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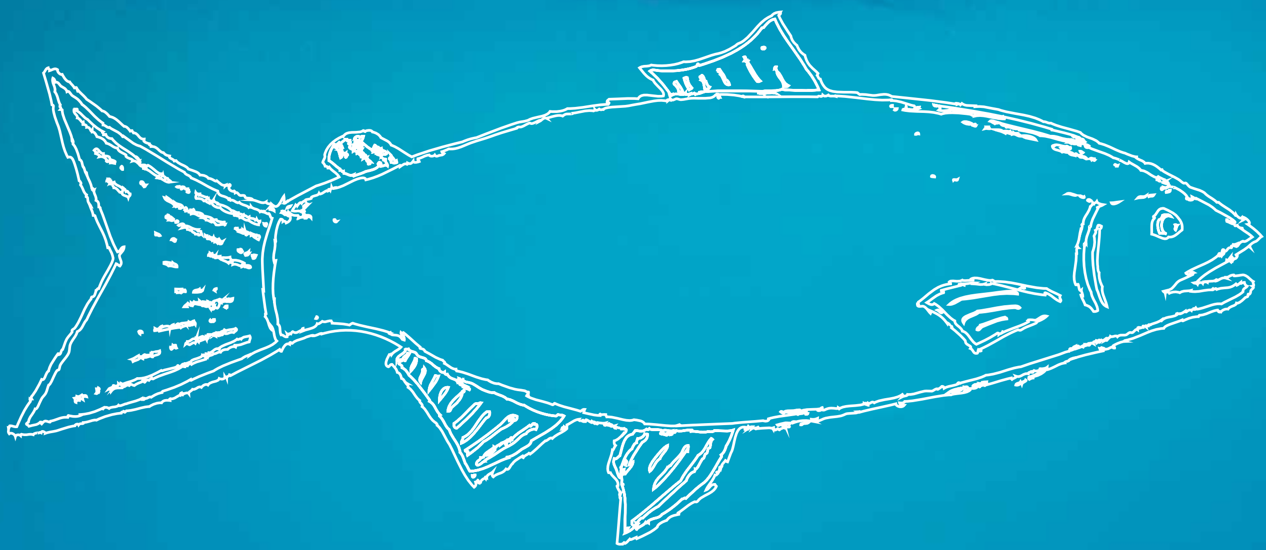


Pre-study

Opportunities and challenges for sustainable farming of salmon in closed systems and offshore in Norway

Contents

Preface Accenture

Norway is one of the leading nations in salmon aquaculture. Growth of the industry is a clear political target, but the industry experiences sustainability challenges. The Norwegian government has defined environmental sustainability within the aquaculture industry through five areas of focus: genetic impact and escapes; pollution and discharges; disease, including parasites; zoning; and feed resources.[1]

Attention from the Norwegian government, increased costs, and negative media coverage have all increased the focus on sustainability in Norwegian aquaculture. Consequently, the authorities will not award new licences for the production of salmon in seawater – which represent the key enabler of growth – before the industry has found a solution to the challenges of lice and escaped salmon. Most agree that the right choice of technical solutions for fish farming would contribute to resolving sustainability issues, but stakeholders have competing views about which solutions are best. There is therefore a need for a knowledge-based political discussion.

The industry works on several parallel tracks to become more sustainable. New technological solutions for closed systems and offshore technologies are considered to be among the potential solutions for environmental sustainable growth in Norwegian aquaculture. On a global basis, few commercial facilities currently use closed technologies or offshore systems for farming salmon, and existing projects are mainly in the development stage. There is a need for more pilot and research projects to obtain more knowledge in this area. This report considers how new technologies can be part of the solution to making the salmon farming industry more sustainable. The key issues in this report are to identify the current status of, the barriers to, and the opportunities for sustainable farming of salmon in closed and offshore systems in Norway.

The main purpose of this report is to assess how the salmon farming industry can use new technology for closed and offshore systems as part of the solution to environmentally sustainable growth within the guidelines defined by the Norwegian government.* The report is based on publically available information and more than twenty interviews with industry stakeholders such as Marine Harvest, Lerøy, Norwegian Board of Technology, Directorate of Fisheries, Sogn and Fjordane County Council and more. By *industry stakeholders* is meant producers, technology suppliers, authorities, NGOs, industry organisations, consumers, scientists, and other interest groups.

Accenture has written this report at the request of the World Wildlife Fund for Nature (WWF), but WWF has not been directly involved in the work. The project was carried out over a two-month period during the summer of 2013 as part of our summer internship programme, and the conclusions are expected to contribute to the public discussion about further development of the salmon aquaculture industry in Norway.

Accenture

Ane Kristine Jacobsen
Norwegian Corporate Citizenship Lead

Frode Hvattum, Nordic Sustainability Services Lead)

* Although feed is an important parameter regarding sustainability of aquaculture, it is a production input factor for all technologies. Due to lack of data, this report will not consider feed usage in different technologies; feed resources are therefore considered to beyond the scope of this report.

Preface WWF

The Norwegian farming of Atlantic salmon accounts for more than 60 per cent of Norway´s total seafood exports. It is an important industry that has grown rapidly in recent years, but this growth has not taken place without environmental impacts and challenges.

Many of these challenges are being addressed, but the environmental impacts from the aquaculture industry are far from resolved.

Aquaculture production has led to problems regarding sea lice and interference with wild salmon through escapes and pollution from sea farms. In addition, there are unknown consequences about its impact on other wild marine life. The industry acknowledges many of these issues, but there is disagreement about their severity. Technology within the industry has developed rapidly in certain areas while other areas have a long way to go. The safest solution is to change the method of production from open-net cages to closed systems and thus improve important parameters such as water quality, emissions, pollution or to prevent sea lice and escapes.

WWF's goal is to obtain the best knowledge at all times, and we believe there is a need to gather more knowledge on closed production systems for the benefit of the environment.

Hence, WWF is grateful for the opportunity to work with Accenture on this topic. Together, we have agreed upon a project and defined the following scope:

- Describe different solutions, knowledge of, and experience with, existing closed production systems, both national and international.
- Describe a model for environmental accounting based on a set of environmental parameters relevant to salmon farming and use this to set up an environmental analysis for closed versus open systems.
- Assess roles and actors in the value chain from an innovation perspective.
- Identify opportunities and challenges/ barriers to further development of closed aquaculture facilities, national and international.

The role of WWF-Norway has been to initiate the project and provide guidance on technical issues within farmed salmon production. WWF Norway did not participate in the work on conducting the interviews or interpreting the responses.

We look forward to presenting the report and the thorough work that Accenture has invested in it.

WWF Norway

Nina Jensen
Secretary General

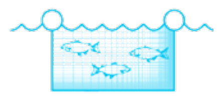
"If we are to run fish farms in the future, we must be environmentally sustainable."
Geir-Magne Knutsen, fish farming manager, Bremnes Seashore

"I believe in open net pen technology. I think it will remain the main production technology for the next ten, twenty or perhaps thirty years."
Harald Sveier, Technical Manager, Lerøy Seafood Group ASA

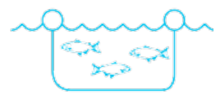
Executive Summary

After oil and gas, the salmon farming industry is Norway's second-largest export. Between 2003 and 2012 the total production volume in Norway more than doubled, reaching 1.2 million tons.[6] Norwegian authorities have stated that further development of the industry is a clear political goal. However, they will not allocate new licences for producing salmon in seawater before the industry has found better solutions to the environmental challenges of escapes and salmon lice. Three new technologies have been pointed out as potential new solutions for the industry:

1. Recirculation aquaculture systems (RAS)



2. Open containment systems with offshore net pens



3. Closed containment systems with coastal cages

Key Findings

Key findings are:

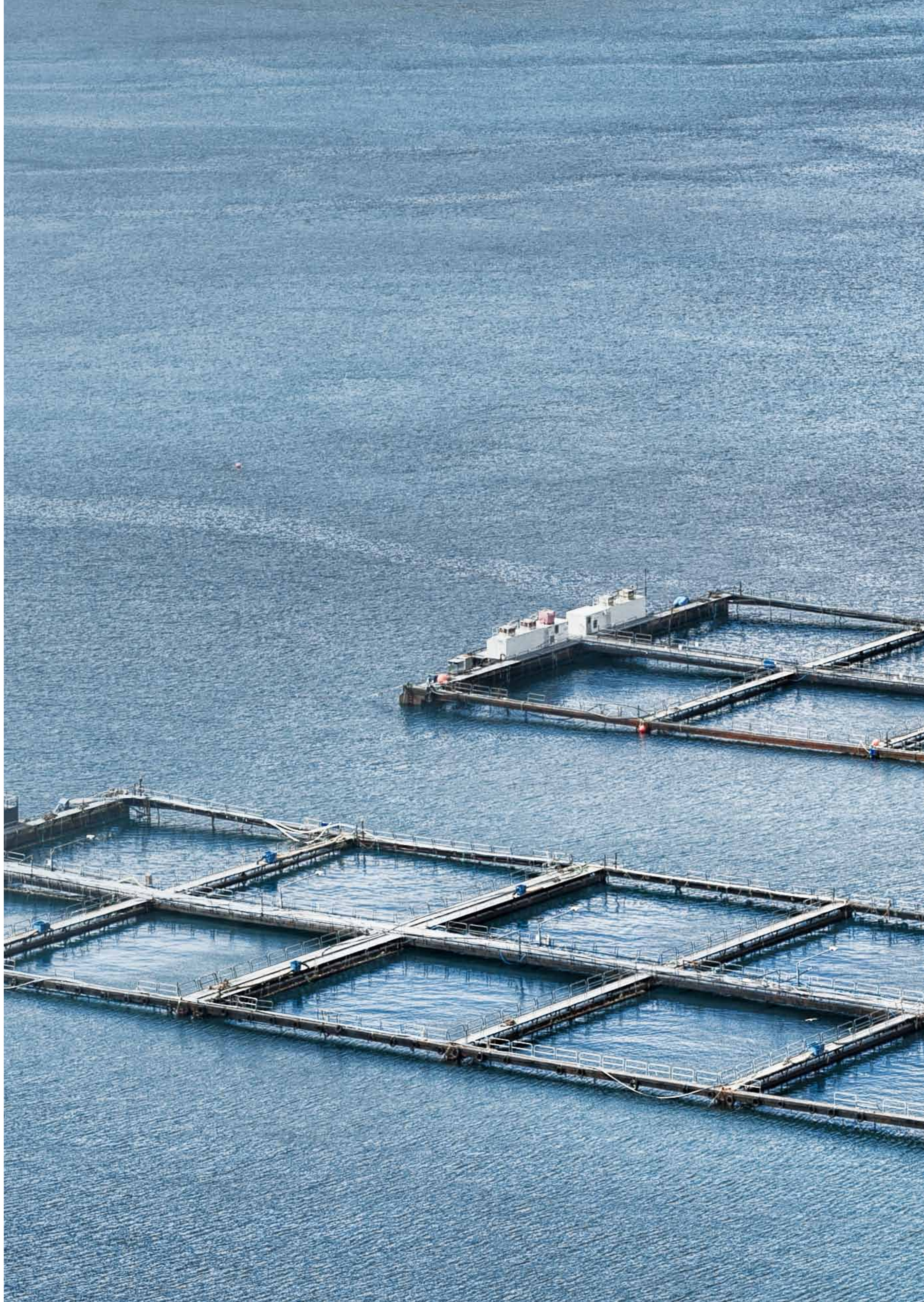
1. Accenture believes that production methods for salmon will be more diversified in the future. To resolve environmental challenges and optimise the total production volume, technology will to a larger extent vary according to location and production phase. New technologies and combinations of technologies that both address environmental challenges and are profitable will persist.
2. Closed systems have great potential because they score relatively higher on environmental parameters such as escapes, lice, fish welfare, direct pollutants/chemical emissions and discharges of nutrient salts and organic materials. The next step for the industry will be to explore the commercial aspects of these technologies.
3. In the short term, the greatest potential for closed systems lies in the smolt stage, the early stage of saltwater production when the fish grows from about 200 g to 1 kg. Keeping the fish in closed systems for longer may optimise the total production process and reduce production losses.

Technological solutions for the saltwater production of salmon between 200 g and 1 kg in recirculating aquaculture systems (RAS) and closed coastal systems are still under development and not yet commercialised. Several pilot projects for these technologies have been established, the results of which will be published within the next two years. These projects will evaluate the economic viability of the solutions. The focus for the industry should be to finalise existing projects as well as to initiate more projects for extended smolt production. The Norwegian authorities are best placed to initiate new projects.

Opportunities in the industry

To ensure a holistic assessment of the environmental impact of salmon farming, Accenture developed a model wherein eight parameters are measured: escapes, lice, fish welfare, environmental effects, direct pollutants/chemical emissions, discharges of nutrient salts and organic materials, zoning, and input factors in construction of system. Given today's environmental challenges, our analysis shows that cases with closed technologies have fewer environmental impacts than cases based on open technologies. Nonetheless, commercial immaturity, regulations that are not adapted to new technologies, limited access to funding, and disagreement between industry stakeholders represent barriers to the development of all new technologies. To overcome these barriers, Accenture has identified four specific opportunities for the industry to promote further development of environmentally sustainable technology:

1. **Adapt regulations to new technologies** – Government regulations are important for moving development in a more sustainable direction. Rules governing the weight limit of smolt and fish density, for instance, must be updated more frequently to keep up with the development of new technologies. Stricter regulations in exposed areas would give producers an incentive to change production technology. Additionally, a better coordinated public administration would make it easier for industry players to navigate their way around the system and thus stimulate sustainable development.
2. **Dedicated financing** – A simplification of existing governmental funding programmes in addition to a dedicated fund for sustainable aquaculture similar to, for example, Enova, could strengthen development of the industry. Furthermore, new technology start-up companies could be supported by seed capital, for instance through angel networks, and gain expertise through cooperation networks. In addition, the industry could form collaborative communities to share knowledge and to jointly fund projects.
3. **Independent research within prioritised areas** – Independent research organisations should conduct studies on areas of expected environmental significance such as the effects of escaped salmon, salmon lice, and fish welfare. Knowledge sharing is essential in order to unify the views of stakeholders and thus enable the industry to focus its efforts on resolving environmental challenges.
4. **Influence consumer behaviour** – To increase demand for sustainably produced salmon, the industry could promote the use of government measures such as standards, labelling, taxes or subsidies, and voluntary initiatives carried out by other stakeholders, including product labels such as the Aquaculture Stewardship Council's certification scheme.



Introduction to Salmon Farming in Norway

Is the Norwegian salmon farming industry sustainable? Can the industry grow with current production technologies? What are the main environmental challenges and how pressing are they? The aquaculture industry will continue to be an important sector in the Norwegian economy, but producers, technology suppliers, authorities, NGOs, industry organisations, consumers, and scientists tend to disagree about how to make the industry more sustainable.

Aquaculture in Norway

In 2012, the total world production of farmed Atlantic salmon was around 1.78 million tons[2], of which Norway produced over 1.2 million tons, reaching a first-hand value of nearly NOK 28.6 billion.[4] The Norwegian aquaculture industry, in which salmon farming accounts for 95%,[4] represents 1% of Norway's GDP[3] and is the country's second-largest export industry after oil and gas. In many local communities along Norway's coastline, the aquaculture industry is the largest employer; about 5,370 people were employed in core processes in 2012[4], while almost 20,000 were employed in related processes such as technology suppliers and distributors in 2011.[3] In the Soria Moria II Declaration, the government stated that Norway should be the world's leading seafood nation[5]. Nevertheless, with the current production method and more than a doubling of the total production volume in Norway from 2003 to 2012[6], the impact on the environment has become an area of focus. The Norwegian government requires further growth to take place within sustainable limits.

