. As such, the β estimate could yield a weak approximation since operations has not been scaled up. Even so, we argue that the method currently is a best estimate to obtain a calculated β for the industry.

Further, we argue that this method will be more robust in the future, when more public data is available and as companies have scaled up operations. As the measure represents great uncertainty of the true unlevered beta we will conduct a sensitivity analysis later in the thesis. This to show how sensitive the value of the project is to changes in the β estimate.

We estimate the equity beta by regressing one month of simple daily returns of Atlantic Sapphire against the Oslo Stock Exchange Benchmark index (OSEBX) from November 11 2019 resulting in a equity beta of 1.21. We use one month of data as longer periods gave results that seemed to not fully reflect the risk involved. The one year equity beta was 0.0, 0.4 and 0.0 against OSEAX, OSEBX and SP 500, respectively. Further, the three month equity beta was 0.1, 0.5 and -0.21 respectively.

We believe, the low estimates are mainly due the shares of Atlantic Sapphire has been illiquid during the period. Several periods had no daily stock movements. As such, the trade may not have fully reflected the risk in relation to the market. We argue that this should not be the case as we believe there exist a higher uncertainty in both operations and the technology of land-based farming compared to that of the overall market.

We justify a short time period for the equity beta estimate by arguing that Atlantic Sapphire has had very little biological assets in its balance sheet a year ago, and therefore more recent returns represents a more accurate estimate of movements representative for the industry. Further, the equity beta estimate has not included returns from days where Atlantic Sapphire stock price did not move. This is called a trade-to-trade method which is used to measure equity beta for stocks with low liquidity (Serra and Goulart, 2013). Note that the equity beta estimate is very sensitive to the inclusion of more data as the time frame used is short. This is a general weakness of our estimate.

The US corporate tax rate is currently 21% (Tax policy center, 2019). In contrast, the Norwegian corporate tax rate is currently 22% (Government of Norway, 2019). Equation 7.3 and 7.4 display the formula we use to estimate unlevered- and re-levered β , respectively. In table 7.9, we show the summarized data in order to obtain the estimate for equity β used in our model.

$$\beta_U = \frac{\beta_L}{(1 + (1 - \tau_c) \times \frac{D}{E})} \quad (7.3)$$

$$\beta_L = \beta_U \times (1 + (1 - \tau_c) \times \frac{D}{E}) \quad (7.4)$$

$\beta_{U/L} = \beta$ unlevered and re-levered, respectively

D = debt, E = equity and τ_c = corporate tax rate

Table 7.9: Beta estimate of modelled land-based project

Equity β for Atlantic Sapphire	1.21
Debt-to-equity ratio Atlantic Sapphire	5.1%
US corporate tax rate	21%
Unlevered β	1.16
Debt-to-equity ratio for this project	12.7%
Norwegian corporate tax rate	22%
Re-levered equity beta	1.28

7.5.2 CAPM estimate

The estimate for the risk-free rate is based on the yield of a 10-year Norwegian government bond as of November 22, 2019 (Norges Bank, 2019a). Further, the equity risk premium

in Norway is based on estimates obtained from Aswath Damodaran (2019), professor in finance at Stern School of Business, NYU. In table 7.10 we display the inputs we have used in order to obtain the cost of equity.

Table 7.10: Cost of equity estimate

Risk-free rate	1.4%
Equity risk premium	6.0%
Beta	1.28
CAPM	7.3%

7.6 Weighted average cost of capital

The cost of capital is the expected rate of return the market requires in order to attract funds to a specific investment (Pratt, 2002). When we discount net cash flows to all invested capital, both debt and equity, the WACC is the appropriate discount rate. The WACC is the weighted average between the cost to finance an investment with equity and debt (Pratt, 2002). In general, WACC is a function of the risk-free rate plus a premium for the risk associated with the investment.

The WACC is used to estimate cash flows after entity-level taxes, thus dealing with imperfect capital markets. Therefore, the WACC is often referred to by literature as the after-tax WACC. Taxes are a cash expense to the company and the return to equity holders are after-tax. Tax results in a benefit of the interest tax deduction that arise from using debt, and can be captured by using the after-tax WACC (Berk and DeMarzo, 2014). The WACC formula is shown in the equation below.

$$WACC = \left(\frac{E}{E + D}\right) \times r_e + \left(\frac{D}{E + D}\right) \times r_d \times (1 - \tau) \quad (7.5)$$

WACC = weighted average cost of capital

E = market value of equity

D = market value of debt

r_e = cost of equity

r_d = cost of debt

τ = corporate tax rate

7.6.1 WACC estimate

We use a cost of debt of 6.5%. This based on a NIBOR one week interest rate of 1.5% Oslo Børs (2019) plus a 5.0% debt risk premium. In comparison, Atlantic Sapphire secured a credit facility with DNB of LIBOR + 6.0% Atlantic Sapphire (2019a). However, Liu et al. (2016) used a total cost of debt of 6.0%. We have chosen debt premium to 5.0%, which makes our total cost of debt between the two. The reasoning behind this is that our modelled facility have a significantly higher capital expenditure per kg than Atlantic Sapphire, closer to that of Liu et al. (2016). This suggest a higher degree of biosecurity of our operation, following a lower risk for our creditors. Nevertheless, we will conduct sensitivity analysis on the WACC to show how a higher WACC will impact our result.

Further, we assume inflation rate at 2.0% equal to long-term target of Norges Bank (2018). We have calculated a nominal and real WACC. We estimate our cash flow in real terms and therefore we discount cash flows by the real WACC. Bjørndal and Tusvik used the same method in their NPV analysis from 2017, however they used an inflation rate of 2.9% and thus arrived at a cost of capital of 4.0%. We argue that the long-term inflation rate should be in line with guidelines from Norges Bank, and therefore the rate of 2.0% is used. In table 7.11, we show the summarized data underlying our WACC estimate.

Table 7.11: WACC for land-based project

Debt	NOK 166.1 m
Equity	NOK 1.3 bn
Cost of equity	7.3%
Cost of debt	6.5%
Corporate tax rate	22.0%
WACC _n	7.0%
Long-term inflation rate	2.0%
WACC _r	5.0%

7.7 Net present value

The concept of NPV is considered to be one of the most fundamental rules within financial decision making (Berk and DeMarzo, 2014). The concept recognizes that the value of

money today is different from the value tomorrow, and it allows projects to be valued in terms of cash today.

Consider an investor with accessible capital. The investor can either consume goods and services now or delay it. The option to delay implies that the investor will miss out on the utility received from consuming the goods now. Therefore, the investor should require compensation for investing the capital.

If the option to invest the capital is considered, the investor determines an appropriate investment based on the preference between risk and return. The field of asset pricing and NPV decision making presents a methodical framework on how specific assets should be priced.

In equation 7.6, the fundamental theorem of asset pricing is shown. It states that the value of any asset is equal to the sum of expected cash flows, discounted to its NPV using an appropriate cost of capital. In this case we use WACC as the cost of capital.

$$P_0 = \sum_{t=1}^{\infty} \frac{E(CF_t)}{(1 + WACC)^t} \quad (7.6)$$

In the following section we present two methods in order to evaluate under which circumstances land-based salmon farming is economically attractive. First we explain how we calculate the implicit maximum total cost per kg for a 10,000 tonnes land based salmon farming facility. Second, we describe how we estimate the revenue and cost components that create a NPV base case, which later is subject to a Monte Carlo simulation. Note that we calculate value of equity in our models. This is defined as the NPV of the project less net debt.

7.7.1 Implicit maximum total cost per kg

In finding the implicit maximum total cost per kg in order to find under which circumstances land-based salmon farming is economically attractive we start by modelling this for a 10,000 tonnes land based salmon farming facility. We model three different price scenarios over two different project life times, as illustrated in table 7.12. The first being a 20-year lifetime project, and the second is an infinite lifetime with re-investments that follows the depreciation plan for the first 100 years. The infinite scenario estimate a

terminal value from year 20 by calculating the expected cash flow in year 20 divided by nominal cost of capital less assumed growth of 2%. This value is then discounted back to its present value. The facilities are assumed to be operational throughout the whole of the modelled periods, without production interruptions. For all scenarios cost of capital, capital structure and production is held at constant levels. We solve for the maximum total cost per kg which yields a value of equity of zero.

