February 2023

THE STATE AND FUTURE OF AQUACULTURE IN ICELAND

Government of Iceland
Ministry of Food, Agriculture and Fisheries

Publisher:
Ministry of Food, Agriculture and Fisheries

The State and Future of Aquaculture in Iceland

February 2023

mar@mar.is

https://www.stjornarradid.is/raduneyti/matvaelaraduneytid/

ISBN 978-9935-9669-4-0

BOSTON CONSULTING GROUP

Government of Iceland
Ministry of Food, Agriculture and Fisheries

This report was prepared by the Boston Consulting Group for the Icelandic Ministry of Food, Agriculture and Fisheries

Authors

Björn Björnsson
Partner

David Perez
Managing Director and Partner

Sverre Martinsen
Managing Director and Partner

Mads Peter Langhorn
Managing Director and Partner

Anita Koralewicz

Guðrún Olsen

Henrik Vedeler

Laurids Schack

Santiago Muedano

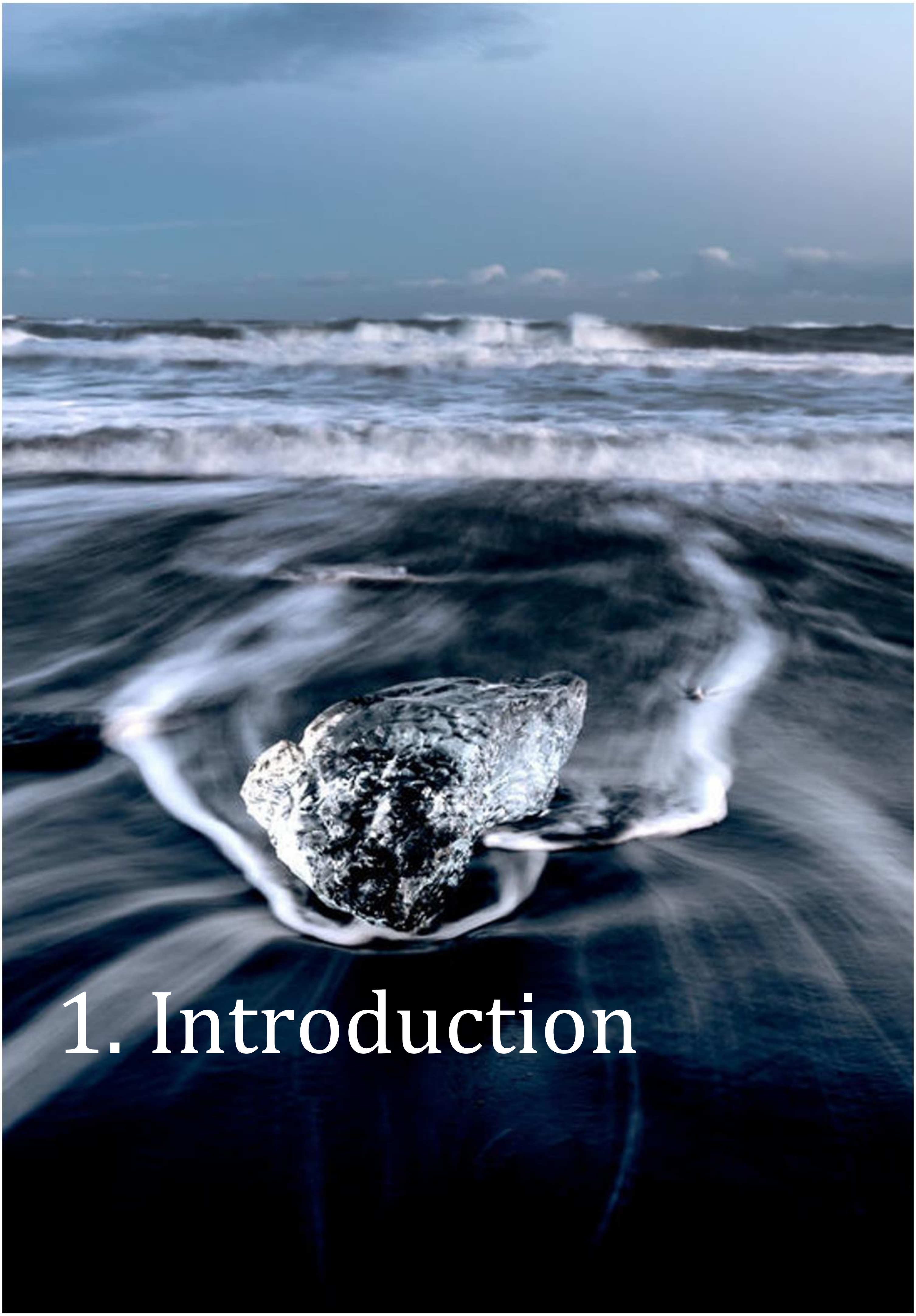
Sophie Thorup

Victor Julegaard

Table of Contents

List abbreviations and acronyms

ASC	The Aquaculture Stewardship Council
bN	Billion
CAGR	Compounded annual growth rate
CAPEX	Capital expenditure
DKK	Danish Crowns
EBIT	Earnings before interests and taxes
ECB	European Central Bank
EIA	Environmental impact assessment
Env	Environment
EU	European Union
EUR	Euro
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed conversion ratio
FTS	Flow-through system
GAA	Global Aquaculture Alliance
GBP	British pound sterling
GHGe	Greenhouse gas emissions
GWT	Gutted weight
HAB	Harmful algal blooms
HFS	Hybrid flow-through system
HOG	Head-on-gutted
Int'l	International
IMTA	Integrated multi-trophic aquaculture system
ISA	Infectious Salmon Anaemia
ISK	Icelandic Króna
k	Thousand
kg	Kilogram
km	Kilometer
kT	Kiloton
LW	Live (fish) weight
m	Million
MAB	Maximum allowed biomass
MAST	Food and Veterinary Authority in Iceland