Historically, the Norwegian salmon industry has been fragmented. During the past decade however, it has become more consolidated. The number of producers contributing to 80% of Norwegian salmon production fell from almost 70% to 24% between 1997 and 2012. This trend is expected to continue in the future.[7]

The Norwegian Atlantic Salmon Industry (2012 numbers)[4]	
Production in tons	1,2 million
Production value	NOK 28,6 billion
Direct employment	5 370
Employment in related processes	20 000[4]

Table 1: Industry facts box

Regulations

Salmon farming is regulated by approximately sixty laws and regulations.[8] In addition, the operation of fish farms must comply with the Food Act, the Pollution Control Act, the Harbour Act, the Water Resources Act, and the Nature Diversity Act. Location applications are administered by the county councils, which coordinate and pass the applications on to the relevant authorities and counties.[7]

For freshwater production, the weight limit for smolt in onshore hatcheries is 250 grams. As of 2012, hatcheries may apply for exemption from the weight limit, allowing smolt up to 1,000 grams.[9]

The law also states that operations must be environmentally responsible and that fish farms must be located at sites approved by local authorities.

For production in seawater, biomass licences are allocated according to the Aquaculture Act. Biomass licences are normally limited to a standing biomass in seawater of 780 tonnes per licence.[10] This limit must be adhered to at all times. The same applies to the maximum allowable stocking density of 25 kg/m³. Production sites in seawater are required to be emptied and left fallow for at least two months after each production cycle.[11]

Salmon farming supply chain

Figure 1[12,13] shows the current supply chain of farmed salmon. The total process from fertilisation to harvest takes about two to three years and can be divided into six phases. Between steps three and four, an additional phase which is not currently in use has been included: extended smolt. Extended smolt is an extension of current juvenile production whereby salmon above the current 250 g weight limit (e.g. from 200 g and 1 kg) is kept on land.

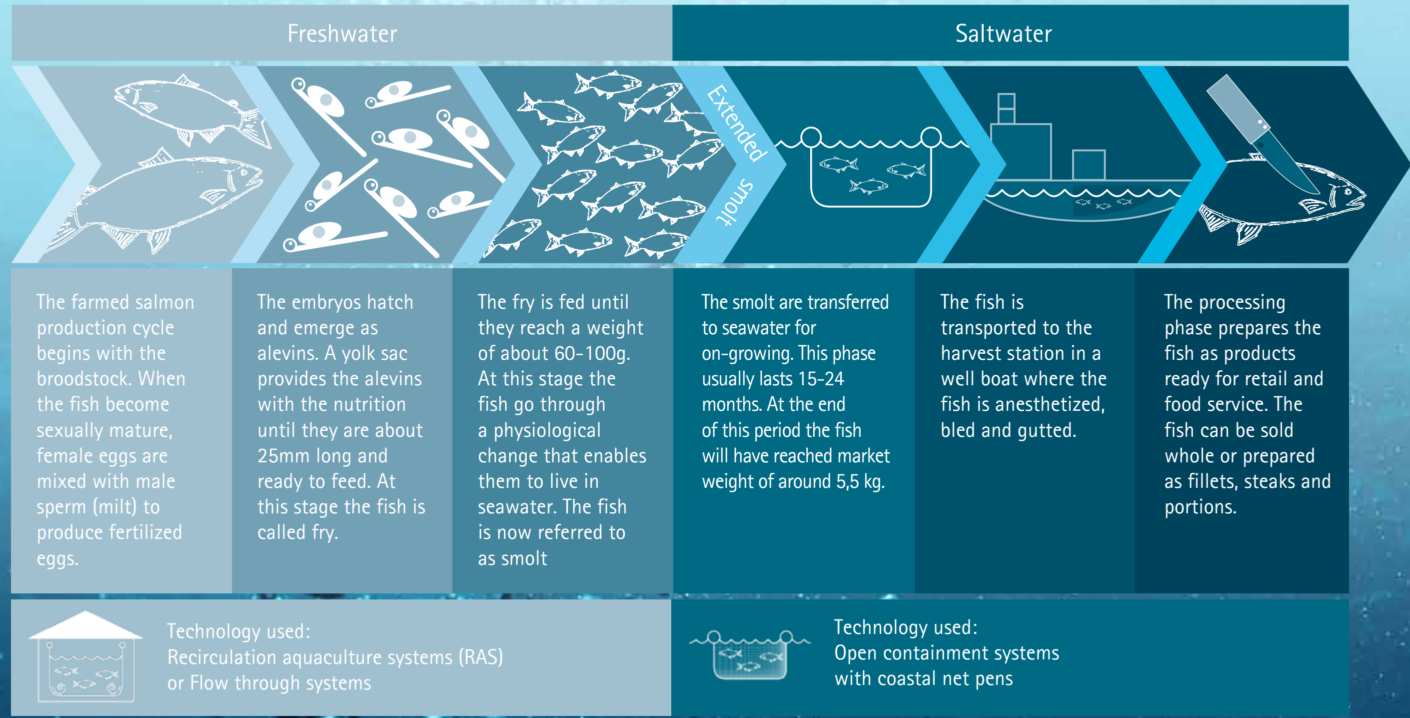


Figure 1: Salmon farming supply chain

Sustainability challenges for the Norwegian salmon farming industry

The aquaculture industry has several challenges with regard to environmentally sustainable development (see Table 2 for details). The Norwegian government has defined "environmental sustainability" within the aquaculture industry through five areas of focus: genetic impact and escapes, pollution and discharges, diseases including parasites, zoning, and feed resources.[1,*] In 2012 the Institute of Marine Research (IMR) conducted a risk assessment of the environmental effects of Norwegian aquaculture and concluded that infection pressure from salmon lice and genetic influences of escaped salmon are the most problematic risk factors for the Norwegian fish farming industry.[14] IMR concluded that there was a medium or high probability that the environmental impacts of the industry conflicted with the goals of the government's strategy for an environmentally sustainable fish farming industry.[15]

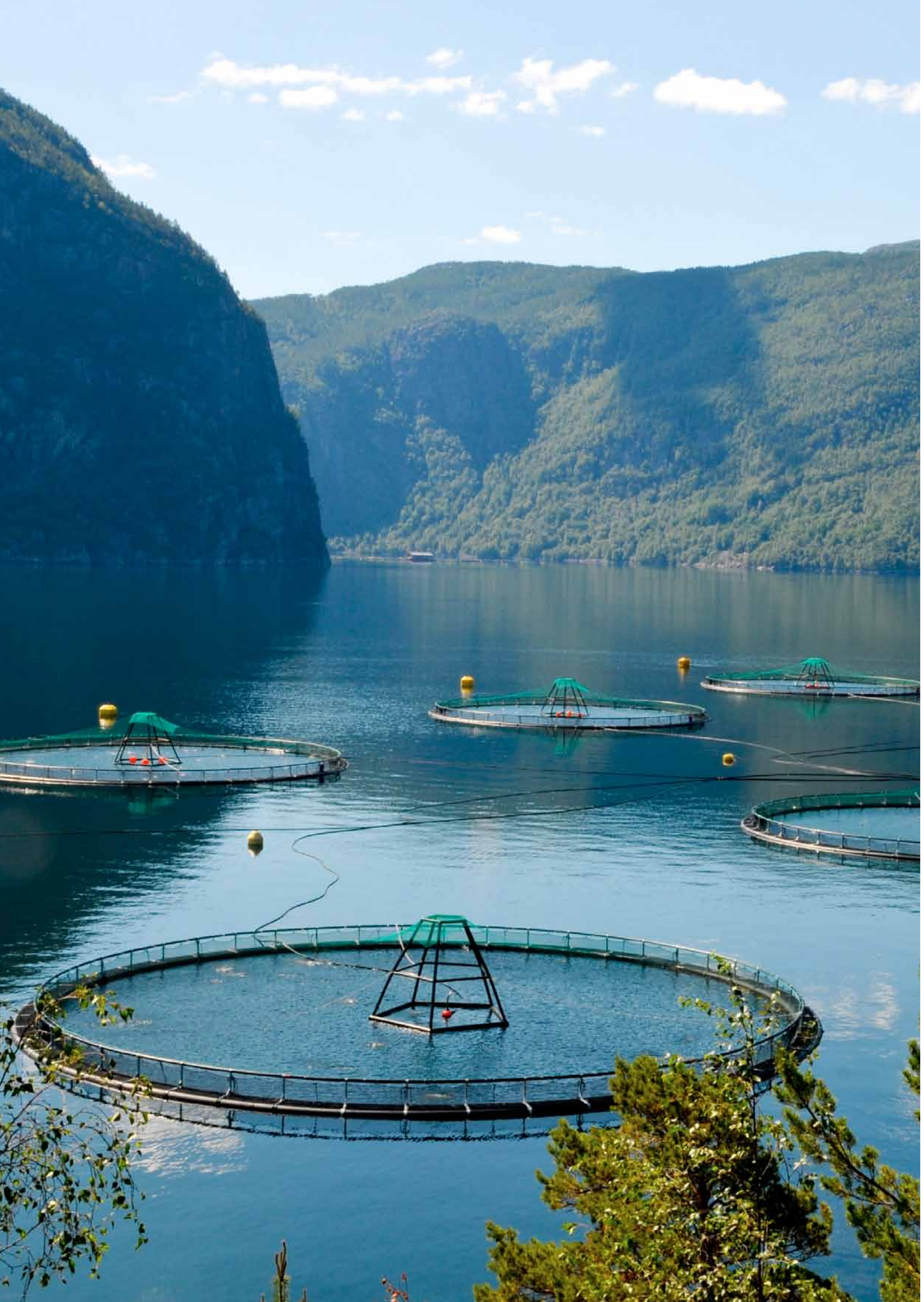
In a consultation paper submitted to the Food Safety Authority in 2009, the IMR recommended that the number of hosts (salmon and trout) should not be increased until the challenge regarding lice had been resolved.[16] Since 2009, conventional licences have not been allocated. However, the government will grant 45 "green biomass licences" in 2013 in order to stimulate the development and use of more environmentally friendly technology. These "green biomass licences" will be allocated to producers who commit to use technology or operational methods that reduce the risk of escapes or that secure a certain level of lice per fish and a certain number of delousing treatments per production cycle.[17]

In order to continue to grow, the industry must overcome the environmental challenges it faces today. Although there is disagreement as to how important some of the challenges are, it is agreed that the loss and mortality rates of salmon are too high and that there is room for improvement. Reducing the number of escapes and the amount of lice would not only have positive effects on the environment; these are also economic parameters that directly affect the bottom line.

* Although feed is an important parameter regarding sustainability of aquaculture, it is a production input factor for all technologies. Due to lack of data, this report will not consider feed usage of different technologies; feed resources are therefore considered to be beyond the scope of this report.

Parameters	Descriptions
Escapes[18]	Escaped salmon can spawn with wild salmon and affect the survival rate and genetic integrity of wild salmon populations. According to the IMR the number of escapes must be reduced to make fish production environmentally sustainable.
Lice[19, 20]	Salmon lice can reduce growth, affect reproduction and increase mortality rates amongst wild fish populations. The infection pressure on wild fish seems to have increased in recent years due to fish farming.[21]
Fish welfare*	The welfare of fish is affected when they are held in captivity as opposed to their natural habitat. Although difficult to monitor directly, fish welfare is believed to be related to factors such as fish density, temperature, water quality, disease, etc. The IMR notes that the fish mortality rate in production systems is a rough indicator of fish welfare.[22]
Climate effects	Transportation and operation of some system facilities lead to carbon emissions. Climate effects will become increasingly important if the industry starts using new technologies that require more energy than today's open systems.
Direct pollutants / chemical emissions	Chemical emissions from delousing substances and medicines can be detrimental to the environment. The IMR states that there is a need for more knowledge regarding chemical emissions through fish feces and waste feed.[23]
Discharges of nutrient salts and organic materials	The IMR concludes that the risk of regional eutrophication is low given today's production level.[24] However, it notes that the risk may be higher in local areas. The risk may also increase if production increases.
Zoning	There are certain challenges regarding the zoning of fish farms. The Area Committee that was appointed by the Norwegian government noted that fish farm operations may have negative consequences for other stakeholders such as fishermen and wild salmon interest groups.[26]
Input factors in construction of system	Materials and energy consumed in production of the containment system lead to emissions of direct pollutants, chemical emissions and carbon emissions.

Table 2: Main environmental challenges for the Norwegian salmon farming industry
* We assume that fish mortality is a result of fish welfare, and that poor fish welfare leads to higher death rates. We include viruses and diseases in fish welfare.



Technologies for aquaculture given Norwegian conditions

Different technologies are used for the salmon's freshwater and seawater phases. The technologies for salmon farming can be divided into six main categories, as illustrated in Figure 2. This report does not consider further development of already commercialised technologies, but instead focuses on new technology development. Land-based flow-through systems, open containment systems with coastal net pens, and freshwater production in recirculating aquaculture systems are therefore beyond the scope of this report. Furthermore, the development of closed systems has mainly focused on coastal near-shore cages, so closed containment systems with offshore cages are therefore considered to be beyond the scope of this report. This report considers the following technologies:

1. Land-based: Recirculation aquaculture systems (RAS)
2. Sea-based: Open containment systems with offshore net pens
3. Sea-based: Closed containment systems with coastal cages

	Land-based	Sea-based	
Within scope	**Recirculating aquaculture systems (RAS)** • Water is pumped through tanks on land • Water is partially reused, and the percentage of recirculation varies	**Open containment systems with offshore net pens** • Same as "Open containment systems with coastal net pens", but located further out to sea with higher flow rates and significant wave amplitudes	**Closed containment systems with coastal cages** • There is a physical barrier between the water inside and around the cage. The Norwegian Board of Technology divides closed systems into four levels, where level 1 is the simplest barrier for water only, while level 4 has strict separations for particles, virus, organic materials and more[26] • Defined as coastal according to flow rate and significant wave amplitude*
Beyond scope	**Flow-through systems** • Water is pumped through tanks on land • No recycling of water	**Open containment systems with coastal net pens** • Seawater flows through the net pens • Located in proximity to the coastline or in fjords	**Closed containment systems with offshore cages** • Same as "Closed containment systems with coastal cages", but located further out to sea with higher flow rates and significant wave amplitudes • Can be on or below the water surface, or a combination

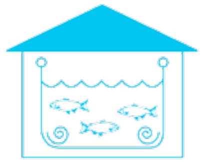
Figure 2: Descriptions of salmon farming technologies

Today, land-based flow-through systems or RAS are commercialised for the freshwater part of the production cycle, i.e. the hatcheries and fingerling production. For the saltwater part of the production, from smolt to slaughtering, open coastal systems are used. Open coastal systems consist of three main components: floating collar, net, and mooring. There are two main trends in commercial cage technology: polyethylene-based pens and steel pens. Polyethylene pens represent the technology most widely used in Norway.[27] The total cost of production is currently about NOK 23 per kg.[28]

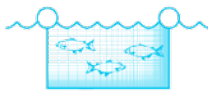
Extended smolt production entails keeping salmon from about 200 g in closed systems until it reaches a weight of 1 kg. The fish is then transferred to open net pens. Thus the time the fish spends in closed cages before being transferred to open net pens is extended. In Norway this phase has been considered as a possible means of introducing new technologies, particularly for closed systems on land or in the sea.[29]

Overview and Assessment of New Salmon Farming Technologies

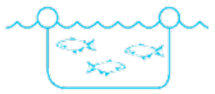
Accenture has mapped projects, both in Norway and globally, for each of the three technologies considered in this report:



Recirculation aquaculture systems (RAS)



Open containment systems with offshore net pens



Closed containment systems with coastal cages

Future salmon aquaculture production technology in Norway

Thus far, the industry in Norway has been able to grow by increasing the number of biomass licences and locations. Presently, however, the availability of locations has become a limiting factor, and Norwegian authorities have placed restrictions on the allocation of new biomass licences. Consequently, the most effective alternatives for achieving industry growth are by optimising existing technology or by developing new production technologies. Losses in the production process due to escape, disease, sea lice, and mortality have direct economic impacts as well as environmental impacts. Shorter production time in open net pens allows for greater flexibility in the management of seawater biomass licences. Reducing production time in seawater could therefore further reduce the risk of losses and increase the output volumes of existing locations.