Table 7.12: Estimates for price per kg (HOG) in NOK for different scenarios

	Scenario 1		Scenario 2		Scenario 3	
	Entire period	Year 0-7	Year 8-14	Year 15-	Entire period	
20-year lifetime	59.0	59.0	50.0	45.0		64.9
Infinite lifetime	59.0	59.0	50.0	45.0		64.9

In the equation 7.7, we show a simplification of the model used to back out the maximum total cost per kg. In the actual estimate we also take into consideration the depreciation tax-shield, net working capital requirements and capital expenditures.

$$0 = \sum_{t=1}^{\infty} \frac{E(\text{revenue}_t - \text{cost}_t)}{(1 + WACC)^t} \quad (7.7)$$

In table 7.13, we illustrate the different cost components that the implicit maximum total cost per kg must cover. The components of other operating cost is explained in more detail in a separate section below. The cost of harvesting has been excluded in the estimates of Bjørndal and Tusvik (2017) and Bjørndal et al. (2018), as they have looked at the farm gate cost of production. We argue that cost of harvesting should be included as it represents a cost producers must consider and therefore should be accounted for.

Table 7.13: Cost components the implicit maximum total cost per kg must cover

Cost of roe
Cost of feed
Vaccine cost
Cost of Labour
Management cost
Other operating cost
Depreciation
Net financial expense
Cost of harvesting

7.7.2 Base case NPV model

The second method used to assess the economic attractiveness of land-based salmon farming is a NPV model where we specify all revenue and cost components, and later capture the uncertainty in these components by using Monte Carlo simulation. In this method we use price scenario 1 from table 7.12 and a 20 year life time. This is our base case for the modelled facility.

In our base case NPV model, we estimate the value to equity from investing in a land-based RAS facility capable of producing 10,000 tonnes annually. The base case use a live-weight price of NOK 49.6 per kg (NOK 59.0 per kg HOG) for the entire period. Costs estimates are too a large extent based on the report by Bjørndal et al. (2018), while the method to model value of equity of a land-based facility is based on the report by Bjørndal and Tusvik (2017). The report from 2017 estimated the NPV from a facility capable of producing 5,000 tonnes annually, as such we have assumed no economies of scale for the different cost components. Our model thereby provide more up-to-date estimates on total cost pr kg, in addition it captures uncertainty by using Monte Carlo simulation which is further elaborated on in its own section.

In addition, our model also includes tax and thereby incorporates the depreciation tax shield that arises from investing in a land-based project. Further, we believe our discussion regarding an appropriate capital structure, cost of capital and assumption regarding the long-term inflation rate represents a more conservative and robust presentation. Furthermore, we add the cost of harvesting as we argue that this gives a more accurate presentation of the full cost associated with production of land-based salmon. Lastly, we remove the insurance cost element as we argue that this is not a production cost in itself, but an element that can be included if decision makers seek to reduce the risk exposure of the project.

We start building our model by explaining the biological assumptions which sets the foundation for the variable cost components. Thereafter, we explain how each cost component is calculated. We also explain the working capital requirement that arises from investing in the project as it takes 18-19 months before the salmon reaches harvest weight.

7.7.2.1 Biological assumptions

The development of Atlantic Salmon from roe to harvest size of approximately 4.6 kg is assumed to take 18.5 months. The assumed growth from roe to 92 grams is shown in table 7.14. According to Bjørndal and Tusvik (2017), the industry has much experience with land-based production of smolt up to this size, suggesting that these growth numbers should be robust.

Table 7.14: Growth from roe to 92 grams

Beginning of month	Weight per fish (gram)
0	0.2
1	0.8
2	3.1
3	8.0
4	24.0
5	50.0
6	92.0

In the period following month six, we use a thermal growth coefficient (TGC) of 2.7, assuming a water temperature of 12 degrees in order to estimate growth until harvest. The TGC is predictor the expected mean growth of Atlantic salmon (see appendix). We use a similar TGC as Bjørndal and Tusvik (2017). The most important factor for determining growth of Atlantic salmon is water temperature (Bjørndal and Tusvik, 2017). As water temperature is an exogenous factor in sea-based farming, it is reasonable to assume that growth can be higher in land-based facilities as the water temperature can be optimized. This is not reflected in our growth estimate, as we have found no information on this effect. However, growth could be higher compared to our estimate, and our estimate is conservative.

Figure 7.6 show the estimated development in grams for Atlantic salmon from roe to harvest weight. We estimate that 50% of the total volume in tonnes is harvested in month 18, where each salmon weigh approximately 4.2 kg, while the remaining 50% grow one additional month before being harvested at approximately 5.2 kg. This gives us an average harvest weight per fish of 4.6 kg. In the following we will give a detailed presentation of each cost component.

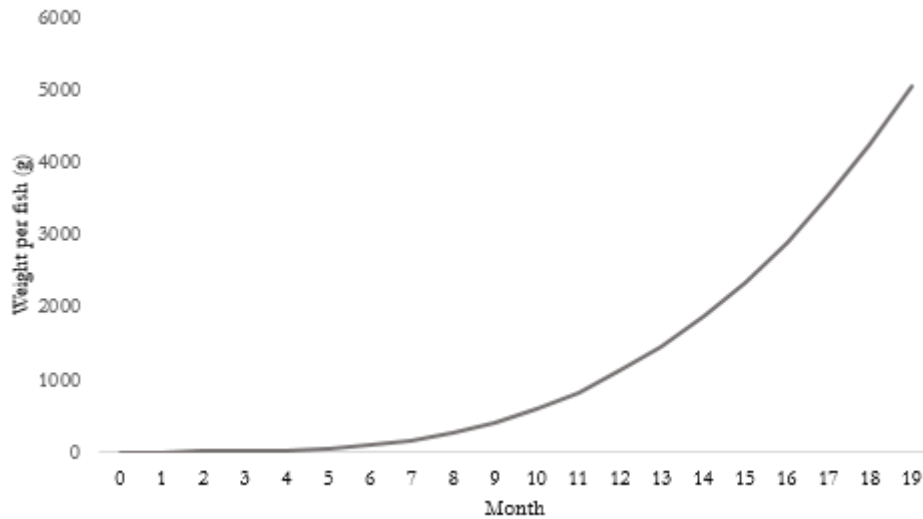


Figure 7.6: Weight development per fish (g)

7.7.2.2 Roe

We assume that 227,000 roe must be bought every month in order to produce 10,000 tonnes salmon annually. This corresponds to 2.7 million roe per year. The unit cost per roe is set to NOK 1.5, corresponding to an annual cost of NOK 4.1 million. According to Bjørndal et al. (2018), the cost of roe is within the range of NOK 1-1.5 per unit depending on the genetics of the roe. Our estimate is in the upper range indicating that the roe should be of high quality. Further, we assume that the mortality rate is 10% from delivery until the smolt has reached 0.2 grams. In the following month, we assume a 4% mortality rate before the monthly mortality rate normalize at 0.5% until harvest. The mortality rate estimate is based on Bjørndal and Tuvik (2017). In figure 7.7 we show the development in number of Atlantic salmon from one generation of roe.

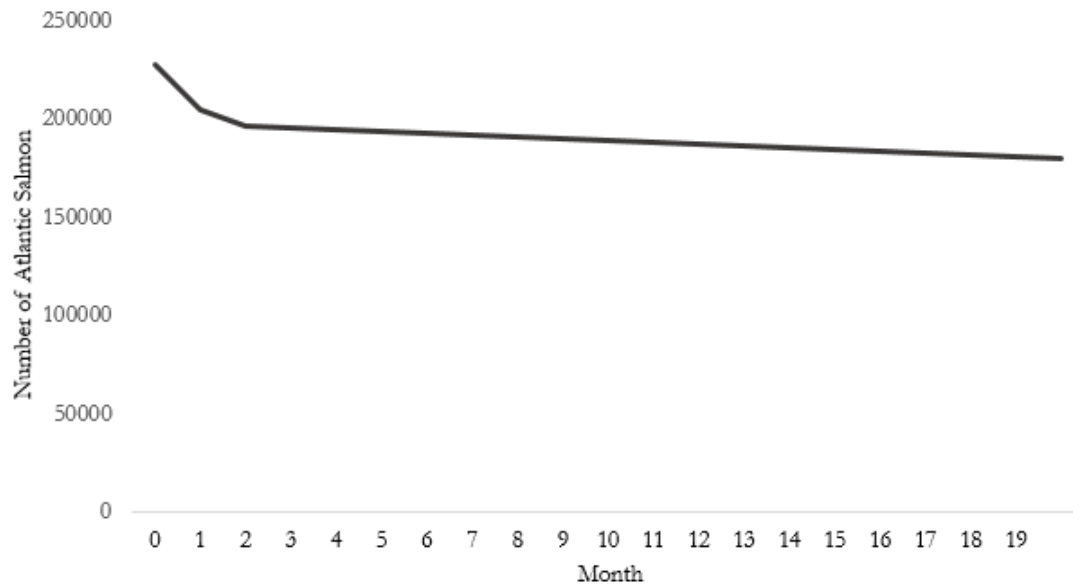


Figure 7.7: Number of Atlantic Salmon per generation of roe

7.7.2.3 Feed

The cost of feed is the largest operating cost associated with salmon farming for both land and sea. The component is a function of the total growth in biomass per month multiplied with the biological feed conversion ratio (BFCR). The BFCR is a measure of the mass of input divided by the mass of output. In this case it measures the amount of feed needed to grow the salmon by 1.0 kg. The BFCR is different from the EFCR as it does not take into account feed waste and mortality. We assume a BFCR of 0.9 for the first 12 months and 1.15 for the remaining 6-7 months. This is based on assumptions from Bjørndal et al. (2018). We estimate total annual feed quantity of 11,157 tonnes in full scale operations and a price of NOK 14.0 per kg.