MFRI	The Marine and Freshwater Research Institute in Iceland
OECD	Organization for Economic Co-operation and Development
OPEX	Operational expenditure
p.a.	Per annum
PBR	Photobioreactors
RAS	Recirculating aquaculture systems
SEPA	Scottish Environment Protection Agency
SINTEF	Stiftelsen for industriell og teknisk forskning
SDR	Special Drawing Rights
T	(metric) ton
Tg	Teragram
UN	United Nations
US	United States of America
USD	United States Dollars
VAP	Value added processing
WC	Working capital
WFE	Whole fish equivalent



1. Introduction

Over the past few decades, the global aquaculture industry has grown considerably and recently surpassed fisheries as the world's primary method of seafood production. Aquaculture is a diverse industry that spans many species. In this report, it is divided into four sectors based on the method of production: traditional, land-based, offshore and algae farming. Aquaculture has a long history in Iceland but has only in the last decade grown significantly, primarily driven by traditional salmon farming. In addition, large-scale projects are already underway in land-based and microalgae farming, and interest growing in offshore and macroalgae farming. Based on current plans, aquaculture has the potential to become a new pillar for the Icelandic economy and important that it develops and grows in a sustainable manner. Considering this, the 2021 Agreement on the Platform for the Coalition Government of Iceland includes the following statement:

"A comprehensive policy will be formulated on the development, framework, and taxation of aquaculture. This work will emphasize opportunities for job creation and the importance of building the industry on sustainability, scientific knowledge, and the protection of wild salmon stocks."