Map of Norwegian and global projects

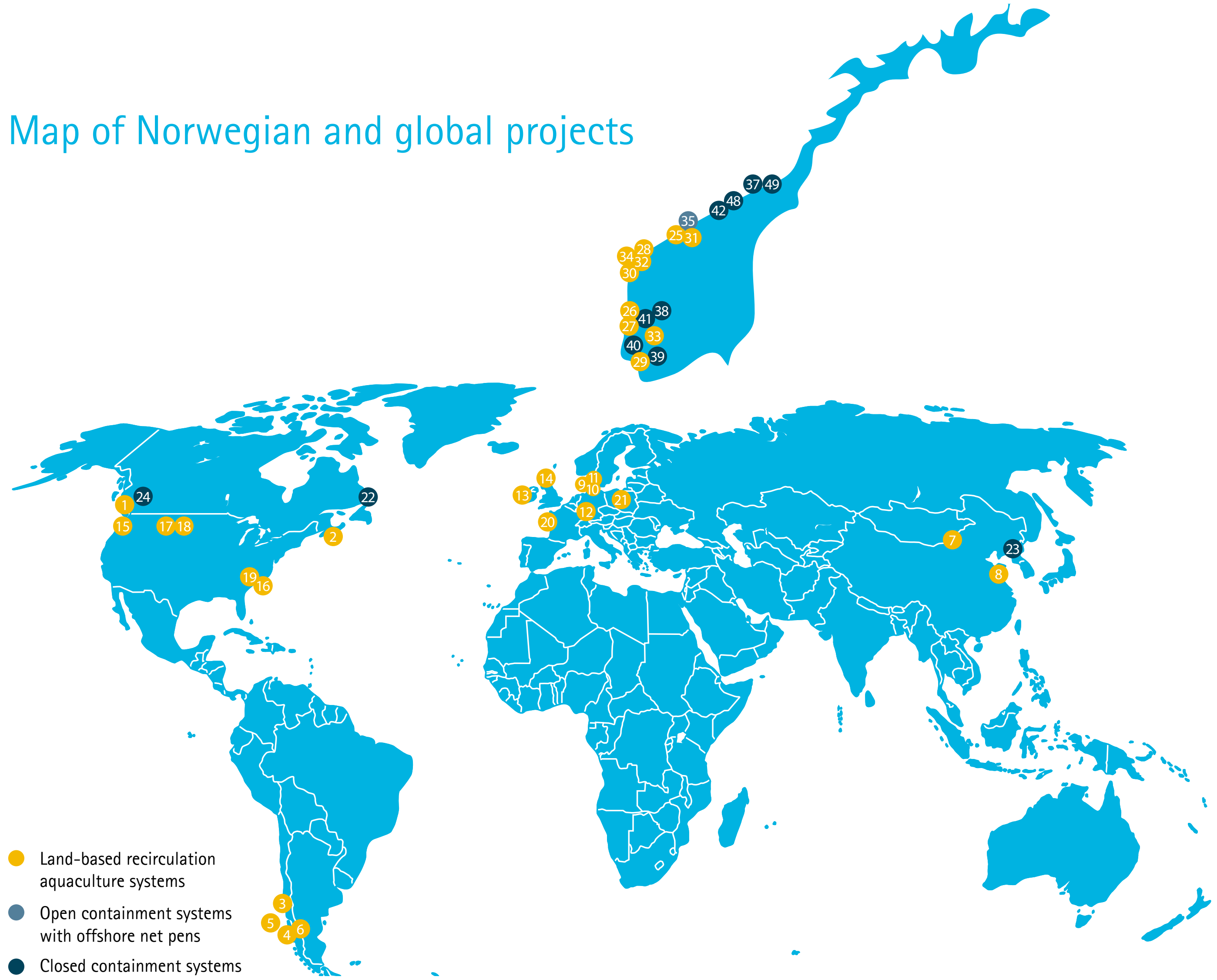


Figure 3: Map of Norwegian and global projects for land-based recirculation aquaculture systems, open offshore systems and closed coastal systems*

* Though not exhaustive, this map provides an overview of many of the projects in the area; from planning and full-scale pilots to commercialised farms. Further details on each of the projects can be found in the appendix, chapters 9.3 and 9.4.

Global projects

RAS technology has a relatively global spread whereas, by contrast, only a limited number of projects for open offshore systems and closed coastal systems were identified in the course of this study. Despite a relatively wide geographic spread of RAS sites, production volumes are presently very low. Various small-scale operations exist, as well as sites where RAS serves as one part of a larger production chain. Nonetheless, commercial full-cycle RAS production has now been established and is actively running in Canada, the United States, Denmark, China, and Chile.

Accenture found no projects for open offshore systems, and the use of closed coastal systems was found to be limited. The technology for closed coastal systems was developed in Canada, where several full production cycles have been tested. Agrimarine is amongst the largest producers, and Canadian producers are working towards spreading this technology to other countries, including China and Norway.

Norwegian projects

In Norway, most projects are in the research and development phase.[30] RAS has been piloted for extended smolt production and holding cages. Offshore cage technology is still immature, as there are technological challenges regarding offshore environmental conditions. There have been several pilots for closed coastal systems, mainly focused on extended smolt production, an extension of current juvenile production whereby salmon is kept on land above the current 250 g weight limit (between 200 g and 1 kg).

Experiences from potential salmon farming technologies

Recirculating aquaculture systems (RAS)

On a global scale, the development of RAS technologies is now mature, and there are several projects for full-cycle and extended smolt production.* Canada and China have commercial production facilities using full-cycle RAS production of salmon, but production volumes are very small due to large initial investments and high production costs. In Norway, RAS pilots have been built for extended smolt production and holding pens. Nonetheless, the technology has only been commercialised for certain species, such as halibut and turbot.

Examples of ongoing projects include:

- The Aquafarm Equipment project by Marine Harvest in Skånevik, Eldøyene is a pilot project for extended smolt that plans to start testing during the autumn 2013.
- The AquaOptima project in Kråkvag is a pilot project for full-cycle production. Although the project is still in the planning phase, the total cost for pumping and oxygen is estimated at NOK 1 per kilo salmon.[31]
- Bremnes Seashore is currently building a land-based holding pen facility in Øklandsvåg.[32] The test operation is planned to start in the summer of 2014.[33]

In the short term, RAS in Norway appears to be more suitable for extended smolt than for full-cycle production. Norway has a long coastline which favours sea-based production. Large tanks on land would conflict with other interests and, although the economic aspect is not considered, many stakeholders believe that the costs for full-cycle RAS are too high. However, more projects should be initiated and financed in order to better understand the potential of RAS technologies for Norwegian conditions in the long term.

Open containment systems with offshore net pens

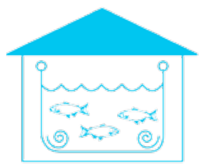
SINTEF[34] conducted a mapping survey of existing salmon farming technologies, including offshore systems. It found technology for open offshore systems to be premature, with few full-scale pilots for salmon and several proposals still in the planning phase. Furthermore, there are persisting challenges with existing technologies. A pilot by Lerøy Hydrotech, for example, was destroyed due to harsh weather conditions offshore in 2011.[35] Another challenge is the fact that suppliers of offshore technologies receive higher margins from the oil and gas industry. Accenture does not believe that offshore technologies will be applicable in the short term, due to technological challenges and few established projects. New pilot projects must thus be initiated to explore the true potential of offshore technologies.

Closed containment systems with coastal cages

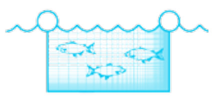
Norway and Canada have been key actors in several large-scale pilot projects for closed coastal. Large-scale projects have been undertaken by AgriMarine, Aquafarm Equipment, Optimized Postsmolt Production, Preline, Aquadom and AkvaDesign* among others. These projects are in the research and development stage and focus mainly on extended smolt production.** Full-cycle production projects are mostly in the research and development stage. Based on results from these projects, it is too early to tell whether these technologies will prove significantly better than current technologies if environmental and economic aspects are taken into account.

AgriMarine has operated closed-system salmon farms since 2005. The estimated energy usage for pumping and oxygen is 0.3-0.45 kWh/kg salmon, given a fish density of 75 kg/m3.[36] AgriMarine contends that increased fish density is the key factor for making closed systems profitable.[3] AquaDome's prototype energy costs are about NOK 1 per kilo salmon.[37] AkvaDesign has not yet published its results, but states that the energy costs have thus far been higher than affordable.[38] The Aquafarm Equipment project launched a closed coastal system in July 2013 and plans to start testing in autumn 2013.[39] The Optimized Postsmolt Production project is ongoing, and the results have not yet been published.[40]

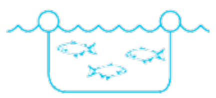
*See page 44 Table of international projects and page 50 Table of Norwegian projects in appendix
**Extended smolt: 200 g–1 kg; see page 13



Recirculation aquaculture systems (RAS)



Open containment systems with offshore net pens



Closed containment systems with coastal cages

Reflections and Accenture's point of view

In the future, technologies and combinations of technologies that are more resistant to resolving sustainability challenges will persist. Accenture believes that future production methods for salmon will be more diversified. To be able to resolve sustainability challenges and optimise total production volumes, the technology will probably vary according to location and production phase.

In the short term, the technologies for extended smolt production in RAS and closed coastal systems are the most mature. Several projects for these technologies have been established and will publish their results within the next two years. In the long term, it is difficult to conclude as to which technologies will be commercialised. Results from extended smolt projects will probably give some indication of the potential for full-cycle production, while more projects for open offshore net pens must yet be carried out.

Model for assessing environmental impact

In this chapter we rank four cases in terms of the environmental impact of a technology applied in a specific setting. We consider full-cycle production in two of the three technologies within the scope of this report: RAS and closed containment systems with coastal cages. Open offshore net pens will not be considered because the technology is immature and few full-scale pilots have been built. We also consider a case for today's open coastal net pens and one for extended smolt production in a closed coastal system.

Purpose

Accenture developed a scoring model in order to highlight the environmental impact of different salmon farming technologies in a structured manner. The model is based on a set of carefully selected parameters that cover the environmental impact of a given technology applied in a given setting. The parameters are based on four of the Norwegian government's five focus areas for environmental sustainability within aquaculture (feed resources are not considered; see page 5), which Accenture supplemented with additional parameters based on discussions with interview stakeholders. These additional parameters are included in order to highlight the overall environmental impact. This is important because if one based an assessment on a restricted set of parameters, the conclusion might be biased. Accenture then weighted each parameter to ensure that the total score reflects the relative importance of the parameters and, consequently, paints a picture of the overall environmental impact. Several dynamics may affect the weighting factors, such as further research on the impact of parameters, environmental development, and technological development. To address these dynamics, the model includes a sensitivity analysis of the weight factors we consider most likely to be affected. Stakeholders will have different opinions regarding the importance of each parameter in the model, and Accenture wants this model to be used as a starting point to discuss the overall environmental impact. The model does not consider economic factors.

Description of the model

The model is dynamic, as parameters, weights and cases can be customised to the model application. The model can easily be adjusted for more specific cases or for other requirements.

The parameters

The model is based on eight parameters (see Table 4) which reflect the entirety of what industry stakeholders have emphasized as current and potential environmental challenges in the industry. The parameters deal not only with issues directly affecting farmed salmon and wild salmon populations, but also with effects related to the local and global environment, such as carbon emissions and zoning. Consequently, when assessing the impact of a case, applying this model ensures that the overall environmental impact is assessed.

Table 4 provides a description of each parameter. For instance, escapes can be related to unforeseen incidents (weather, boat collisions, etc.) and to planned activities (smolt transfer, etc.). When Accenture set the score for a given parameter, all subcriteria were balanced.

Parameters*	Description	Scoring Criteria
Escapes	Risk of salmon escaping containment and consequently affecting wild salmon populations.	Risk of escapes related to unforeseen incidences. Risk of escapes related to planned activities.
Lice	Generation and spread of salmon lice affecting farmed and wild salmon.	Contamination risk for fish inside the system. Contamination risk for fish outside the system.
Fish welfare**	Capture factors affecting fish welfare ultimately leading to salmon mortality.	Fish ulceration (sores) Non-observable fish welfare. Viral diseases.***
Climate effects	Indirect or direct emission of greenhouse gases.	Energy usage. Carbon emissions. Energy-producing properties.
Direct pollutants / chemical emissions	Direct pollutants emitted, primarily related to medication and chemical lice treatments	Intentional pollutants and chemical emissions. Unintentional pollutants and chemical emissions.
Discharges of nutrient salts and organic materials	Discharges of nutrient salts and organic materials.	Organic substance emissions. Nutrients emissions.
Zoning	Area claimed by the fish farming system.	Sea space. Onshore space.
Input factors in construction of system	Input factors required in the production of containments systems.	Materials consumed. Energy consumed.

Table 4: Descriptions of parameters and scoring criteria

* Although feed is an important parameter regarding sustainability of aquaculture, it is a production input factor for all technologies. Due to lack of data, this report does not consider feed usage of different technologies; feed resources are therefore considered to be beyond the scope of this report. See appendix, page 54 for details.
** We assume that fish mortality is a result of fish welfare, and that poor fish welfare leads to higher death rates compared to good fish welfare
***Viral diseases affect the mortality rate and level of fish welfare of the fish in the farming system. In addition, the Institute of Marine Research states that despite uncertainty regarding the risk of infection from farmed salmon to wild salmon populations, the risk is considered to be low. Our model therefore assumes that viral diseases mainly affect the fish in the production system, and that virus diseases affect fish welfare.

Weighting of parameters

The parameters presented in the model are not of equal importance in terms of environmental impact. In order to ensure that the total score reflects the relative importance of the parameters, the parameters are weighted high, medium or low. The weight factors in this report are primarily based on research and publications by the Institute of Marine Research. However, information gathered through interviews and publicly available sources have also been taken into account. The importance of the different parameters is a much debated topic, and different stakeholders often have different views regarding the importance of each of the parameters. As a consequence information from different stakeholders and sources has been balanced.*

The weights are based on the assumption that production takes place along the Norwegian shore or in a Norwegian fjord. This implies the following general assumptions:

- Temperature, feed factor, growth, release date, fallowing period and other external production factors are considered to be equal for all cases, so that the production cycle is equal in all cases
- The salmon farming system is in the proximity of wild salmon populations
- Salmon lice are present, and the introduction of farmed fish will stimulate lice generation if the fish have unrestricted contact with the seawater
- Viral diseases may be present in the area, implying a risk of infection
- Energy usage implies indirect emissions of greenhouse gases

*It should be noted that for some parameters the actual environmental impact is not thoroughly documented. The weight factors portray the relative importance of the parameters based on currently available information, but the relative importance may change over time as more research is conducted.

Table 5 shows the weights and explains their rationale.

Parameters	Weight	Rationale
Escape	High	Escaped salmon is one of the most problematic environmental factors in the industry.[14] Because the evidence for escaped salmon impacting wild salmon populations is not indisputable, the topic remains a contentious political issue.
Lice	High	Lice are one of the most problematic environmental factors in the industry.[14] "Infection pressure of salmon lice on wild salmon seems to have increased in areas of intensive salmon farming".[41] In addition to the direct health impact on farmed salmon and wild salmonids, lice infections involve chemical treatment and/or medication.
Fish welfare	Medium	Documentation of fish welfare is becoming increasingly important for consumers and authorities, and operating regulations are becoming stricter. Poor fish welfare ultimately leads to higher mortality rates, but impacts outside the system are believed to be limited.
Climate effects	Low	Compared to pig and chicken, salmon farming has a relatively high energy and protein retention[42]. This may change in the future due to development of more energy retention food sources and stricter emission regulations.
Direct pollutants / chemical Emissions	Medium	Medication and chemical lice treatments may potentially affect local fauna and flora.
Discharges of nutrient salts and organic materials	Low	Only an issue for the local environment surrounding the production facility. Eutrophication on a regional level is considered low given today's production level.
Zoning	Low	Even though limited, land is currently not a scarce resource along the Norwegian shore. Zoning is, however, politically sensitive, partly due to esthetical considerations.
Input factors in construction of system	Low	The environmental impact related to the consumption of input factors in production of the containment systems is regarded to be low compared to other factors.