The feed cost increase for the first two years as production increase. From year two, we get a steady state feed cost as the total biomass is expected to remain constant. This is illustrated in figure 7.8, showing the development in total biomass for the first seven generations of salmon. We have not included total biomass from generation eight and beyond, as the figure is only a illustration. We estimate total feed cost at NOK 38.8 million, NOK 101.0 million and NOK 156.2 million in year 0, year 1 and from steady state (year 2) for the remaining lifetime of the project, respectively.

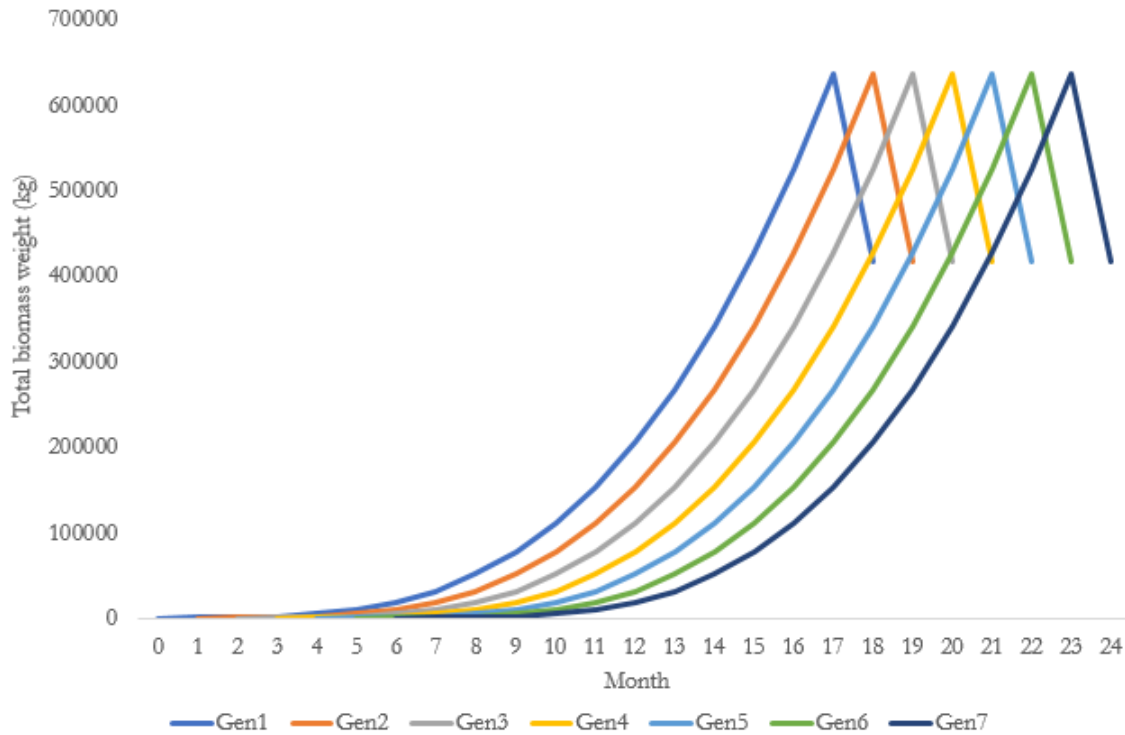


Figure 7.8: Development in total biomass for the first seven generations

7.7.2.4 Vaccination

We assume monthly vaccination of the smolt when weighing approximately 92.0 grams. After mortality, this suggests vaccination of 191,800 smolt monthly. According to Bjørndal et al. (2018), the cost per vaccine is NOK 1.8. This results in an estimated vaccine cost of NOK 4.1 million annually in steady state. The cost is estimated to be NOK 1.6 million in year 0 before reaching NOK 4.1 million in year 1 based on ramp up from Bjørndal and Tusvik (2017).

7.7.2.5 Labour

We assume that 32 workers are needed to operate the facility. This is a scaled up estimate from the 16 workers estimated to operate the 5,000 tonnes facility from the Bjørndal and Tusvik (2017) report. The total annual cost for the firm per worker is estimated at NOK 665,000. The total cost of labour is estimated to be NOK 21.2 million annually.

Further, we have assumed that the facility needs five managers with a salary of NOK 975,000 per manager. This results in a total annual management cost of NOK 4.9 million.

7.7.2.6 Insurance

We argue that the cost of insurance is a optional for the decision maker. It is a consideration based on the probability of loss multiplied by the expected loss held up against against the cost of insurance. As such, it should not be included as an operating cost, rather the operational risk should be accounted for in the cost of capital. By being included as a cost component in the cash flow analysis, it may be accounted for twice. As such, it is assumes, that the cost of capital will reflect the risk associated with the modeled project.

7.7.2.7 Other operating costs

Figure 7.9 show the components included in other operating costs and their respective size in NOK million. Total other operating costs are assumed to be NOK 117.8 million annually. The cost is based on calculations from Bjørndal et al. (2018).

Electricity is the largest component representing NOK 48.0 million. The price per kWh including network rental and electricity fee is estimated to be NOK 0.8. Further, we assume that 6 kWh is needed per kg of production.

Oxygen is expected to be NOK 26.1 million when assuming a price of NOK 2.6 per kg, and consumption of 0.9 kg oxygen per kg of feed. Oxygen tank rental is expected to have an annual cost of NOK 0.3 million.

Sludge and wastewater are estimated to NOK 13.4 million, and are based on 1.5 tonnes of wastewater per kg of feed equal to 16,700 tonnes annually. The cost per tonne of waste water is assumed to be NOK 800.0.

Service, maintenance and repairs, office and administration and other annual operating costs represents NOK 7.0 million, NOK 3.0 million and NOK 20.0 million, respectively. Other operating cost is expected to be 30.0% of full operating cost in year 0 and 60.0% in year 1, before reaching steady state cost from year 2.