Table 5: Weights and rationale

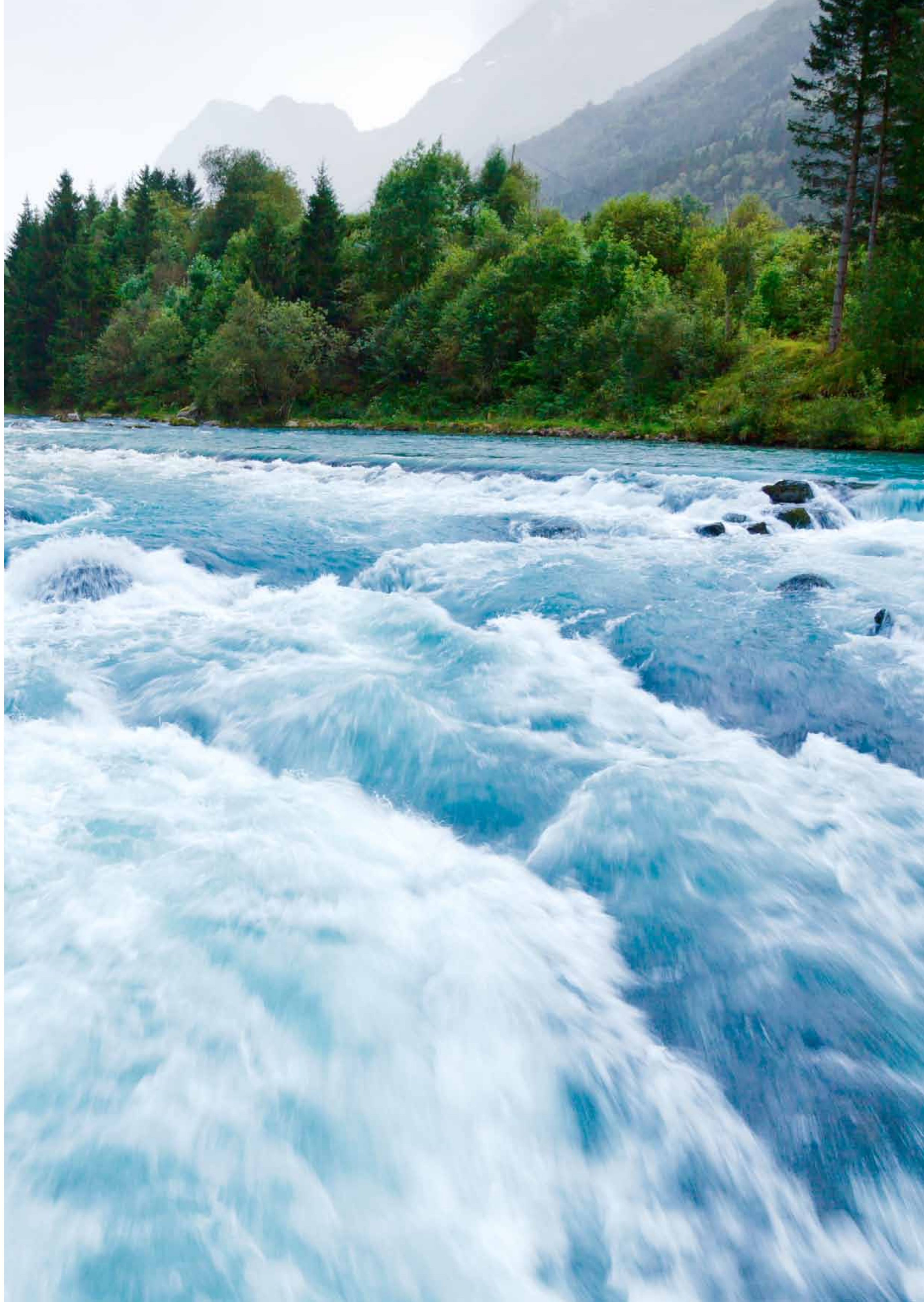
Ranking and comparing cases

Each case is ranked on a scale from 1 to 5 according to its environmental impact represented by a given parameter. For instance, a case with a relatively low probability of escapes will score high on the escape parameter.

Based on the given weights and scores for the different parameters, the model calculates a total value for each case.

It is thus possible to compare different cases within and across parameters and on an overall level. As discussed, the weight scale may need to be adjusted over time due to findings of further research on the impact of the respective parameters and to environmental and technological developments. Since the total score of a case depends on the weighting, this implies that the total score for each case would be affected differently and that comparisons may yield different results.

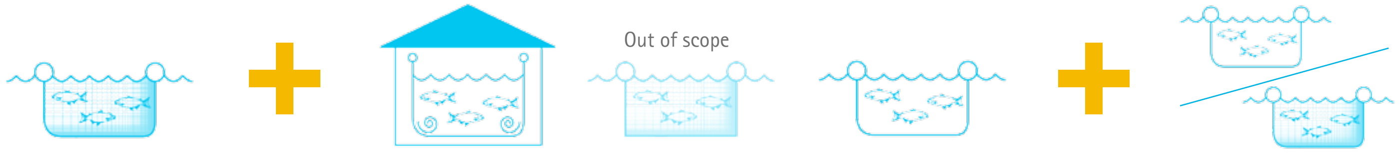
Poor
Fair
Good
Very Good
Excellent



Application of the model

In the following chapter the model is used to compare the environmental impact of four different cases based on technologies outlined on page 17.* The technologies, either individually or in combination, are placed in cases where specific assumptions – such as system specifications and locational factors – enable us to undertake a holistic assessment. In addition to case-specific assumptions, the common assumptions discussed on page 23 are applied to each of the four cases.

*Offshore installations are excluded because technological development is mainly at the research and development stage, and there are still technological challenges with existing technologies; see page 20.



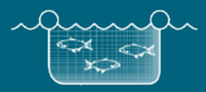
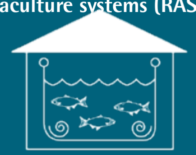
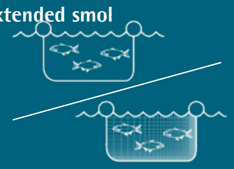
Cases		
Case 1: Today's solution – open coastal net pens 	Description: This case is based on open coastal net pens where seawater flows through the net pens without any form of water treatment.	Assumptions: • System is close to land • Distance to seabed is in line with regulations • Water, particles and parasites flow unhindered through the net pens • Net pens are made of flexible polyethylene
Case 2: Closed coastal cages 	Description: This case is based on closed coastal cages where there is a physical barrier between the water inside and around the net pens. Both closed systems with flexible and rigid walls are included in this case.	Assumptions: • Walls are impenetrable • Water can only enter or exit through intake/outlet • Particles and parasites are filtered at water intake/outlet • Water temperature determined by water pumped in
Case 3: Recirculating aquaculture systems (RAS) 	Description: This case is based on RAS which are closed containment systems placed on land that filter, treat and recirculate the water used for production	Assumptions: • Water is pumped from the shore • Particles and parasites are filtered • 90% of the water is recirculated and reused • The system is placed near the shore
Case 4: Extended smol 	Description: This case is based on a combination of closed coastal cages and open coastal net pens in the sea. Smolt up to 1kg is produced in the closed system and then transferred to the open system	Assumptions: • Smolt is transferred at 1kg from closed to open containment • Same assumptions as for case 1 and 2

Table 6: Case descriptions and assumptions

Results

The four cases are ranked in Table 7. The scores are based on information gathered through extensive interviews with stakeholders throughout the fish farming value chain; see appendix page 42, reports, and other relevant sources. Consequently the ranking will reflect input from various perspectives such as technology companies, NGOs, industry organisations, academia and governmental agencies. We have used our best judgment when aggregating these inputs into scores, and we believe the comparison provides a good basis for further discussion of the environmental impacts of the respective cases.

Parameters	Weight	Open coastal net pens	Closed coastal cages	Recirculating aquaculture systems	Extended smolt	Comments
Escapes	High	1	4	5	2	Cases with closed technologies score higher because the pens are impenetrable and more robust. RAS scores highest because it is located onshore, where salmon most likely cannot escape.
Lice	High	1	4	5	2	Cases with closed technologies score higher because water can be filtered and disinfected [43] in and out of the system and pumped from depths with fewer lice. RAS scores highest because the system is located onshore and only 10% of water comes from the sea (90% is recycled).
Fish welfare	Medium	3	4	4	3	Despite higher fish density, cases with closed technologies score slightly higher due to water temperature and nutrition/oxygen level control. Fewer lice and diseases will positively affect fish welfare.
Climate effects	Low	4	2	1	3	Cases with open technologies score higher because they use less energy. RAS scores lowest due to high energy consumption related to water pumped up above sea level.
Direct pollutants / chemicals	Medium	1	3	4	2	Cases with closed technologies score higher score because medication/treatment has no unfiltered contact with seawater. Fewer lice reduces the need for treatment/medication.
Discharges of nutrient salts and organic materials	Low	1	4	5	2	Cases with closed technologies score higher because waste mass can be collected. RAS scores highest because 90% of the water is recycled.
Zoning	Low	3	4	1	3	Case 2 scores highest because new and remote areas can be taken into use. RAS scores lowest score because it claims land along the coastline.
Input factors in construction of system	Low	4	2	1	3	Case 3 scores lowest because RAS systems require relatively more input factors in production compared to the other cases
Weighted average (1–5)		1,9	3,6	3,9	2,4	

Table 7: Results

Discussion

Based on the weighted scores, it is evident that cases based on closed technologies have fewer environmental impacts than cases based on open technologies, given today's environmental challenges. Impenetrable walls prevent fish from escaping and lice from entering and leaving the system, and closed walls make it possible to collect waste mass such as feces and waste feed.

Closed coastal cages can also be placed in new areas where conditions are not suitable for today's open net pens. The main disadvantage for the cases with closed systems is high energy consumption related to water pumping compared to the case with open net pens. The need for space can also be a disadvantage if closed systems are placed on land.

It is important to note that the model focuses exclusively on environmental impact and does not take economic aspects into account. Accordingly, the RAS case is ranked best case solely from an environmental perspective. An analysis that factors in economic aspects must be undertaken in order to conclude which case is most feasible given Norwegian fish farming conditions.

Sensitivity analysis

The total score is sensitive to the relative weights associated with each of the parameters. As discussed, weighting is based on a synthesis of currently available information. Future research and development may lead to new knowledge which may necessitate adjusting the weights. For example, in the analysis above, escapes are weighted as "high". New research may indicate that the assumption of genetic dilution of wild salmon is exaggerated, which would justify an adjustment of the weight factor. In order to address this uncertainty, we conducted a sensitivity analysis.

Based on current environmental drivers, we identified a set of future states. These states highlight how the results would differ if the relative importance of the parameters changed.

Future State 1

- Due to increased awareness of global warming and stricter regulation of greenhouse gas emissions, the climate effect parameter is weighted as **high** instead of **low.**
- Due to political tension regarding coastal areas and public rights concerning the shoreline, the zoning parameter is weighted as **high** instead of **low**
- Due to increased awareness regarding sustainable consumption of resources, the input factors in construction of system parameter is weighted as **medium** instead of **low**.

Table 8 shows the new total scores after changing the weights of the three parameters climate effect, zoning, and input factors in construction of system. The new weights result in a slightly higher score for case 2 compared to the RAS case. This is because the RAS case scores low on the climate effect, zoning and input factors in construction of system parameters while the closed coastal cages in case 2 scores relatively high. The relative ranking of cases 1 and 4 remains the same.

Future State 2

- Due to research and new knowledge within genetics and medical research and/or the use of sterile salmon, the escape parameter is weighted as **low** instead of **high**.
- Due to the introduction of new technologies or medicines, lice is no longer considered an environmental challenge, and the lice parameter is weighted as **low** or **medium** instead of **high**.

Table 9 shows the new total scores after changing the weights of the two parameters escapes and lice to low instead of high. This does not alter the relative ranking of the four cases, but we see that case 2 and the RAS case now are almost equally good.

Future States 1 and 2

If both Future States 1 and 2 materialise, the relative ranking would change:

Table 10 shows the new scores given that both Future State 1 and 2 occur. Cases 2 and 3 with closed systems perform poorly compared the original weight factors, while the cases with open technologies perform better. The new weight factors change the relative ranking, as the RAS case is no longer considered environmentally friendly but rather the worst of the four cases. Case 2, closed coastal pens, receives the highest score given the new weights.

Key takeaways

- It is difficult to determine which specific case would have the least environmental impact in the future. However, given our future states based on current environmental drivers, the case based on closed coastal pens performs well in all states.
- While the RAS case is best given today's cases, it is actually the worst case from an environmental perspective if both -future states 1 or 2 occur.
- If both Future States 1 and 2 occur, the case with closed coastal cages receives the highest score. This implies that the extended smolt case would be better the longer the fish remained in the closed coastal cages compared to open net pens.
- The results are highly sensitive to weights of the model. Future developments will most likely alter the relative ranking due to changing weights. Technological development may also change the parameter scores for the cases.
- In our base case the **lice** and **escape** parameters are weighted as high, which implies that the overall result is particularly sensitive to changes in scoring within these two parameters. One should consequently pay attention to technological development going forward to verify that the scoring remains correct.

	Open	Closed	RAS	Extended
New weighted average (1-5) in future state 1	2.3	3.4	3.1	2.5
Change from original	+0.5	-0.2	-0.8	+0.2

Table 8: Future State 1

	Open	Closed	RAS	Extended
New weighted average (1-5) in future state 2	2.2	3.4	3.4	2.5
Change from original	+0.3	-0.2	-0.5	+0.1

Table 9: Future State 2

	Open	Closed	RAS	Extended
New weighted average (1-5) in future state 1 + 2	2.7	3.2	2.6	2.7
Change from original	+0.8	-0.4	-1.3	+0.3

Table 10: Future State 1 and 2 combined

Next step for the Model

Several steps should be considered in order to further improve the model and expand its scope of application.

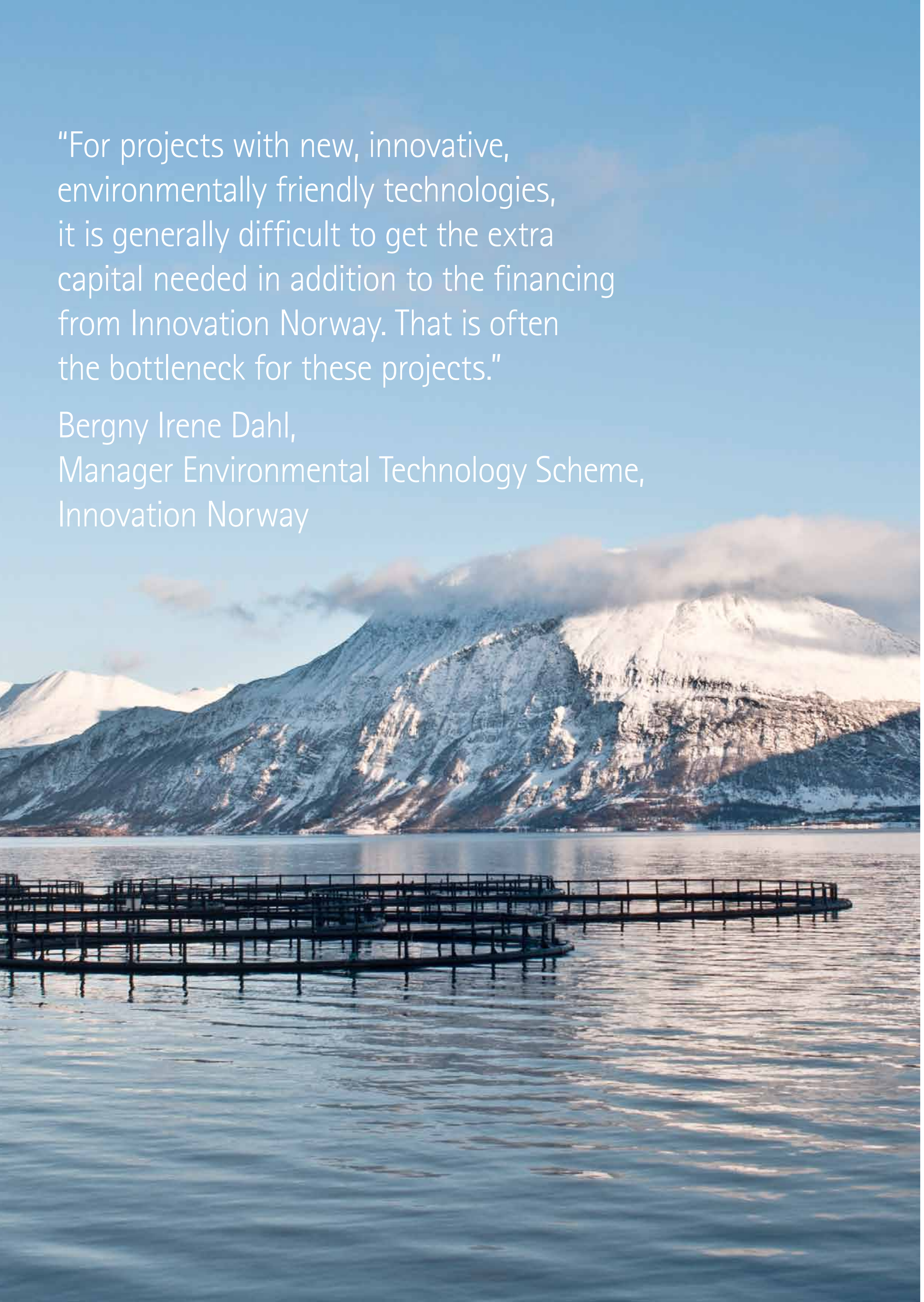
- Since several of the technologies are in the developmental phase, access to empirical data is limited. As technologies mature, one should seek to leverage empirical data across parameters to increase the robustness of the analysis. However, since the model is likely to be used to evaluate emerging technologies, one may still have to rely on qualitative assessments.
- The model in this report focuses on the operational part of the life cycle and on the consumption of input factors in construction of the fish farming systems. However, the environmental impact of processes such as distribution, maintenance and decommissioning could also be assessed in order to increase the comprehensiveness of the model.
- One should consider granting independent third-party ownership of the model. Such a party could develop the model, especially with regards to life cycle assessment. Furthermore, the party could guide and monitor the use the model and ensure that different cases received an objective and robust score.

In the future, application of the model could be extended. Our interviews show that several companies do not use a particular framework for assessing the environmental impact of salmon farming technology. Some companies may therefore find the model a useful tool when evaluating technologies or internal projects to which the model could be applied. Furthermore, the model could help applicants in documenting the environmental impacts of the relevant fish farming technologies in connection with applying for "green biomass licences". Similarly, it may help local authorities evaluate applications.

It should be emphasized that if the model is to be acknowledged by industry stakeholders, it must allow them to influence its methodology and further development.

"For projects with new, innovative, environmentally friendly technologies, it is generally difficult to get the extra capital needed in addition to the financing from Innovation Norway. That is often the bottleneck for these projects."

Bergny Irene Dahl,
Manager Environmental Technology Scheme,
Innovation Norway



Evaluation of barriers to and opportunities for more sustainable technology

To secure sustainable growth for the salmon farming industry, an important aspect of the efforts made is the development of more sustainable production methods. There is a need to conduct more research, further testing of new technologies, and documentation and sharing of results in order to achieve the long-term goal of fully commercialised solutions. The stakeholders that play a key role in this development are technology suppliers and producers supported by government authorities, research institutions, and investors. We identified some barriers to further development and opportunities to overcome them.

Barriers

Existing, proven production methods for salmon farming have been incrementally developed over the past forty years. When acquiring production assets, producers tend to focus on economic viability. Environmental externalities are often viewed as an issue that must meet government regulations rather than as a factor that affects the longevity of the industry. Accenture divided the main barriers to further development within the industry into five categories.

Regulations and public administration of the aquaculture industry

As explained on page 13, current regulations are adapted to the use of open systems. The laws for density, maximum smolt weights and fallowing periods in saltwater production are mentioned as barriers by several new technology suppliers because these laws impact the economy directly. The authorities must ensure that updated laws are based on documented research, which means that amending regulations can take years. This leads to uncertainty around the profitability of new technologies and provides little incentive to shift from open pens.

In addition, public administration of the aquaculture industry is fragmented, with many different interests to consider. Obtaining approval for new sites or for expanding existing ones can be long and demanding processes. The county councils coordinate the reviewal process for new sites, but several other sectoral authorities are involved in reviewing applications for compliance with various guidelines and regulations in areas such as pollution, animal health and welfare, harbours and fairways, biodiversity, and spatial planning. A licence may only be granted if all parties involved issue their approval.

Access to funding for start-up technology companies

Access to financing for new technology projects is one of the major barriers to development. Innovation requires large and risky investments in research and development. The aquaculture industry consists of many small producers with little or no funds for research and development, investment costs are often high, and it can take a long time to get past the first peak in the cost curve to achieve profitability and economies of scale.

The Norwegian support system for funding is extensive, from basic research to support for commercialisation of new technology.[44] Nevertheless, access to capital beyond financing from such programmes is generally difficult to acquire. The venture capital market in Norway is small, and especially the early stage investment segments are suffering.[45] In addition, public funding is spread over many different programmes, so the system can be difficult to navigate and there is no responsible authority to coordinate the development and qualification of technology.[44]

Disagreement between stakeholders

Interviews conducted suggest that stakeholders across the industry have different, often opposing opinions as to what the main industry challenges are, what the barriers to further development are, and how these should be overcome. In areas where scientists disagree, the stakeholders often use reports that support their view, for example, the degree to which lice and escapes have a regulating effect on the wild salmon population. Lack of consensus is a barrier in itself, as it prevents a focus of efforts.

Technological immaturity

As many new technologies are in an early phase of development, it is too early to draw any conclusions about long-term environmental impact or economic sustainability. In current projects, economic data are often based on estimates, and many projects have not yet published their results.

Concern that closed systems will harm Norway's competitive advantage

Interviews conducted indicate that there is some concern in the Norwegian aquaculture industry that development of closed systems may harm the natural advantages Norway holds. The use of closed systems may enable other countries to produce salmon more cost-efficiently than Norway. Another concern is that the use of closed systems, especially onshore, may affect the brand of salmon produced in Norwegian fjords and thereby reduce the price premium producers can expect in the market. This attitude may impede development of new technologies.

Opportunities to overcome barriers

Accenture formulated four key enabling initiatives that can contribute to overcoming barriers and making the industry more sustainable. The four initiatives are:

Government regulations

Government regulations are an important driver of development of new technology. To stimulate development of closed and offshore systems, it is crucial that regulations facilitate development so that, for example, hatcheries can apply for exemption from the 250 g weight limit, allowing smolt up to 1,000 g.[46] Regulations should be updated at a faster pace to keep up with changes in the industry.

There is little incentive for fish farmers with well operated open coastal net pens to take the risk associated with the transition to closed systems. Stricter regulation of, for example, lice, escapes, and fallowing in particularly exposed areas would force industry players to move in a more sustainable direction and perhaps look at alternative options to open coastal net pens. The risk is that premature regulations could have the undesired effect of inhibiting growth and development. Regardless of whether or not more stringent requirements are introduced, it is critical that the current regulations be enforced and no dispensations be granted to certain producers because this may affect production for neighbouring producers.

The aim for the "green biomass licences" is to encourage the use of new technological solutions or methods of operation which contribute to reducing the environmental challenges of escapes and the spread of lice.[47] It is still too early to say whether the "green biomass licences" will prove effective because the application deadline is October 1st 2013. Assessing the success of the "green biomass licences" will be important because they could play an important part in stimulating development of more sustainable technology.

There are many sectoral authorities involved in administrating the aquaculture industry. There is need to review not only the regulatory framework but also the administration of the aquaculture industry. A more coordinated and unified public administration, such as better coordination of government supervisory authorities, would make it easier for industry players to navigate the system and lead to shorter processing times. This would facilitate establishment of new sites and, ultimately, stimulate development.

One of the areas the authorities should focus on is reviewing the maximum allowable stocking density to determine whether the limit should be increased for closed systems. The density regulation is a major economic restriction and can affect the business case for many technologies. More knowledge about the relationship between fish density and fish welfare – such as water flow, oxygen levels – is necessary before new limits for closed systems can be set.[48]

Closed systems both on land and in sea are highly relevant for extended smolt production. As of 2012, it is possible to apply for dispensation from the 250 g weight limit for smolt in hatcheries on land and to keep smolt up to 1 kg.[11] The same regulations do not apply for extended smolt production in closed coastal cages. The application process for dispensation should be uncomplicated, and it should be relatively easy to obtain permission so as to stimulate more testing of closed technologies in addition to producing more knowledge about fish welfare in closed systems.

"To get a better informed and nuanced discussion of different technologies, it is important to develop a better knowledge base."
Jon Fixdal, Senior Project Manager, Norwegian Board of Technology

"The producers are the main force in developing the technology further and in making it sustainable. However, we see that the rate of technological development increases if we put pressure on the industry. "

Elisabeth Aune, Senior Advisor, Sogn and Fjordane County Council

Financing

One of the major barriers to further development of new technologies is lack of financing. While an extensive support system provides support for start-up companies, few schemes are directed specifically at environmentally sustainable technology in the aquaculture sector, and no governing body exists to coordinate the funding processes across different programmes. The Norwegian Board of Technology suggests that the authorities should review the support systems in terms of the number of players and the coordination between them.[44] The support system would be more manageable for applicants if there was a responsible party that had an overview and that could coordinate the different funding programmes. This entity could inform applicants where and how to apply for funding as well as coordinate the application process. A more navigable support system would perhaps encourage more companies to apply.

In addition to a better overview of the funding programmes, there is need for a funding programme aimed at supporting ideas for sustainable development within the aquaculture industry. Such a programme could be funded through public-private cooperation. Enova is an example of a funding programme that has been successful in increasing environmentally sustainable projects within energy consumption. Enova focuses on aiding the restructuring of energy use, converting to renewable energy sources, and providing financing as well as counselling and expertise.[49]

Enova

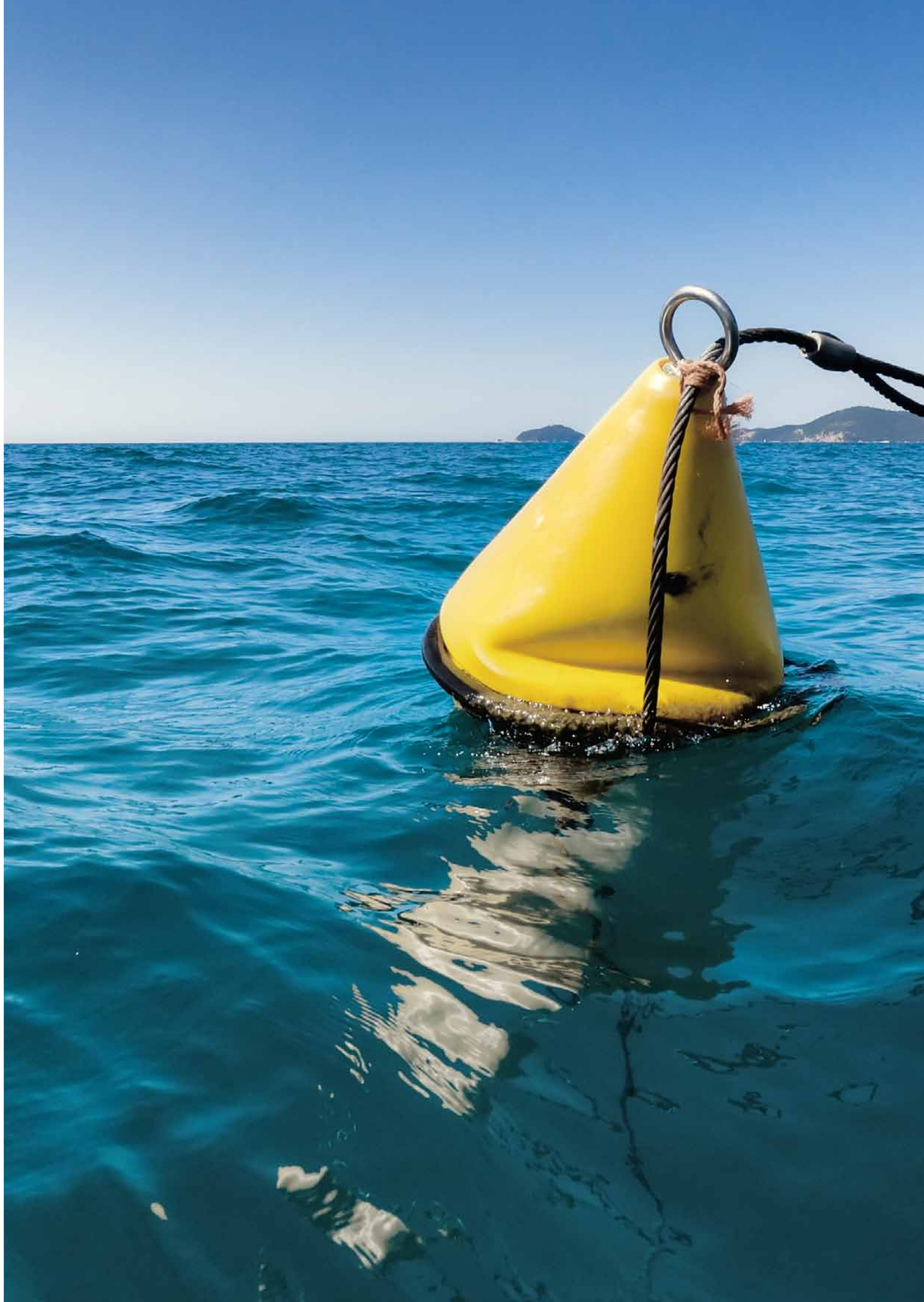
Enova SF was established in 2001 as a public enterprise owned by the Ministry of Petroleum and Energy. Enova promotes more efficient energy consumption and increased production of "new" renewable energy. Enova has targeted programmes and support schemes in the areas where the greatest effect of saved, converted or generated clean energy can be documented. Enova wants to become the driving force in the comprehensive work to create an energy-efficient Norway. [49]