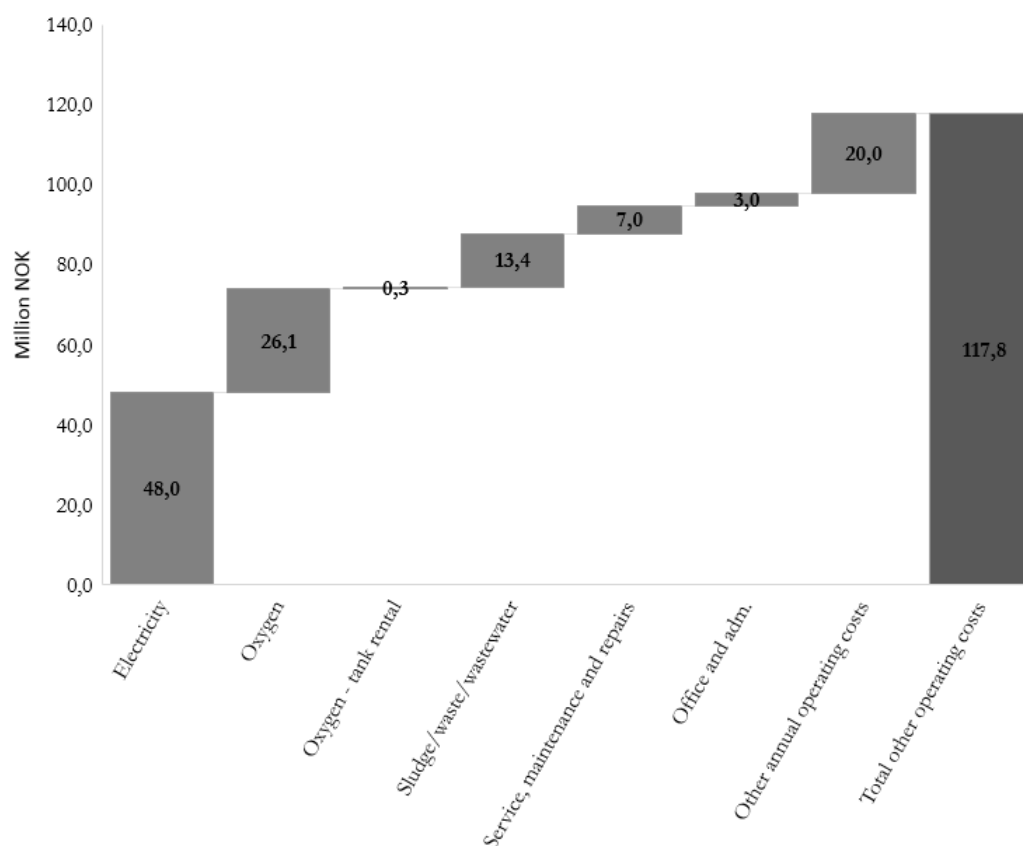


Figure 7.9: Breakdown of other operating costs in NOK million

7.7.2.8 Depreciation

Annual depreciation is assumed to be NOK 66.4 million based on the total investments divided by the lifetime of each asset, using linear depreciation. All investment components experience depreciation except the land area. The land area is expected to be sold of for the same amount as the initial cost in real terms, this is accounted for in year 20 in the cash flow analysis.

7.7.2.9 Net financial expense

The annual net financial expense is the working capital requirement multiplied by the cost of debt at 6.5%. This represent an annual amount of NOK 10.8 million. Since the capital structure is assumed to stay constant, this represents an annual cash outflow through out the project lifetime.

7.7.2.10 Cost of harvesting

The cost of harvesting is expected to be NOK 3.6 per kg live weight corresponding to NOK 4.2 per kg in HOG. We have used the similar cost of harvesting per kg as reported by the Norwegian Directorate of Fisheries for the average in Norway. The cost in year 1 is estimated to be 33.3% of harvest cost in steady state. Harvest is expected to start in month 20, resulting in four months of harvest in year 1 with a harvest cost of NOK 11.8 million. In steady state, the cost of harvest is expected to be NOK 35.5 million annually.

7.7.2.11 Total costs

In table 7.15, we summarize the total cost estimated and cost per kg (HOG). Figure 7.10 show the cost per kg (HOG) for all the different cost components in steady state. Our total production cost is estimated to be NOK 50.1 per kg (HOG), corresponding to NOK 42.1 per kg live weight.

Table 7.15: Total cost in NOK million and total production cost per kg (HOG) for year 0, 1 and steady state

	Year 0	Year 1	Steady state
Cost of Roe	4.1	4.1	4.1
Cost of Feed	3.9	101.0	156.2
Cost of Labour	8.0	16.0	21.3
Management cost	2.9	4.9	4.9
Vaccine cost	1.16	4.1	4.1
Other operating cost	36.4	72.8	117.8
Net financial expense	10.8	10.8	10.8
Cost of harvesting	-	8.9	35.5
Depreciation	66.4	66.4	66.4
Total cost	133.7	288.8	421.0
Cost per kg (HOG)	-	103.1	50.1

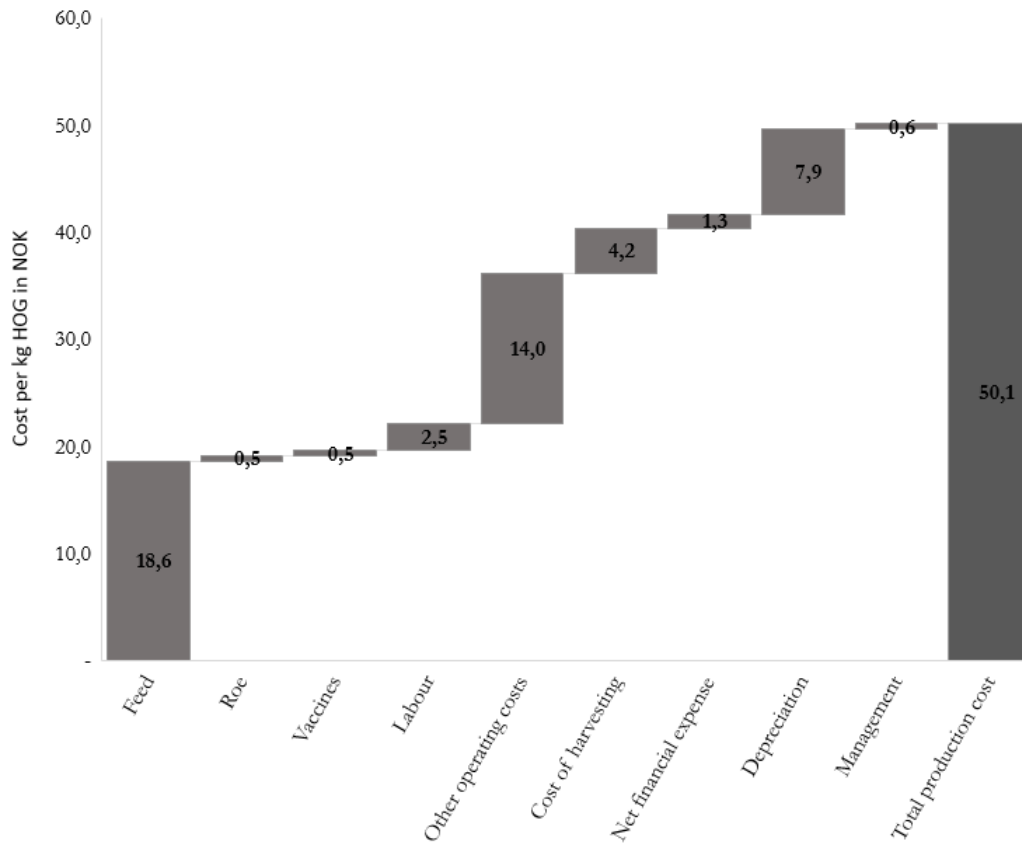


Figure 7.10: Total production cost per kg live weight in steady state

The Norwegian directorate of Fisheries report operational cost per kg in whole fish equivalent (WFE). Using the conversion ratio between live weight and WFE of 1.067, suggest a cost per kg of NOK 44.9 (WFE) in our model.

7.7.2.12 Monte Carlo simulation

We will now capture the uncertainty in these components by using Monte Carlo simulation. The purpose of the Monte Carlo method is to approximate an expected value $E(x)$ by an arithmetic average of the outcome of a large number of independent experiments, all with the same distribution as X (Korn, 2010). The Monte Carlo method is based on the law of large numbers (Korn, 2010). The law of large numbers states that the arithmetic mean of a sequence of independent, identically distributed random variables

$$(X_n)_{n \in N}$$

converges to the expected value $\mu = E(X_1)$ (Korn, 2010). This section seeks to explain how we use Monte Carlo simulation in our model rather than to derive the specifics of Monte Carlo simulation.

In the NPV base case model presented above, all cost components calculated were represented by their expected value. The assumptions about the cost components are based on Bjørndal et al. (2018). Even though we argue that these cost estimates currently is the most up-to-date estimates, they still represent uncertainty and are likely to fluctuate. We therefore assign a probability distribution for some of the most important components. We conduct 1,000 simulations where the components are varied at the same time. The result is a distribution of how the value of equity varies between the 1,000 simulations. The most important part for running robust simulations depends on deriving the distribution of the components realistically (Damodoran, 2018).

In order to capture the uncertainty inherent in expected costs, we assign probability distributions. Cost of roe, vaccine and feed have increased significantly over the last couple years. Although for different reasons, increased product complexity has been a substantial contributor. This is not a development that is expected to be reversed in the foreseeable future. In addition, currency movements has affected cost of feed considerably (DN, 2019b).