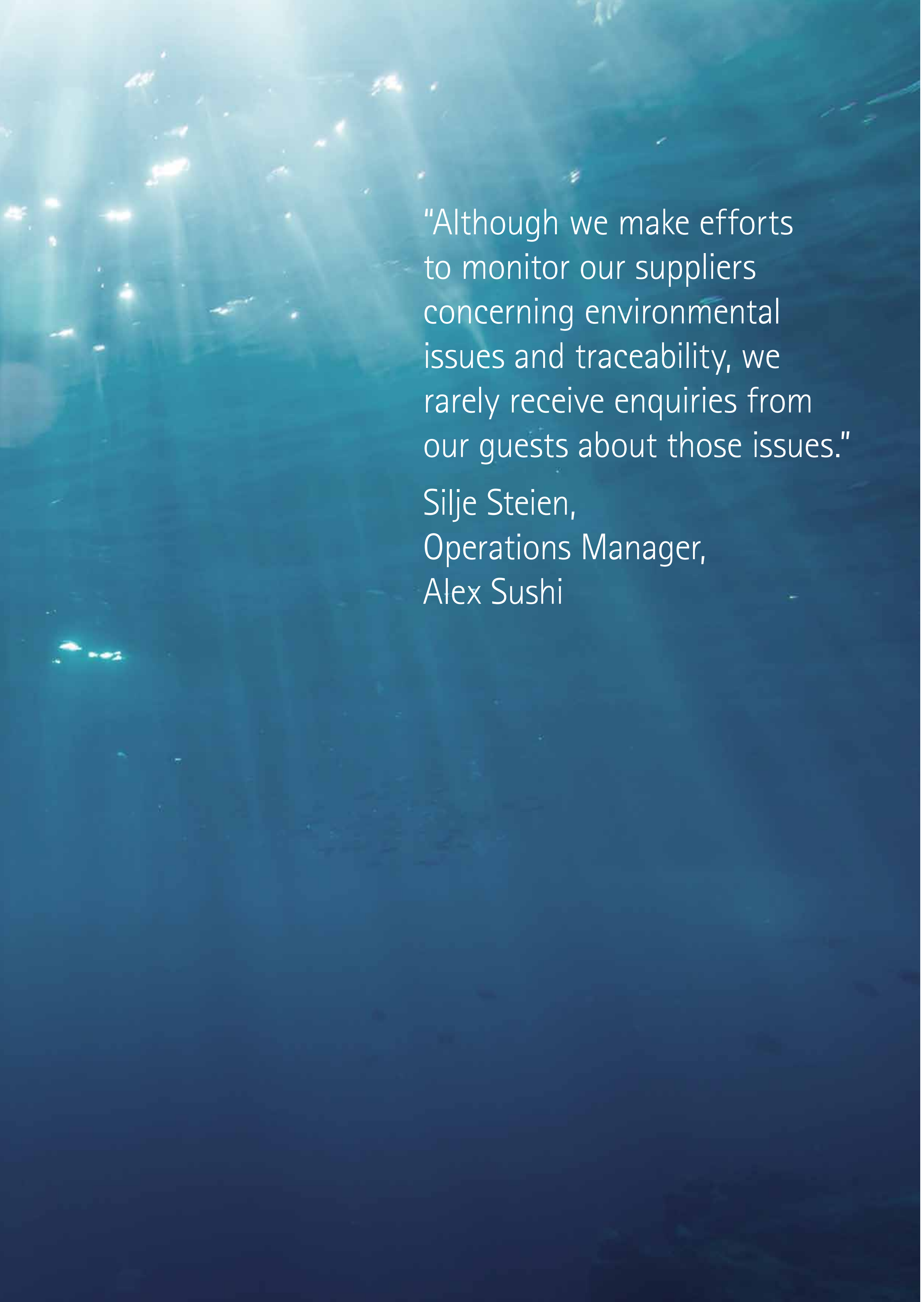
Case 1: Enova

Many of the technologies for closed and offshore systems are in the early stages of development and are consequently often in need of seed capital.* In addition to research grants and the founders themselves, angel investors represent a typical source of seed capital. An angel investor is often a wealthy individual who provides seed capital in exchange for convertible debt or ownership equity. Angel investors are often found among a founder's family or friends and might invest for reasons that go beyond pure monetary returns. Contact with angel investors is often established through referrals or attendance at symposiums. Groups of angels are often brought together at meetings where companies seeking seed capital can pitch their ideas. These meetings may be instigated by, for example, industry organisations, governmental institutions or angel networks. The establishment of such gatherings should be considered by the Norwegian fish farming industry organisations and governmental institutions in order to stimulate funding of salmon farming technology start-ups.

*Seed capital is a relatively small long-term investment aimed at growing companies in early stages and often carries high returns at the cost of significant risk.

Access to financing is not enough to ensure innovation; expertise and cooperation between players in different parts of the value chain are also needed. There are few arenas in the aquaculture industry where networks for cooperation can be formed. Through forming collaborative communities, industry players could accomplish more than they would on their own by sharing knowledge and experience and by using commonly held resources to pursue innovation projects. The overall purpose of a community would be to provide "ongoing, trust-based environments where firms can share technical and market knowledge without fear of exploitation and with the expectation of common gain."[50] In addition, they could provide an opportunity for joint funding of projects and research. Such communities could collaborate with research institutions and authorities to ar-





"Although we make efforts to monitor our suppliers concerning environmental issues and traceability, we rarely receive enquiries from our guests about those issues."

Silje Steien,
Operations Manager,
Alex Sushi

range innovation competitions for sustainable solutions where the winners receive funding from major industry players. This would provide opportunities for start-ups to receive funding at the same time as the industry players would strengthen their efforts within research and development. The Optimized Postsmolt Production (OPP) project is an example of an interdisciplinary collaboration where various industry players, research institutions and the Research Council of Norway have come together to fund a project and to share expertise and experience.[51]

Independent research within prioritised areas

In order to increase knowledge, it is important that independent research organisations are involved in research projects and are responsible for publishing results. Objective research results will contribute to establishing a unified view of the environmental challenges among industry players. Furthermore, independent research organisations would publish results that could be shared across the industry.

It is also important to focus research on areas where the environmental impact is expected to be high and where there is a lack of objective data. With more objective information, it would be possible to establish a common knowledge platform and to identify where future efforts should be focused. We believe there are three key areas that lack knowledge about where research should be focused.

Effects of escaped salmon - There is need for more research on the effect of escaped salmon from fish farms on wild salmon stocks. The Institute of Marine Research has defined escaped salmon as a threat to the genetic integrity of the wild salmon population. However, there are relatively few empirical studies that evaluate the genetic effects of escaped salmon that cross into wild populations.[52] There is a need to quantify cross-breeding and its biological consequences.

Salmon lice - It is widely agreed that lice has a negative effect on both farmed and wild salmon and other salmonids such as trout. However, there is still limited regional data on salmon lice infections, uncertainty as to what the maximum sustainable infection pressure is, and to what degree lice is a population-regulating factor for wild salmon.[53] In order to develop more precise values, more knowledge about the impact of a given infection pressure is needed.

Fish welfare - With respect to new technologies, extensive research and testing are necessary in order to assess both the environmental and economic sustainability of different technologies. There is inadequate knowledge about what the biological requirements should be for extended smolt in closed systems in order to achieve optimal growth, health, and welfare. Closed systems have a number of advantages, such as the potential to better control the salmon's environment with respect to water temperature, oxygen levels, and water flow, but have other challenges to overcome.[54] More research is needed to determine, for example, how oxygen, CO_2, and higher density levels affect the welfare of fish.

Influencing consumer behaviour

Consumer demand is a key driver for sustainable production and development, as it will force the industry to change and also lead to changes in regulations; for example Safeway and Wholefoods in USA want sustainably produced seafood.[55] Methods for promoting more sustainable consumption include government measures, voluntary initiatives by industry players, and campaigns by NGOs. Government actions to promote sustainable consumption include performance standards and mandatory labelling, taxes or subsidies, and public information campaigns.[56] Producers can help consumers make more sustainable choices through the use of voluntary labelling. Product labelling is most credible when it is verified by a third party, and in the aquaculture industry the Aquaculture Stewardship Council's certification is one of several labels.[57] A number of Norwegian producers have shown an interest in becoming certified. An alternative to product labelling is product differentiation through creating a sustainable product brand.

The Swan Eco-Label

The Swan logo demonstrates that a product is a good environmental choice, so with the help of eco-labelling consumers can choose the most environmentally friendly products. When new and more sustainable technology is available, they are incorporated into the label's requirements. An example is how dosage of laundry detergent has decreased since the 1980s and environmentally damaging substances like phosphate have been removed.[58]

Case 2: The Swan Eco-Label

Closing remarks and the way forward

Results from the model for environmental impact show that closed systems in general are the most environmentally sustainable technologies, regardless of assumptions for future development. From an environmental perspective, the industry should therefore seek to increase the use of these technologies.

Accenture identified four opportunities for the industry to overcome the main barriers to development of new technologies: government regulation, financing, independent research within prioritised areas, and influencing the mind of the consumer. All four opportunities play a role in stimulating the rollout of fish farming projects based on sustainable technologies. Accenture's understanding is that the Norwegian authorities have the greatest ability to influence these opportunities. However initiatives should be launched in collaboration with producers, industry organisations, and NGO's.

In the short term

Accenture believes that the greatest potential for new technology lies in closed technologies applied at the extended smolt stage* of the production process:

- Salmon are more vulnerable in the earlier stages of life and, since closed technology reduces lice exposure and better controls water quality, it may result in lower mortality rates
- Shorter production time in open net pens results in more flexibility in operating seawater biomass licences
- Based on our model assumptions, allocating a share of production to closed pens yields environmental benefits
- Allocating the extended smolt stage in closed pens involved less uncertainty related to new technologies compared to full-cycle production

The fact that current regulations related to density, biomass, and decontamination (discussed in chapter 3 and 6.1.1) are not adapted to extended smolt production does, however, limit the potential of the technology. Projects for extended smolt production in RAS and closed coastal systems are currently being undertaken both in Norway and globally. The technological and economical results of these projects are not finalised, and it is too early to draw definitive conclusions. However, empirical data from these projects will provide valuable insights into technological and economical parameters for extended smolt as well as contribute to knowledge about full-cycle production. Accordingly, completing closed production cycles – particularly for extended smolt production – and extracting data and insights are key objectives for the industry going forward. Results from the projects will provide more knowledge about environmental and economic impacts, and will serve as important input for legislators.

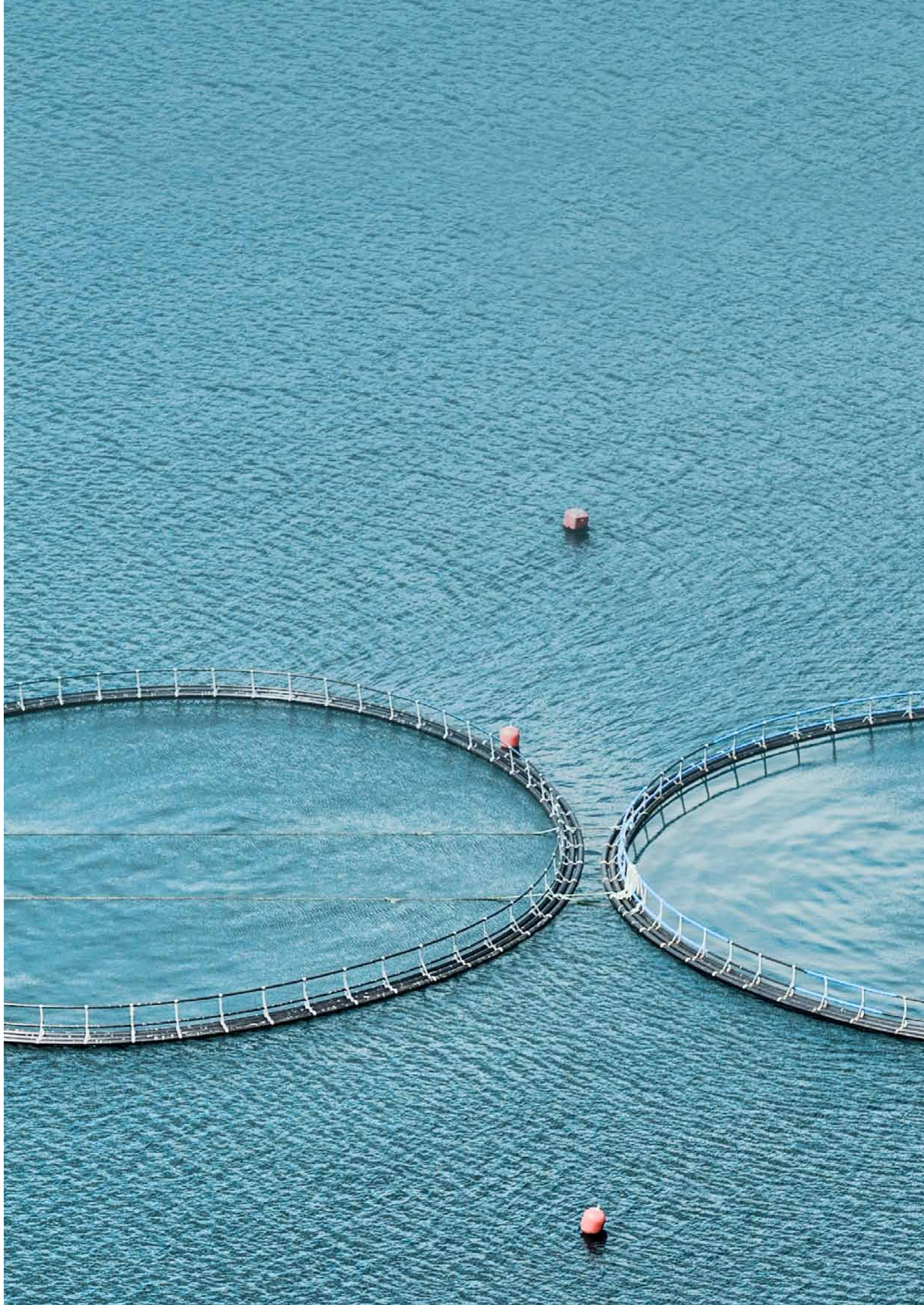
*200 g–1 kg

In the long term

It is difficult to foresee how salmon farming technology will evolve and mature in the long run. A critical factor for the success of sustainable technologies is documentation of economic feasibility and environmental benefits. As argued above, knowledge about closed coastal systems and offshore net pens is limited, whereas knowledge about RAS is somewhat greater due to more projects being undertaken. However, one cannot unequivocally conclude as to whether or not the technologies are environmentally and economically sustainable in the long run. Due to the fact that conditions for seawater production are ideal in Norway, requirements for documented upsides are particularly high.

Accenture believes that viable closed full-cycle production will rely heavily on insights generated from experimental projects and closed extended smolt production. We believe that profitable closed full-cycle production, both coastal and land-based, is not likely to be realised until the end of the decade. Viable offshore production is believed to lie even further into the future.

In order to accelerate this timetable, the focus for the industry and stakeholders should be to launch full-cycle closed production projects and to leverage insights from these and comparable projects, such as ones for closed extended smolt production. The Norwegian authorities have a key role to play in facilitating initiation new projects, and this aspect should be considered when the incoming government carry out the new fishery and aquaculture strategy after the general election in 2013. Furthermore, the government must ensure that the interests of small actors be taken into consideration in further development of the industry.



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58. We assume that fish mortality is a result of fish welfare, and that low fish welfare leads to higher death rates compared to when fish welfare is high.

59. Viral diseases affect mortality and fish welfare for the fish in the farming system. In addition, the Marine Research Institute states that even though there is uncertainty regarding the risk of infection from farmed salmon to wild salmon populations, the risk is considered to be low. Our model therefore assumes that viral diseases mainly affect the fish in the production system, and that virus diseases affects fish welfare.

Appendix

List of acronyms

FSA – Food Safety Authority
GDP – Gross domestic product
IMR - The Institute of Marine Research
LCA – Life cycle assessment
MASD – Maximum allowable salmon density
NGO – Non-governmental organisation
OPP – Optimized Post-smolt Production
RAS – Recirculation aquaculture systems
WWF - World Wildlife Fund for Nature

List of interviews

#	Name	Company
1	Elisabeth Aune	Sogn and Fjordane County Council
2	Bjørn Bilberg	Preline
3	Barry Costa-Pierce	University of New England
4	Bergny Irene Dahl	Innovation Norway
5	Else Marie Djupevåg and Henrik Hareide	Directorate of Fisheries
6	Jon Fixdal	Norwegian Board of Technology
7	Inger Fyllingen	Norwegian Food Safety Authority
8	Piers Hart	WWF UK
9	Inger Jakobsen	Standards Norway
10	Bjørn Vegard Løvik	Atlantic Sapphire
11	Geir Magne Knutsen	Bremnes Seashore
12	Endre Korsøen	Hordaland County Council
13	Anders Næss	AkvaFuture
14	Tom N. Pedersen	County Governor of Hordaland
15	Ole Fredrik Skulstad	Green Marine
16	Rikard Slaski	Scottish Aquaculture Research Forum
17	Geir Spiten	Akvatech
18	Silje Steien	Alex Sushi
19	Erik Sterud	Norwegian Salmon Rivers
20	Harald Sveier	Lerøy Seafood Group ASA
21	Ørjan Tveiten	Marine Harvest
22	Bent Urup	Kruger Kaldnes AS
23	Aina Valland	Norwegian Seafood Federation
24	Soleig Willis	Salmon Group

Table of international projects

Table of international projects for:

1. Land-based recirculating aquaculture systems (RAS)
2. Open containment systems with offshore net pens
3. Closed containment systems with coastal cages

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Land-based closed containment with recirculation aquaculture systems (RAS)					
1. 'Namgis First Nation's Closed Containment Salmon Farm, Vancouver, British Columbia, Canada	• Land-based, closed RAS	• K'udas Limited Partnership (built and operates), 'Namgis First Nation • SOS Marine Conservation Foundation (project partner), • Tides Canada (project advisor)	Commercial	From smolt to market size: 100g to 5-6 kg	• 3 cohorts per year. Fish harvested every 2 weeks. • Peak density will be 90 kg/m3, producing 470 MT annually • 98% of water is recirculated • This is the first module of five module farms being built on Northern Vancouver Island. The combined productivity of all 5 will be 2000-3000 MT/year). • Slightly saline groundwater from wells is disinfected on entry and heated to 10 - 15°C. • Capital cost $8 million • 2-stage disease screen • Multiple energy conservation measures
2. Sustainable Blue, Centre Burlington, Nova Scotia, Canada	• Land-based RAS		Commercial	Smolt to market size (3.5 to 4kg) in 12 months	• Not yet built • Projected to produce 375 to 500T per year
3. AquaGen Chile S.A., Puerto Varas, Chile	• Land-based RAS	Billund Aquaculture (build)	Commercial	Spawning adult	• Broodstock facility producing 180T of smolt per batch
4. Salmon Chaicas S.A, Puerto Montt, Chile	• Land-based RAS	Billund Aquaculture (build)	Commercial	Spawning adult, smolt	• Broodstock and smolt Production System. 120 million eyed eggs and 4 million smolt per year
5. Salmones Rio Coihue S.A, Maullin, Chile	• Land-based RAS	Billund Aquaculture (build)	Commercial	Smolt to market size: from 100g to 4.5kg	• 8T per year
6. NeoSalmon, Los Lagos, Chile	• Land-based RAS	Salmon Rio Ciohue S.A; Reciculatrionchilde Ltda	Commercial	Full-cycle up to market size (4.5kg)	• Not yet built • No antibiotics to be used • Mortality rate expected at 7% • Owned by 11. Salmones Rio Coihue S.A
7. Gobi Desert, China	• Land-based RAS	• Billund Aqua Culture (build) • Chinese government	Commercial		• 1000T per year • To obtain water farmers have drilled a 70 m deep well. Recycling technology used in land-based plants, make sure they use relatively little water.
8. Yantai Salmon Farm, Shandong Province, China	• Land-based RAS	• Shandong Oriental Ocean Sci-Tech Co. (owner and facilitator); AquaOptima (build); • Ocean Research Institute of the Chinese Academy of Science	Commercial		• 700T per year; projected to increase to 1400T per year • First Atlantic salmon harvested in 2011 at 1.5 kg

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Land-based closed containment with recirculation aquaculture systems (RAS)					
9. Langsand Laks AS, Hvide Sande, Denmark	• Land-based RAS	• Atlantic Sapphire AS (former organic salmon farmers) • Polar Salmon AS (processor) • Aquapri AS • Steensgaard Holding AS • Sohn Invest ApS • Preben Kristensen • Thue Holm	Commercial	Full-cycle: from egg to 4.5kg adult	• 1000T per year in its current phase; next phase to yield 3000T per year • Water consumption is 250l per kg of fish produced • No use of antibiotics • Low mortality • No diseases or parasites • Low power consumption: less than 1.3kW per kg of fish produced • Stakeholders include 36. Atlantic Sapphire
10. Odense Produktions Højskol, Odense, Denmark	• Land-based RAS	• Billund Aquaculture (build)	Commercial	Broodstock, hatchery, smolt	• Up to 1.3 million fish per year • Bulit in 2000
11. Danish Salmon, Hirtshals, Denmark	• Land-based RAS	• Billund Aquaculture (build) Biomar (feeds) • AquaPri (processing and sales) • Denmark Technical University (management) • Orbicon (regulatory due diligence) • RK Plastics (bio-filter elements) • North Sea Science Park • Hjørring Municipality • Ministry of Food, Agriculture and Fisheries' Green Development and Demonstration Programme	Commercial		• Target projection: 60T per cycle • 95% water reuse
12. Stiftung Wasserlauf NRW, Sankt Augustin, Germany	• Land-based RAS	• Billund Aquaculture (build)	Commercial	Spawning adults, fry (5g)	• Hatchery and Broodstock system • 150,000 fish per year
13. NIRI Ireland, Cork, Ireland	• Land-based RAS		Commercial	Smolt, but has had production up to 2.8 kg in 2002	• Sister operation of 44. NIRI Ireland
14. Fishfrom, Tayinloan, Scotland, UK	• Land-based RAS	Fishfrom (operator)	R&D	Full-cycle	• Not yet built • Target projection of 800,000T per year • Planned production start in 2014 • Density of 50kg per m2 • Power from solar and hydro, eventually maybe factory's own waste • Feeds will be from own supply of specially farmed ragworm • Onsite water recycling • Currently already supplies the Fat Duck restaurant • Plans to build 2 more in UK, in talks to build in 3 other countries (New Zealand, USA, Romania) • Borders a Site of Special Scientific Interest

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Land-based closed containment with recirculation aquaculture systems (RAS)					
15. SweetSpring, Washington, USA	• Land-based RAS	• Aquaseed (through acquisition of Domsea Farms) • Gordon and Betty Moore Foundation	Commercial	Smolt to market size: 60g to 3kg in 8 months	• 100T per year • 40L of new water used per kg of feed • 100% system volume replacement each day • All organic wastes are removed mechanically in settling ponds before the majority of the water re-enters the system • No antibiotics, pesticides or harsh chemicals used • There has never been a major disease outbreak • Produce is purchased almost exclusively by Overwaitea Food Group, a company that owns several grocery chains through British Columbia and Alberta • SweetSpring salmon was the first farmed salmon to receive a 'Best Choice' ranking by the Monterey Bay Aquarium's Seafood Watch program • Won an award for environmental innovation from the Association of Washington Businesses. • Essentially a joint venture with 37. Teton Fisheries LLC
16. Atlantic Sapphire, mid-Atlantic, USA	• Land-based RAS	Main shareholder Alsco AS	R&D	Full-cycle	• Target production of 16,000T per year • This project owns a stake in 23. Langsand Laks AS
17. Teton Fisheries LLC, Choteau, Montana, USA	• Land-based RAS	• Miller Hutterite Colony (founder, owner, facilitator) • SweetSpring Salmon (joint venture)	Commercial	Full-cycle up to 2.5/3 kg	• 90% or more of well water is filtered and reused • Ranked 'Super Green' by Seafood Watch • No diseases since opening • Essentially a joint venture with 15. SweetSpring • Sister facility is 18. Hill Fisheries LLC
18. Hill Fisheries LLC, Havre, Montana, USA	• Land-based RAS	• East End Hutterite Colony	Commercial	Full-cycle up to 2.5/3 kg	• Sister facility is 37. Teton Fisheries LLC
19. The Conservation Fund's Freshwater Institute, Shepherdstown, West Virginia, USA	• Land-based RAS	• Atlantic Salmon Federation (ASF) • The Conservation Fund's Freshwater Institute • Canada's Department of Fisheries and Oceans	R&D	Extended smolt to harvest size: 340g to 4-4.6kg within approximately 12 months	• 12-month outgrow trial • Water recirculation (4800L/min) ; 99.8% reuse • 99% of fish wastes and phosphorus reclaimed for fertiliser • Total loss to mortality (3.9%), culls (5.6%), and jumpers (1.9%) accounted for 11.4% of the population • No obligate pathogens, sea lice, or Kudoa were detected in the fish or the system. • No fish were vaccinated. No antibiotic, pesticide, or harsh organic chemotherapeutants were used.
20. BDV SAS, Normandy, France	• Land-based [undetermined]	Eco Farms AS	Commercial	Up to market size: 4-6kg	• Not yet built – approved and awaiting construction • Technology provided by the Norwegian company Eco Farms AS, with both mechanical and the biological filter in the middle of the tank
21. NIRI Poland, Szczecin, Poland	Land-based [undetermined]				• Sister operation of 30. NIRI Ireland

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Sea-based closed containment systems with coastal cages					
22. Middle Bay Demonstration Farm, Campbell River, Middle Bay, Canada	• Solid-walled floating tanks	• AgriMarine (build and facilities provider) • Middle Bay Sustainable Aquaculture Institute • Sustainable Development Technology Canada • Gordon and Betty Moore Foundation • David Suzuki Foundation; Living Oceans Society; the Coast Sustainable Trust; the Georgia Strait Alliance	R&D and showcase		• The Chinook salmon grown here have been shown to have a particular resistance to sea lice compared with other species of salmon • The floating tank system really does nothing to stop disease and parasite interactions between wild and farmed fish. The tank is open to the ocean at the top and below. The risk still exists to transmit pathogens between wild and farmed fish. • Farm production currently suspended at Middle Bay, pilot tank dismantled due to storm damage, operations to be resumed TBA
23. Near the city of Benxi, Liaoning Province, China	• Stream fed closed containment	• AgriMarine (build and facilities provider) • Benxi City	Commercial	Juveniles and small fish (2.5kg)	• 500 metric T per year, with plans for increase • Stream-fed closed containment system in Guanmenshan Reservoir: floating tanks outfitted with low-pressure pumping systems • Water levels at the firm's Benxi reservoir base have proven inadequate, creating problems in summer when the temperature rises. • Low water levels contribute to disease and health issues. Hence the firm has sourced new sites along the North Korean border, though Buchanan declined to say how many new sites are under development. • China's first and only closed containment Chinook or King salmon from Canadian ova
24. British Columbia, Canada	• Floating closed containment tankage	• Agrimarine Industries Inc	Commercial		• Agrimarine Industries Inc is installing 12,000 cubic meters of floating closed containment tankage at the West Coast Fish Culture Steelhead farm in British Columbia, Canada. • Two different tanks styles are being evaluated including the latest generation of 3000 cubic meter floating closed containment tanks which embody the lessons learned from both previous land based installations, the companies experience at its ocean test site and its operational farm in China. • This installation is planned to be phase one of a larger project to prove and to continue to improve the company's technology on a commercial scale at an active farm in North America.

Location	Source
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4. Salmon Chaicas S.A, Puerto Montt, Chile	1) «Reference List – July 2013», Billund Aquaculture (direct correspondence), 22.07.2013 ; 2) Correspondence with Bjarne Hald Olsen, Billund Aquaculture, 25.07.2013
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24. British Columbia, Canada	1) Geir Spiten, Akvatech

Table of Norwegian projects

Table of Norwegian projects for:

1. Land-based recirculating aquaculture systems (RAS)
2. Open containment systems with offshore net pens
3. Closed containment systems with coastal cages

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Land-based closed containment with recirculation aquaculture systems (RAS)					
25. Kråkvåg	Land-based closed containment	• GRØMI AS (Project owner) • AquaOptima AS • SINTEF Fiskeri og Havbruk AS • APS Automasjon AS • ITT Flygt AS • AquaCulture Engineering AS	Commercial (Not started)	Full-cycle	• Grømi is prepared to invest 50-60 million NOK • Production target of 20 000 ton • Estimated 1 NOK per kg in energy costs
26. Askøy	• Land-based RAS	• Marine Harvest • NorStone AS (current operator of the quarry)	Commercial (not started)	Full-cycle	• Planned location is a quarry that will be 20 meters below sea level • The city council is resisting the lowering of the ground level and the project is therefore on hold • If realized, it will be one of the largest land-based aquaculture facilities
27. Øklandsvåg	• Closed land-based waiting containment	• Bremnes seashore • Innovasjon Norge (financial support)	Commercial (Testing will commence in 2014, commercial in 2015)	Pre-harvest	• The fish goes straight from well boat to land-based waiting containment • Cold water pumped from 70-80 meters depth • Increased hygiene control • Increased fish health
28. Barstadvik	• Land-based RAS • Utilizing high quality groundwater 30 meters below the bottom of the sea	• Profunda AS (operation and owner) • Lerøy (Main customer and collaboration partner)		Broodstock (from egg to 10-15 kg)	• Have previously produced cod and halibut in the same facility
29. Kårstø	• Land-based RAS	• Marine Harvest	R&D (concept stage)	Extended smolt (up to 500 gram)	• Utilizes pre-heated water from nearby gas facility
30. Florø	• Land-based RAS	• Green Marine • Ecofarm (supplier of technology) • Innovasjon Norge	Commercial (Tests have been conducted, awaiting permissions)	Extended smolt (up to 1 kg)	• 2% mortality • Estimated energy cost: 2,55 NOK per kg
31. Belsvik, Hemne	• Land-based RAS • One of the world's largest smolt facilitites (11000m2)	• Lerøy Midnor	Commercial	Smolt	• Escape proof • No contact with external environment • Expected to cost ~350 million NOK
32. Steinsvika	• Land-based RAS	• Marine Harvest	Commercial under construction (finish 2014 or 2015)	Smolt	Expected to cost ~200 million NOK

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Land-based closed containment with recirculation aquaculture systems (RAS)					
33. Fjæra	• Land-based RAS	• Marine Harvest	Commercial (Partly approved)	Smolt	• 7.5 million smolt per year • Department of environment has approved
34. Stongfjorden	• Land-based RAS	• Marine Harvest	Commercial (Seeking approval at the moment)	Smolt	• 7.5 million smolt per year • The community is criticizing the plans that will include severe changes to the shoreline where the facility will be located
Sea-based open containment systems with offshore net pens					
35. Kristiansund	• Offshore open containment	• Lerøy Hydrotech (development)	R&D	Smolt to harvest	• Cancelled in 2011 after a storm caused severe damage to it
36. No location	• Offshore, submersible net pen	• Ocean globe	R&D (concept stage)		• Den første prototypen var for svak. • The OceanGlobe project has now been fully financed, and can therefore be moved on to full-scale testing. • A 40,000 cubic metre facility will now be built and tested in one of the world's toughest marine environments
Sea-based closed containment systems with coastal cages					
37. Lamholmen, Brønnøysund	• Sea-based closed containment. Flexible walls	• AkvaDesign AS (development) • Norsk Havbrukssenter (operation) • Innovasjon Norge	R&D	• Full-cycle finish autumn 2013 • Large smolt completed	• No lice registered • Same growth as open containment • Lower mortality • No escapes • 5-7kW per hour for 300 ton fish a year • 1.5 NOK per kg fish (power and oxygen)
38. Tørvikbygd	• Sea-based closed containment • Horizontal pipes floating at the water surface.	• Preline (development) • Lerøy Vest • Innovasjon Norge	• R&D • Commercial project is commenced	Extended smolt (850-1000 gram)	• The water is pumped from 25-30 meters depth • Lice only during loss of power • Same energy cost apart from additional 0.1 NOK per fish for stream creation • Feces transportation is still an issue
39. Dirdal	• Half-sphere shaped closed containment made with glass reinforced plastic (GRP)	• EFAF AS (development) • EWOS Innovation (operation)	R&D	Smolt (300-400 gram) to harvest during test	• No escapes • No lice • Same quality as wild salmon • Energy costs: 1 NOK per kg fish
40. Skånevik (Eldøyene)	• Sea-based closed containment system made with GRP • Four pumps will ensure all the water is replaced every 70 minutes	• Aquafarm Equipment (development) • Marine Harvest (operation) • HighComp (producer of walls)	R&D (Not started, testing will commence Autumn 2013)	Extended smolt	• The world's largest sea-based closed containment • 65 million NOK is allocated to the project