To simulate future development in these cost components, we have assigned negatively skewed distributions. By doing so we attribute a higher probability for high future outcomes. The scale, a built in parameter in the Crystal Ball software for the variance of variables, for roe and vaccine is set to 10.0%. This is viewed to be conservative and give robust cost simulations. The scale for feed is set at 7.0% based on the sample standard deviation on the price of feed from 2012 to 2018 (Norwegian Directorate of Fisheries, 2018a). Price and WACC are assumed to be normally distributed, as we do not have any insight on their underlying determinants. Thus, we assign equal probability for higher as well as lower outcomes for these variables. The price standard deviation is estimated by calculating the sample standard deviation using weekly data from Fishpool (2019) from week one 2000 to week 36 in 2019. The standard deviation for WACC is set to 0.5% as suggested by Damodoran (2019). Table 7.16 outlines the assumptions for the Monte Carlo simulation.

Table 7.16: Assumptions for Monte Carlo simulation

Component	Average	Distribution	Standard deviation/Scale
Price (NOK/kg, live weight)	49.56	Normal	11.76
Roe (unit price in NOK)	1.50	Negative skew	0.15
Vaccine (unit price in NOK)	1.80	Negative skew	0.18
Feed (NOK per kg)	14.00	Negative skew	1.00
Insurance	-	-	-
Labour	-	-	-
Depreciation	-	-	-
Electricity	-	-	-
Oxygen	-	-	-
Oxygen tank rental	-	-	-
Waste water	-	-	-
Service, maintenance and repairs	-	-	-
Office and administration	-	-	-
Other annual operating costs	-	-	-
Cost of harvesting	-	-	-
Fixed costs	-	-	-
WACC (%)	5.00	Normal	0.50

8 Analysis

In the following section we will present our findings. First, we present the different results obtained to calculate the maximum total cost per kg, before we present the value of equity from the base case NPV analysis and the Monte Carlo simulation. Lastly, we show a comparison of our total production cost per kg estimate compared to previous studies.

8.1 Implicit maximum total cost per kg

This section present the maximum total cost per kg which results in a value of equity equal to zero, for modeled 10,000 tonnes, with the assumptions outlined in our methodology. We have included three different price scenarios and have varied the lifetime of the project between 20-years and an infinite lifetime. The results for each scenario is presented separately below.

8.1.1 Results when assuming 20-year lifetime

In scenario 1, we assume a fixed price of NOK 59.0 per kg HOG (NOK 49.6³). This gives us a maximum total cost per kg HOG of NOK 50.1. In scenario 2, we assume a HOG price of NOK 59.0 (NOK 49.6) for the first eight years, NOK 50.0 (NOK 42.0) for the following seven years and NOK 45.0 (NOK 37.6) for the remaining six years. In this scenario we obtain a maximum total cost of NOK 43.7 per kg HOG. In scenario 3, we assume a 10% price premium corresponding to a HOG price of NOK 64.9 (NOK 55.8). In such scenario, the maximum total cost is estimated to be NOK 55.8 per kg HOG.

The three different scenarios, based on our assumptions and scenarios, results in a maximum total cost of production for land-based projects is in the range of NOK 43.7-55.8 per kg HOG. Scenario 1 might be of most interest as it is based on the forward price for Atlantic salmon, and should represent a valid estimate of the situation faced by decision makers today. Scenario 2 represent a more pessimistic view on the price outlook for Atlantic salmon, and scenario 3 represents a markup in prices achieved for land-based producers. The results are presented in table 8.1.

³live weight costs in parenthesis

Table 8.1: Implicit maximum total cost per kg (HOG)

	Maximum total cost pr kg
Scenario 1	NOK 50.1
Scenario 2	NOK 43.7
Scenario 3	NOK 55.8

Our results presented could change if development in prices follow a different path compared to what we have modeled. We argue that the information still is valuable, especially for decision makers within the industry who already has developed a specific view on achievable prices for a land-based project. If a decision maker has the price view similar to one of the scenarios, the information can be used to get an approximation of how high total production cost can be before the project has an expected negative value to equity under our assumptions.

The maximum total cost per kg estimates are most sensitive to the WACC assumptions. All the estimates that has been presented so far has used a real WACC of 5.0%, equal to a nominal WACC of 7.0%. We argued in the methodology section that the WACC is a highly uncertain estimate. Decision makers and investors could have a different opinion about the cost of capital, therefore we conduct sensitivity analysis on the WACC in the following section. The estimate is also dependent on estimates regarding capital expenditures, tax rate and working capital requirements. We argue that these assumptions are more fixed and has a smaller impact on the value to equity, thus we only look at changes in the WACC.

8.1.2 WACC sensitivities

This section estimates how the implicit maximum total cost per kg shift when the WACC changes. We estimate the real WACC at 5.0%, 6.0% and 7.0%, corresponding to a nominal WACC of 7.0%, 8.0% and 9.0%, respectively. The result is presented in table 8.2.

Table 8.2: Implicit maximum total cost per kg (HOG) for changes in the real WACC

	WACC 5.0%	WACC 6.0%	WACC 7.0%
Scenario 1	NOK 50.1	NOK 48.0	NOK 46.2
Scenario 2	NOK 43.7	NOK 42.3	NOK 40.5
Scenario 3	NOK 55.8	NOK 53.9	NOK 51.9

8.1.3 Results when assuming an infinite lifetime

This section present the same maximum total cost per kg (HOG), but assumes that the project has an infinite lifetime. The method is explained in the methodology chapter. The results are presented in table 8.3. The table suggest that the maximum total cost per kg is reduced to NOK 46.2 per kg (HOG) in scenario 1 if the real WACC is estimated to be 7.0% instead of 5.0%.

Table 8.3: Implicit maximum total cost per kg (HOG)

	Maximum total cost per kg
Scenario 1	NOK 51.4
Scenario 2	NOK 42.6
Scenario 3	NOK 57.1

In scenario 1 and 3, the maximum total cost per kg is higher when we assume that the project has an infinite lifetime. This because the terminal value calculated in the infinite scenario is higher compared to the present value associated with re-investments in the facility. Therefore, value of equity is higher compared to with the project lifetime of 20 years. In scenario 2, this is not the case because the price used to calculate the terminal value is NOK 37.8 per kg live weight (NOK 45.0 per kg HOG), and the value of these cash flows are smaller compared to the costs associated with capital expenditure re-investments. Put differently, the project has a negative value of equity from year 20 and should therefore be discontinued.

Also worth noting is that the difference in the value of equity estimate with 20-year lifetime compared to infinite life time is NOK 1.1 per kg at most, which we consider to be relatively small. In comparison Bjørndal and Tusvik (2017) estimated a NPV of NOK 745.4 and NOK 1580.8 million, almost doubling the NPV when modelling the project lifetime for 20 years compared to infinity. One of the reasons could be that a lower cost of capital of 4% would value future cash flows higher compared to our estimate.

8.1.4 WACC sensitivities

In the following, we present the same WACC sensitivity for the infinite maximum total cost per kg in production. The results are presented in table 8.4. If the real WACC is

changed to 7.0%, the implicit break-even cost of production is reduced from NOK 51.4 to NOK 47.3.

Table 8.4: Implicit maximum total cost per kg (HOG) for changes in the real WACC

	WACC 5.0%	WACC 6.0%	WACC 7.0%
Scenario 1	NOK 51.4	NOK 49.3	NOK 47.3
Scenario 2	NOK 42.6	NOK 41.3	NOK 39.9
Scenario 3	NOK 57.1	NOK 55.0	NOK 52.9

8.2 NPV base case

Based on the assumptions and cost estimates outlined previously, we arrive at an expected value of equity of NOK -53.6 million. In figure 8.1, we present how sensitive the value of equity is for different assumptions. We estimate a 1.0% change in the WACC and a 3.5% change in the price of Atlantic salmon, while the cost components are changed with 5.0%. Note that the most sensitive parameter is the WACC, followed by the price of salmon and feed cost. The figure have labelled the change in equity value in absolute terms while the x-axis shows the %-change in equity value. Note that the %-change is high due to the relatively low value of equity. As such, changes in some of the assumptions results high percentage changes in the value of equity.

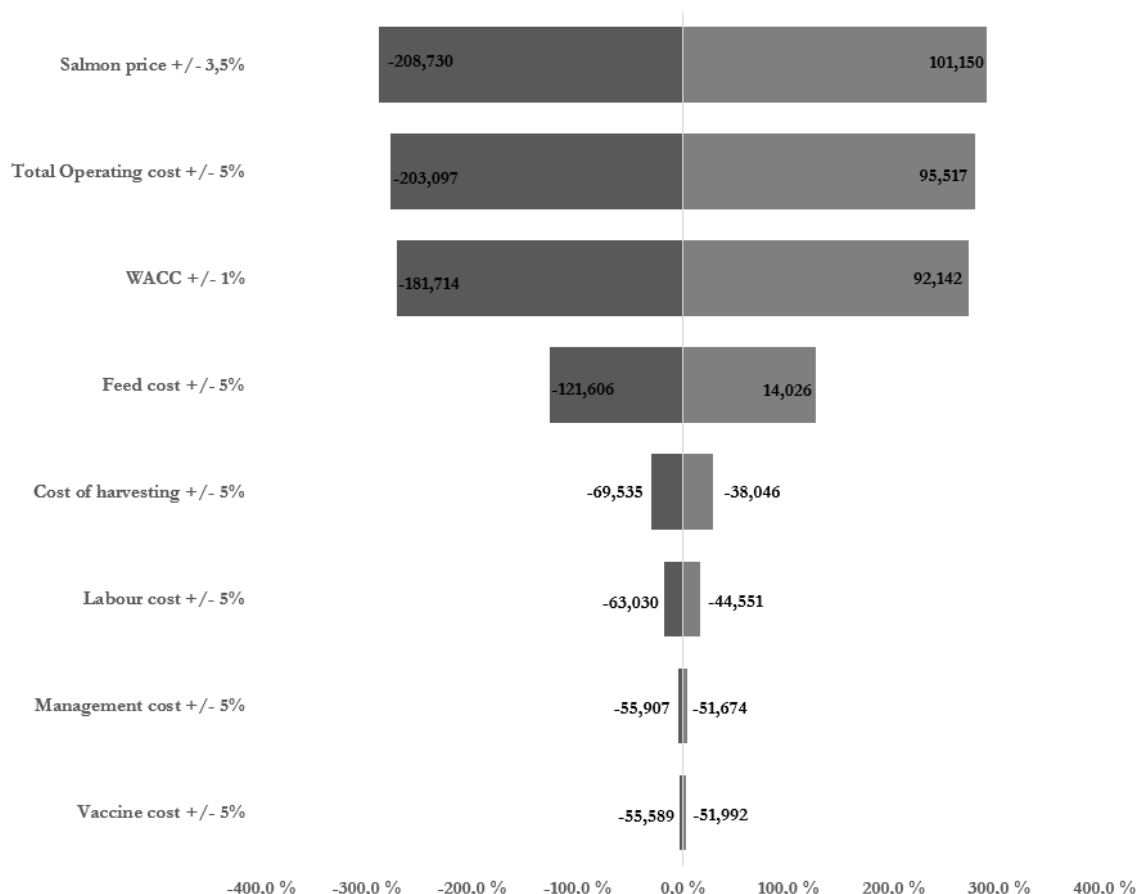


Figure 8.1: Sensitivity in the value of equity for changes in assumptions

We have previously highlighted that the cost of equity component in the WACC estimate is uncertain for the land-based project as it currently has few comparable public companies. Therefore, table 8.5 present how changes in the unlevered β results in changes in the cost of equity and the WACC.

Table 8.5: Sensitivity for changes in unlevered β

Unlevered β	Cost of equity	WACC _r
1.1	6.9%	4.7%
1.2	7.4%	5.2%
1.3	7.9%	5.6%
1.4	8.4%	6.0%

The table suggest that if the unlevered β is 1.4 compared to our estimate of 1.16, the WACC would be 6.0% and the value of equity would be reduced to NOK -181.7 million from NOK -53.6 million.

Cost of feed is another component that represents uncertainty, as the cost relies on the cost of feed, the BFCR and mortality rates. The price of feed is assumed to be NOK 14.0 per kg and will be varied in the Monte Carlo simulation. The BFCR is estimated to 0.9 for the first 12 months of production, as this is assumed to be standard in the smolt phase and the following six months. After month 12 a BFCR of 1.15 is used, based on the Bjørndal et al. (2018) report. This differs from Bjørndal and Tusvik (2017), which used 1.1. However, they re-estimated the BFCR to 1.15 in Bjørndal et al. (2018). The BFCR suggests that 1.15 kg of feed is needed to grow the Atlantic salmon by 1.0 kg.

According to industry sources, the BFCR for land-based salmon farming has been suggested to be better compared to sea-based farming, where the BFCR typically is 1.25. Some suggest that the BFCR on land can be less than 1.0 during effective production. In table 8.6, we conduct sensitivity analysis on the cost of feed in steady state to changes in the BFCR. We present the result in absolute values and in cost per kg. The BFCR is set to 0.9 for the first 12 months in all scenarios, while it is changed for last seven months of the production cycle. The difference in cost per kg live weight, between a BFCR of 1.15 compared 0.9, is NOK 2.7 per kg. However, we do not have enough information to suggest a specific view on BFCR, and therefore use 1.15 as proposed by Bjørndal et al. (2018). As such, our estimates should be robust.

Table 8.6: Sensitivity in cost of feed as a result of changes in the BFCR (live weight)

BFCR	Cost of feed	Per kg (NOK)
0.90	129,106	12.9
0.95	134,523	13.5
1.00	139,940	14.0
1.05	145,357	14.5
1.10	150,775	15.1
1.15	156,192	15.6

The total mortality rate, from the salmon is 100.0 gram until harvest, is approximately 6.2% in land-based farming. This is considerably lower compared to the mortality rates in sea-based farming, where the median in 2018 was 15.0%. We do not have a specific view on the mortality rate which can be achieved in land-based farming, and we therefore use an estimate similar to Bjørndal and Tusvik (2017).

8.3 Monte Carlo simulation

The Monte Carlo simulation is conducted on the NPV base case with a 20 year project lifetime, where the value of equity is assumed to be NOK -53.6 million. The method is explained in the methodology section along with the rationale for the chosen assumptions, and a discussion regarding the appropriate distribution and standard deviation/scale.

In figure 8.2, we present how the value of equity changes when the assumptions are considered to be random variables for 1,000 simulations. The expected value of equity is NOK -53.6 million, corresponding to the NPV base case. The value of equity is expected to be positive 47.8% of the time. Further, the 90.0% confidence interval is between NOK -1,429.3 million and NOK 1,340.5 million.

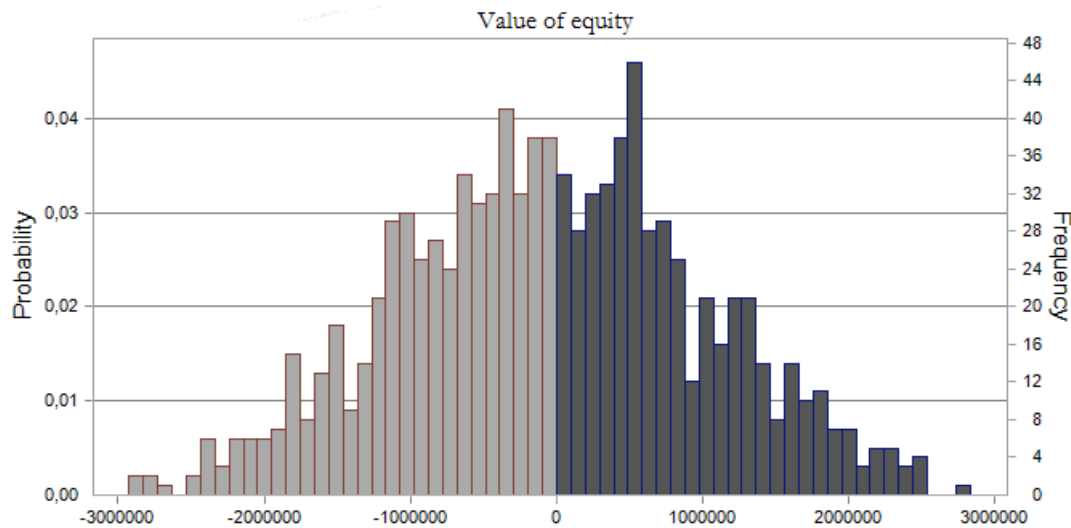


Figure 8.2: Monte Carlo simulation of the value of equity using 1,000 simulations

8.4 Comparison to previous studies

In table 8.7, we compare previous studies' estimates of total production cost per kg (HOG) with our estimate. The figure suggest that *estimates* on total production cost has increased. This may reflect more available information and differences in underlying assumptions.