Location	Type	Main players involved	Nature of operation	Stages of production	Documented results, energy usage and interesting notes
Sea-based closed containment systems with coastal cages					
41. Bergen, Sunndalsøra (optimized postsmolt production)	Sea-based closed containment	• Marine Harvest (project owner) • Lerøy SG • Grieg Seafood • Smøla Klekkeri • Norsk Forskningsråd (Financing) • Agrimarine (Akvatech)	R&D	Smolt to Extended smolt (1kg)	• 25 million NOK is allocated to this project over three years • The aim is to prolong the time spent in closed containment to prevent diseases and escapes
42. Trondheim	Closed flexible cages (CFC)	• Norges Forskningsråd, Havbruks-programmet • Flere partnere inkl. SINTEF Fiskeri og havbruk, NTNU, US Naval Academy, University of New Hampshire, Aqualine, Botngaard, Smøla Settefisk og klekkeri, Osland fiskeoppdrett, Lingalaks m.fl.	R&D	Closed flexible cages (CFC) offers a route for developing closed fish production systems (CFPS) that might be faster than developing new CFPS in rigid material	• Testing of external sea loads and internal hydraulics on small scale prototypes • 5 year project, 01.01.2012 - 31.12.2016
43. No location	Sea-based closed containment on decommissioned floating vessels	• Mood Harvest	R&D (concept stage)		• Reasoning: Decommissioned floating vessels have most of the prerequisites for an aquaculture facility • Currently developing a fish farm with capacity of 10-15000 ton a year • Seeking investors
44. No location	Sea-based closed containment system with rigid steel walls	• Coast Innovation • Svanøy Havbruk	R&D (concept stage)		• The concept includes several steel containments located on the same platform • Two central pump stations provide water
45. No location	Sea-based closed containment system Concrete walls	• Dr Techn Olav Olsen • Marine Harvest	R&D (concept stage)	Extended smolt (up to 1 kg)	• Robust material • Low maintenance demand • Stabile • Chemical processes might reduce pH on surface • Concluded that it would be too expensive as of today
46. No location	Sea-based closed containment system with flexible walls	• Ecomerden AS	R&D (concept stage)		• Sparsely mentioned solution except on homepage
47. No location	Closed sea-based containment system with both net and flexible wall (plastic)	• Botngaard • Aqualine • ITT Flygt • LiftUP • Smøla Klekkeri & Settefisk • NOFIMA • Patogen Analyse	R&D (concept stage)	Extended smolt (800 gram)	• Potentially shorten the time in open containment with 8-10 months • Water is pumped from 20-30 meters depth
48. Middle-Norway	Sea-based closed containment tankage	• Akvatech has a contract with Smølen Handelskompani AS/Ute AS	Commercial	Extended smolt	• Last generation of 3000 cubic tanks • Expected delivery of the first tanks is the spring and autumn 2014
49. Bindal	• Sea-based closed containment • Flexible walls	• AkvaDesign AS (development) • Bindalslaks AS			• Planned to set out 50 tons in closed tanks during the autumn 2013 • The project has a time frame of 3 years

Location	Source
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30. Florø	1) www.njff.no/portal/pls/portal/.../1/45123020.PPT
31. Belsvik, Hemne	1) http://blogg.smn.no/2013/06/et-av-verdens-storste-settefiskanlegg/ 2) Interview with Ørjan Tveiten
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35. Kristiansund	1)http://www.nrk.no/video/mislykka_forsok_med_oppdrett_til_havs/7D744074661D799A/emne/oppdrettsanlegg/
36. No location (Måløy)	
37. Lamholmen, Brønnøysund	1) Interview with Anders Næss 2) www.akvafuture.com
38. Tørvikbygd	1) Interview with Bjørn Billberg 2) http://www.preline.no/default.aspx
39. Dirdal (Aquadome)	1)http://www.tekna.no/ikbViewer/Content/839996/09%20Olav%20Gr%F8nolen%20AquaDome%20Presentasjon%203.1.12.pdf 2) http://www.smolaks.no/wp/wp-content/uploads/2012/04/laks21.pdf
40. Skånevik (Eldøyene)	1) http://www.sunnhordland.no/article/20130418/NYHENDE/130419798 2) http://www.sunnhordland.no/article/20130702/NYHENDE/130709943
41. Bergen, Sunndalsøra (optimized postsmolt production)	1) http://www.nofima.no/prosjekt/optimalisert-postsmoltproduksjon ; 2) http://www.forskningsradet.no/servlet/Satellite?c=Prosjekt&cid=1253971359447&lang=no&pagename=ForskningsradetNorsk/Hovedsidemal
42. Trondheim	1)http://www.forskningsradet.no/servlet/Satellite?c=Prosjekt&cid=1253971359280&pagename=havbruk/Hovedsidemal&p=1226994216935 2)http://www.nofima.no/filearchive/22_onsd_rosten.pdf
43. No location	1) www.moodharvest.com
44. No location	Rosten et al. (2011), Kartlegging av ulike teknologiske løsninger
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49. Bindal	1) http://www.akvadesign.com/event/doLink/famid/369513

The environmental model – additional tables and assumptions

Parameters	Description
Escapes	Related to unforeseen incidences: - System breakdown due to weather conditions - System breakdown due to boat traffic - System breakdown due to humans Related to planned activities: - Fish stocking operations increase the risk of escapes because there are more manual operations - Fish harvesting operations increase the risk of escapes because there are more manual operations
Lice	Contamination risk for fish inside the system: - Ability of system to prevent lice from entering the system - Ease of carrying out lice treatments/medication if lice is present in the system Contamination risk for fish outside the system: - Ability of system to prevent lice from exiting the system
Fish welfare[60]	Fish ulceration (Sores): - Scrape/frictions against the nets/walls can cause ulceration - Sores can be caused by cold water Non-observable fish welfare: - Fish density in the farming system can affect fish welfare - Water quality related factors such as water flow, water temperature and oxygen levels affect fish welfare Viral diseases13 - Fish density can affect the speed of infection - Stress and sores increases the likelihood of infection
Climate effects	Energy usage: - Water pumping requires energy - Water heating/cooling requires energy Carbon emissions: - Operation of system facilities can lead to carbon emissions - Increased need for transportation by well boats, trucks etc. increases carbon emissions Energy producing properties: - Retained biogas can be used as feedstock in biomass power plants or used to generate other sources of energy
Direct pollutants / chemical emissions	Intentional pollutants and chemical emissions - Both orally and bath administered delousing substances and medicines can lead to chemical emissions and be poisonous for the environment. Unintentional pollutants and chemical emissions - Chemical emissions can be caused by copper and other material decompositions from the system - Chemical emissions can be caused by oxidation from the system - Boats and other equipment can cause fuel and oil emissions
Discharges of nutrient salts and organic materials	Organic substance emissions: - Feces, waste feed and filtered mass can be emitted from the system and affect marine life outside the system Nutrients emissions: - Phosphorus, nitrogen and other nutrients can be emitted from the system and affect marine life outside the system
Zoning	Sea space - Livestock volume positively affects zoning - Fish density positively affects zoning - Anchoring systems affect the need for sea space - Different anchoring systems require different zoning - Systems in the sea can cause conflicts of interest with regards to fishermen, boat traffic and other infrastructure in sea and near the shoreline Onshore space - For land-based systems livestock volume positively affects zoning - For land-based systems fish density positively affects zoning - Land-based systems can cause conflicts of interest if placed near established infrastructure
Input factors in construction of system	Materials consumed - The amount and type of raw materials, semi manufactured goods and sub components required in production of the fish farming system affect resource scarcity and can have an environmental impact Energy consumed - The energy consumed in the production process of the fish farming system can have an indirect impact (electricity consumption) and/or direct impact (impact (Co2 emissions) on the environment

Note: Feed is not a separate parameter in the model, however environmental externalities related to emitted organic material is covered through teter Discharges of nutrient salts and organic materials, and emissions of medication added to the feed is covered through teter Direct Pollutants/Chemical Emission. Environmental externalities related to resource consumption in feed production and economical aspects of feed efficiency is considered out of scope.

Case assumptions:

Scenario 1: Open Coastal Net Pens – assumptions
- The fish is transferred to the system when it reaches 100g and stays until it reaches harvest weight
- The system is close to the shore or in a fjord (not offshore)
- Net pens are flexible polyethylene meshes
- Water, particles and parasites flow unhindered through the net pens
- Distance to seabed is in line with regulations (water circulation and oxygen levels are not issues)

Scenario 2: Closed Coastal Cages – assumptions
- The fish is transferred to the system when it reaches 100g and stays until it reaches harvest weight
- The system is close to the shore or in a fjord (not offshore)
- Walls are made of impenetrable concrete
- Water is pumped from 20-30 meters below the surface where there is less lice
- Water can only enter or exit through intake/outlet
- Inlet and outlet water is filtered (fish, particles and parasites cannot enter or exit the system at normal operation)
- Water temperature is given by water pumped in
- There is no water recirculation
- Regulations allow for a higher fish density compared to open systems and oxygen levels are managed to support the higher density
- Biological material and nutrients are collected and transported to land (but insufficient infrastructure to manage and/or leverage disposal)

Scenario 3: RAS – assumptions
- The fish is transferred to the system when it reaches 100g and stays until it reaches harvest weight
- The system is placed on land near the shore
- Distance from shore and elevation from sea level affects energy required to pump water
- Water is pumped from 20-30 meters below the surface where there is less lice
- Water temperature can be adjusted
- 90% of the water is recirculated and reused
- Non-recycled water is pumped from sea
- Inlet and outlet water is filtered (fish, particles and parasites cannot enter or exit the system at normal operation)
- Regulations allow for a higher fish density compared to open systems and oxygen levels can are managed to support the higher density
- Biological material and nutrients are collected and transported to land (but insufficient infrastructure to manage and/or leverage disposal)

Scenario 4: Extended smolt – assumptions
Phase 1: Closed system in the sea:
- The fish is transferred to the system when it reaches 100g and stays until it reaches 1 kg
- The system is close to the shore or in a fjord (not offshore)
- In close proximity to the open net pens
- Walls are made of impenetrable concrete
- Water is pumped from 20-30 meters below the surface where there is less lice
- Water can only enter or exit through intake/outlet
- Inlet and outlet water is filtered (fish, particles and parasites cannot enter or exit the system at normal operation)
- Water temperature is given by water pumped in
- There is no water recirculation
- Regulations allow for a higher fish density compared to open systems and oxygen levels can are managed to support the higher density
- Biological material and nutrients are collected and transported to land (but insufficient infrastructure to manage and/or leverage disposal)

Phase 2: Open system in the sea:
- The fish is transferred to the system when it reaches 1 kg and stays until it reaches harvest weight
- The system is close to the shore or in a fjord (not offshore)
- Net pens are flexible polyethylene meshes
- Water, particles and parasites flow unhindered through the net pens
- Distance to seabed is in line with regulations (water circulation and oxygen levels are not issues)

Parameters	Weight	Open	Closed	RAS	Extended smolt
Escape	HIgh	1 - Many escape incidences in the past - System relatively sensitive to weather conditions - High probability of net holes	4 + Impenetrable walls and secured filtering systems prevent escapes + The problem of holes and wear on nets is avoided - Relative movement of water inside the construction can toss fish out of the system (Sintef = S) - Possible escapes related to water pumping and construction errors (S)	5 + The system is placed onshore (no currents, little or no risk related to weather conditions and boat traffic) - Still possible to have structural collapse or breakdown of water filtering	2 + Same as closed coastal system up top 1kg (reduced time in open nets) - Same as open system after 1kg
Lice	High	1 - Open nets do not prevent lice from entering the system - The system uses surface water which contains relatively high amounts of lice compared to water from deeper sea levels	4 + Water can be filtered and disinfected in and out of the system + Water can be pumped from depths where there is less lice - Filtering system and water pumps can break down - Reduced water flow (sintef) and increased density can increase infection rates - Surface water containing lice can splash into the system	5 + Water can be filtered and disinfected in and out of the system + Water can be pumped from depths where there is less lice + Only inlet for lice is through the filtered water intake which only counts for 10% of the water consumption	2 + Same as closed coastal system up top 1kg (reduced time in open nets) - Same as open system after 1kg
Fish welfare	Medium	3 - Relatively high mortality rates in early smolt stages - Possible scrape/frictions against the nets - Not possible to control water temperature - Open nets do not prevent spread of viruses	4 + Water flow and oxygen levels can be controlled + Filtering water intake can prevent the intake of viruses + Regulations for water quality can possibly assure equally good water quality as in open systems (tekn.råd) - Water from deeper sea levels can affect growth patterns and growth rates (tekn.råd) - Water from deeper sea levels can cause new diseases (tekn.råd) - Increased fish density increases the risk that infections will spread and might increase stress	4 + Possible to control water temperature, water flow and oxygen levels + Filtering water intake and recycling of water can prevent the intake/reduce spread of viruses + Regulations for water quality can possibly assure equally good water quality as in open systems (tekn.råd) - Water from deeper sea levels can affect growth pattern and growth rate (tekn.råd) - Water from deeper sea levels can cause new diseases (tekn.råd) - Increased fish density increases the risk that infections will spread	3 + Same as closed coastal system up top 1kg (reduced time in open nets) - Same as open system after 1kg
Climate effects	Low	4 + No water pumping reduces energy consumption - Emissions related to transportation	2 +/- Retained biomass can be used to produce energy, but as of today we lack the necessary infrastructure - Energy consumption related to water pumping water, add oxygen, collect waste and recycle the waste - Emissions related to transportation - Extra energy will be used if the water is filtered (tekn.råd)	1 +/- Retained biomass can be used to produce energy, but as of today we lack the necessary infrastructure + Less transportation/ logistics - Energy used to pump water, add oxygen, heat/cool water, recycle water, collect waste and recycle the waste - Extra energy consumption needed for water pumping since the system is above sea level - Extra energy will be used if the water is filtered (tekn. råd)	3 + Same as closed coastal system up top 1kg (reduced time in open nets) - Same as open system after 1kg
Direct pollutants / chemicals	Medium	1 - High risk of lice means more use of drugs and delousing substances - Copper used to impregnate the nets	3 + Less risk of lice means less use of medication and delousing substances + Feed containing medication is collected + Filtering can reduce emission of delousing substances - Some substances can escape through the filtering system, and the filtering system can break down	4 + Less risk of lice means less use of medication and delousing substances + Feed containing medication is collected + Filtering can reduce emission of delousing substances + Not in immediate contact with water - Some substances can escape through the filtering system, and the filtering system can break down	2 + Same as closed coastal system up top 1kg (reduced time in open nets) - Same as open system after 1kg
Discharges of nutrient salts and organic materials	Low	1 - Open nets does not prevent organic and nutrients emissions	4 + Feces, waste feed and filtered mass can be collected which leads to less nutrients and organic emissions (if deposited elsewhere) +/- Retained biomass can be used to produce energy, but as of today we lack the necessary infrastructure	5 + Feces, waste feed and filtered mass can be collected which leads to less nutrients and organic emissions (if deposited elsewhere) +/- Retained biomass can be used to produce energy, but as of today we lack the necessary infrastructure + Not in immediate contact with sea water	2 + Same as closed coastal system up top 1kg (reduced time in open nets) - Same as open system after 1kg
Zoning	Low	3 - Claims sea acreage	4 - Claims sea acreage + Can take new and remote areas into use (areas where conditions are too poor to use open systems) + Higher MASD can lead to less space needed per MAB (given same pen depth)	1 - Claims land acreage - High conflicts of interest on the Norwegian shore - More space needed in absolute terms (housing around pens) - Opportunity cost more relevant than in sea - More space needed in due to more shallow pens (source?)	3 - Claims sea acreage - The extra closed system is assumed to be placed close to the open net pens and will not claim an additional location. The marginal impact is assumed to be small.
Input factors in construction of system	Low	4 + The open containment system is the least complex construction and requires the least amount of mate-rials in production + Relatively simple produc-tion process leads to mod-est energy consumption	2 - The coastal closed cages are based on a sturdier con-struction than open pens and the systems involve water pumping and filtering components. Consequently coastal closed cages con-sume more materials and energy during production compared to open pens	1 - RAS systems are the most complex construction (in addition to onshore tanks RAS requires housing, filter-ing systems, recirculation systems, pumping facilities etc.) and requires the most amount of materials and energy in production	3 + Part of the production happens in open pens - Part of the production is done in closed coastal cages
∑		1.9	3.6	3.9	2.4

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