The estimate from Liu et al. (2016) was in HOG⁴, while the estimate form Bjørndal and

⁴Liu et al. (2016) used a conversion factor between live weight and HOG of 0.825 while we adjusted the estimate using a conversion factor of 0.84

Tusvik (2017) and Bjørndal et al. (2018) was initially in live weight and has been converted to HOG. Our total production cost estimate is based on the assumptions outlined in the Bjørndal et al. (2018) report, but it differs as we have included cost of harvesting and excluded the cost of insurance associated with fish, buildings and equipment. In addition, our estimate use a different capital structure, resulting in a slightly different net financial expense of NOK 0.2 per kg compared to Bjørndal et al. (2018). Our total production cost estimate in steady state is NOK 50.1 per kg (HOG), meaning that our estimate is higher compared to previous studies.

Table 8.7: Estimates of total production cost per kg in NOK (HOG) from previous studies

	Total production cost
Liu et al. (2016)	38.6
Bjørndal and Tusvik (2017)	43.2
Bjørndal et al. (2018)	48.7
Our estimate	50.1

The estimate from Liu et al. (2016) seems to be optimistic compared to assumptions outlined by Bjørndal et al. (2018). Despite this, Liu et al. (2016) estimated a negative NPV. This was due to a price estimate of NOK 42.0 per kg (HOG), which resulted in low margins as his cost estimate was NOK 38.6 per kg (HOG). The report from Bjørndal and Tusvik (2017) estimated a NPV of NOK 745.4 million and NOK 1580.8 million when using a 20 year and an infinite lifetime, respectively. They used a price of NOK 59.0 per kg (HOG), and a estimated cost in steady state of NOK 43.2 per kg (HOG). Their estimate did not include cost of harvesting, and used a real cost of capital of 4.0%. This in our opinion optimistic, because they use a long-term inflation rate of 2.9% compared to the inflation rate target set by Norges Bank of 2.0%. This has a major effect on the NPV as it reduces the cost of capital by 0.9%. Furthermore, Bjørndal and Tusvik (2017) estimated a capital expenditure of NOK 110.0 per kg (HOG). This seems low compared to estimates provided by Billund Aquaculture AS and other industry estimates. In comparison, we estimate a capital expenditure per kg of NOK 155.8 (HOG).

In the report by Bjørndal et al. (2018) an estimate of NPV was not included, but they estimated the total production cost at NOK 48.7 per kg (HOG).

9 Implications and discussion of the findings

9.1 Implications of the findings

Our results suggest a marginally negative value of equity, when using the forward price and a 20 year modelling period. With a project infinite project lifetime or assume a markup in achieved prices, our modelled facility has a positive value to equity. In addition, the Monte Carlo simulation suggest that the probability for a positive value of equity is 47.8% in the base case scenario. Further, our findings suggest that it is possible for decision makers to calculate positive value of equity in planned projects. This is also demonstrated by the 809,450 tonnes of planned capacity. An implication of this may be that the industry has used more favorable assumptions compared to our base case with a 20 year lifetime. However, only small changes are required in order to achieve a positive value of equity.

Capital expenditures in sea is similar compared to land-based facilities, while operating cost is lower in the sea. However, costs in sea-based farming has experienced an increasing trend. An implication of our findings is that there exists great variation in capital expenditures per kg for planned land-based farming facilities. A possible reason could be that many of the estimates that has been publicly disclosed could be biased and to optimistic, as companies has an incentive to report low numbers in order to more easily attract funding. Another reason could be variation in planned biosecurity, primarily in the form of number of fish tanks per RAS. Our estimate is in the higher end in terms of capital expenditure per kg, and suggests high biosecurity. Therefore, it should be possible to achieve reduced capital expenditure per kg, however with the higher probability of increased operational risk which in turn leads to a higher cost of capital. These differences clarifies that land-based projects should not be considered homogeneous, and that the cost of capital must reflect the risk of the project.

We find that previous studies have estimated positive NPV under more optimistic assumptions, and that some have excluded cost of harvesting. The result can be an inaccurate representation of the economic attractiveness of a land-based farming facility.

9.2 Discussion of the findings

The economic success of land-based salmon farming depend on achieving the operational assumptions made when planning the facility. Particularly, being able to achieve the planned fish density, EFCR and growth function seems to be of high importance. If assumptions made on these factors proves challenging to fulfill, it may result in facilities becoming economically unattractive. This can potentially influence the development of the land-based salmon farming industry negatively. In such scenario, the amount of effort invested in land-based farming technology may be considerably reduced and commercial scale projects may fail to materialise. Focus may shift to research and development to prove the technology successful, which seems to be a prerequisite before new commercial scale projects once again can materialise.

Specialised breeding programs for salmon farmed on land may improve the performance of land-based farming facilities and help overcome some of the current challenges. Increased tolerance for CO₂ and particles may improve biological performance considerably and thereby the economic attractiveness of the industry.

The regulatory trend in Norway has been to let biologic conditions determine growth in aquaculture production. However, the acceptance for biological and environmental impact is a matter of professional assessment and political decision (Norwegian Ministry of Trade and Fisheries, 2015). In order to comply with current regulations, the sea-based salmon farming industry has experienced a trend of increasing cost over the last couple of years. This trend can mainly be attributed to considerable biological challenges which has affected operating expenses as well as capital expenses significantly (Iversen and Øystein Hermansen, 2019).

Increased focus on fish welfare and environmental impact may reduce future acceptance for the current conditions in sea-based salmon farming. Further, if land-based salmon farming proves successful and offer a real alternative to farming in sea, it may reduce this acceptance even further. This might result in increased regulatory requirements related to fish welfare, HSE and environmental impact. Complying with increased regulation result in operational and administrative consequences which affect operational expenses and capital expenses negatively (Iversen and Øystein Hermansen, 2019). Thus, the rising cost

trend in sea-based farming may be expected to continue going forward.

The current biological situation in sea-based salmon farming, and the implications it entails, suggest that there are several negative externalities. These externalities consist of e.g. escapes, emissions and negative impact on the wild salmon stock due to sea lice, reproduction and disease. These externalities are not an issue in land-based salmon farming. If the technology is proven successful, this may reduce acceptance for externalities in sea-based farming and make land-based salmon farming relatively more attractive.

In November 2019, a recommendation to implement a resource tax on the aquaculture industry was proposed by Ulltveit-Moe et al. (2019). A similar tax would not apply to land-based farming of salmon (Ulltveit-Moe et al., 2019). If such a tax is implemented, the effect would be higher prices of salmon and a net negative effect for conventional sea-based farmers. In contrast, land-producers would benefit from higher prices. It is important to note that the tax has only been suggested and implementation has not yet been decided. However, decision makers still have to take the proposal into consideration today, and adjust for the probability of such a tax implementation. It is therefore natural to assume that it already has an impact on decision making within the industry and should make land-based farming relatively more attractive.

Full-cycle land-based salmon farming builds on a relatively new and not fully understood technology. As the industry increase the effort invested, this will result in increased accumulation of knowledge and a deeper understanding of the technology. Further, as technological performance may increase as a function of effort invested, accelerated technological improvement may be expected.

Land-based salmon farming may represent a discontinuous technology, satisfying the same market need while building on a new knowledge base (Schilling and Esmundo, 2009). As land-based salmon farming technology is not fully understood and each firm has an incentive to differentiate its design from those already available, a substantial amount of design variants emerge during its period of technological ferment (Tushman and Anderson, 1986; Knudsen, 2019b).

Currently, it seems that land-based salmon farming has a lower performance/price ratio than sea-based salmon farming. However, substantial progress in determining

the technological design with the most attractive performance/price ratio will probably be made over the coming years, as different facilities reaches operations. Over time we expect designs to converge towards a dominant design, optimizing the performance/price ratio. This development is expected to reduce total capital expenditures per kg considerable, which in turn lowers the required operating margins in order to have a positive NPV. As such, at some point land-based salmon farming may reach a higher performance/price ratio than sea-based salmon farming. This may form the basis for significant production volumes coming from land-based farming facilities over time.

At the time of this writing, the largest constraints for the land-based salmon farming industry seems to be employees with the required competence as well as financing. Financing may prove easier to obtain if other projects turn out to be successful. However, being able to obtain the right set of competences within the organisation seems to be a constraint for the industry also in the nearest future.

The sea-based industry experience considerable biological challenges, which has resulted in a trend with increasing costs. Further, it exist several negative externalities associated with operations in sea. As such, land-based salmon farming represent a solution to these problems and has a total cost per kg which is expected to decrease over time as new projects evolves. In addition, a resource tax has been proposed for sea-based farming which suggest that the attractiveness associated with land-based salmon farming should improve. In total, this could mean that land-based salmon farming can increase its competitiveness compared to conventional sea-based farming over time and improve its economic attractiveness.

10 Limitations and further research

10.1 Limitations

Our findings are limited by the lack of verified biological information, assumptions underlying the Monte Carlo simulation as well as the limited availability of relevant financial information.

For land-based salmon farming under constant water temperature, a verified biological growth model do not currently exist. This because the land-based salmon farming industry is entirely new. Thus, our biological modelling are based on growth models from sea-based farming. Any differences in biologic growth model may impact our findings. Such differences affect our assumption on BFCR, which in turn affects cost of feed. As cost of feed is the largest cost component, it may affect our cost per kg estimates significantly. However, due to our conservative estimates such differences may be lower rather than higher.

The lack of verified modelling assumptions for land-based salmon farming is another limitation of our findings. We have adopted assumptions presented by Bjørndal et al. (2018) as we do not have any basis for providing better estimates, however these are not verified. Thus, as commercial-scale operational experience emerge, it will be revealed whether the assumptions turns out to be realistic. As these may be revised, they affect the relevance of our findings. Nevertheless, our findings build on the best available information currently available.

As Monte Carlo simulation builds on the law of large numbers, the results provided are sensitive to assumptions made with respect to choice of distribution, standard distribution and scale. We have done our best to ensure that these parameters are as realistic as possible. However, if they prove not to be, it may affect our findings.

When it comes to share price development, limited historical price information for publicly listed land-based farming companies exist. Further, the companies that are listed have yet to reach commercial scale. Thus, our β estimate could be inaccurate which results in high uncertainty for our estimate of cost of equity.

Further, as there exist few comparable companies, the capital structure of such projects could be different from our assumptions. Lastly, the capital structure is assumed to be constant while a more realistic scenario could be that the debt level will increase as the project and technology matures.

10.2 Suggestions for further research

We recommend other researchers to conduct a similar study when verified operational information becomes available. This may provide a more precise estimate of the economic attractiveness of land-based salmon farming. In addition, we recommend future research on the economic attractiveness of other growth options like offshore farming, post-smolt strategies and floating closed containment systems. A comparison between these and land-based farming may help the industry to determine the most attractive non-conventional growth option. Finally, we recommend future research on implications for the competitiveness of sea-based farming in Norway, should land-based salmon farming become successful.

11 Conclusion

Land-based salmon farming is an entirely new industry which has faced massive interest in recent years. Despite several projects being under construction and several more being planned, there is a lack of robust information about its economic attractiveness. Our primary objective has been to provide up-to-date, reliable and robust estimates on the current economic attractiveness of land-based farming, as well as an outlook on how this might change in the future. In addition, we have presented a comprehensive overview over the emerging industry, providing stakeholders a source containing all relevant information.

We used two approaches in entirely new ways for this industry to address the lack of reliable information. First, we estimated the implicit maximum total cost per kg for two different project lifetimes and three different price scenarios, and second we used the most up-to-date information and captured the uncertainty in our assumptions with a Monte Carlo simulation. We modelled a 10,000 tonnes RAS facility located in Norway for both methods. By doing so, we better reflect the development in production capacity witnessed in the industry, compared to previous studies.

Our principal result is that a maximum total production cost of NOK 50.1 per kg (HOG) results in a net present value of equity of zero, when using the forward price throughout a 20 year lifetime. This is considered the point of break-even for when land-based farming is economically attractive. When we considered an infinite modelling period, we estimated that the implicit maximum total cost of production increased to NOK 51.4 per kg (HOG).

We also report that our modelled representative land-based facility, with the same forward price and 20 year modelling period, have a slightly negative value of equity of NOK -53.6 million. Further, by using Monte Carlo simulation we find a probability of 47.8% for a positive net present value of equity.

Our findings suggest that land-based salmon farming is currently not economically attractive. However, based on our assumptions there are only small changes required to alter this. If land-based farmed salmon is able to achieve a price premium, or the BFCR is lower than currently assumed, land-based salmon farming will be economically attractive. Based on the number of planned projects it seems likely that this may be the case.

We assume the significant volumes of planned production to hold a positive value to equity. Because of this, it is likely to assume that they estimate 1) cost below either our implicit maximum total cost per kg or the total production cost estimate we presented in the Monte Carlo simulation, 2) they believe in achieving higher prices or 3) a combination of the two. This may suggest that our analysis provide conservative and robust estimates.

Furthermore, future outlooks of reduced acceptance for current practices, stricter regulation and increasing biological challenges in sea-based farming might lead to higher production cost per kg in combination with higher investments in operating equipment. As land-based salmon farming uses technology which is not fully understood, its performance/price ratio is expected to improve as more efforts are being invested. Further, a resource tax has been proposed for sea-based salmon farming, where land-based salmon farming has been excluded. These factors may lead to even better competitiveness of land-based salmon farming compared to sea-based farming in the future.

With regards to the underlying assumptions, the biological growth curve has not been validated for salmon farmed on land. This may affect the BFCR and thus the cost of feed per kg as well as the turnover ratio of salmon. Further, we have assumed that land-based salmon farming are able to achieve the modelled production assumptions. Should this fail, it may impact production and the economic attractiveness significantly.

We consider the findings to be of high value to decision makers and stakeholders, especially investors and creditors. This as the outlined developments affects both the future of the land-based and sea-based industry significantly. Our findings are the most robust and reliable estimates to date.

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Appendix

A1 The thermal growth coefficient (TGC)

One of the most common ways to calculate the average growth rate of salmon is by Growth Factor 3, known as the thermal growth coefficient (TGC). It takes into account both fish size and water temperature. The formula is presented in equation .1 where day degrees consist of water temperature in Celsius times the total number of growth days.

$$TGC = \frac{(Final\ weight^{\frac{1}{3}} - Start\ weight^{\frac{1}{3}}) * 1000}{Day\ degrees} \quad (.1)$$

Our growth plan is similar to Bjørndal and Tusvik (2017) where the formula to calculate growth is presented in equation .2.

$$Final\ weight = (Start\ weight^{\frac{1}{3}} + TGC * \frac{Day\ degrees}{1000})^3 \quad (.2)$$

A2 Production plan

In the table below, we present how the feed cost is calculated. The feed cost is a function of the survival rate, increase in biomass weight and FCR. The total feed cost per month in steady state (year 2) is equal to the sum of feed cost in the column to the right.

Production plan for land based facility

Month beginning	Weight (g) per fish, Wt	Weight (g) increase,		Survival %	Number of fish (given survival rate), Nt	Total biomass weight increase (kg), incl, mortality, ((wt+1- wt)*Nt)/1000		Biomass weight (kg), Bt = NTwt/1000	Biological feed conversion ratio, FCR:	Feed quantity (kg) per month FCR x Total biomass weight increase (kg), incl. Mortality		Feed cost (NOK) per month
		wt+1 - wt										
0		0,2	0,6	96 %	204300		123	41	0,9	110		1545
1		0,8	2,3	99,50 %	196128		451	157	0,9	406		5684
2		3,1	4,9	99,50 %	195147		956	605	0,9	861		12048
3		8	16	99,50 %	194172		3107	1553	0,9	2796		39145
4		24	26	99,50 %	193201		5023	4637	0,9	4521		63293
5		50	42	99,50 %	192235		8074	9612	0,9	7266		101731
6		92	73	99,50 %	191274		13963	17597	0,9	12567		175933
7		165	104	99,50 %	190317		19793	31402	0,9	17814		249392
8		269	141	99,50 %	189366		26701	50939	0,9	24030		336427
9		410	183	99,50 %	188419		34481	77252	0,9	31033		434456
10		593	231	99,50 %	187477		43307	111174	0,9	38976		545670
11		824	284	99,50 %	186539		52977	153708	0,9	47679		667512
12		1108	342	99,50 %	185607		63477	205652	1,15	72999		1021987
13		1450	406	99,50 %	184679		74980	267784	1,15	86226		1207170
14		1856	477	99,50 %	183755		87651	341050	1,15	100799		1411185
15		2333	551	99,50 %	182836		100743	426557	1,15	115854		1621960
16		2884	632	99,50 %	181922		114975	524664	1,15	132221		1851095
17		3516	719	99,50 %	181013		130148	636440	1,15	149670		2095384
18		4235	810	99,50 %	180108		72944	416805	1,15	83885		1174391
19		5045 -	-		179207							