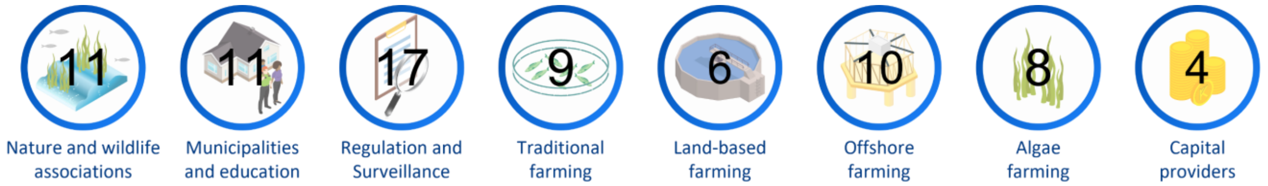
In preparation for the formulation of this policy, the Ministry of Food, Agriculture and Fisheries has commissioned the creation of this report to assess future opportunities and challenges for Icelandic aquaculture. The report analyzes the current state and outlook of global and Icelandic aquaculture across industry sectors and provides a comparison with other relevant supply markets. The report also examines different regulatory frameworks, environmental impact, and value creation potential.

1.1 Report structure

This report is divided into eight chapters and written with the aim of being equally accessible to industry stakeholders and the public. Following a summary of findings, the first content chapter looks at aquaculture as an industry, both globally and in Iceland. Four chapters then follow, one for each sector. These include a sector introduction, historical overview, current state, and outlook, for Iceland and key markets. The final chapter looks at economic value creation opportunities across three future scenarios and consider environmental and societal impacts.

1.2 Data gathering and analysis

In writing this report, emphasis has been placed on sourcing information based on research and data from reputable organizations, including previous Icelandic reports on the topic. In addition, information and perspectives were obtained from 76 Icelandic and global industry experts and stakeholders.

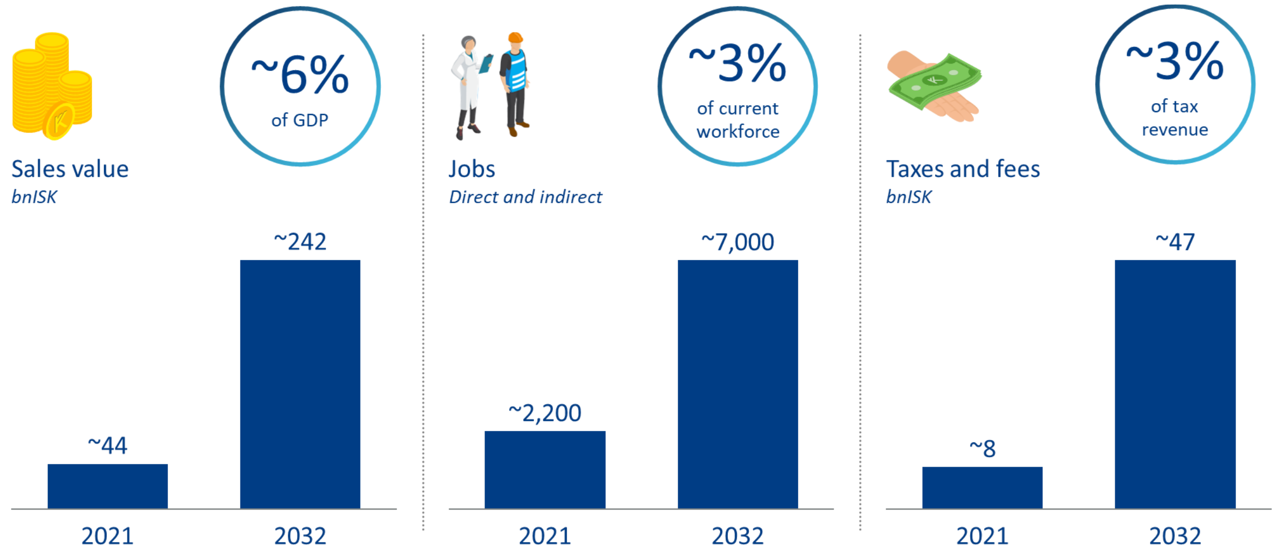


As product prices are quoted in foreign currency, numerical analysis is generally based in euros. This is done to minimize foreign exchange exposure from assumed value creation over time. Other currencies are directly quoted from sources. Where Icelandic Króna values are provided a conversion rate of 141 ISK/EUR is applied.

2. Summary

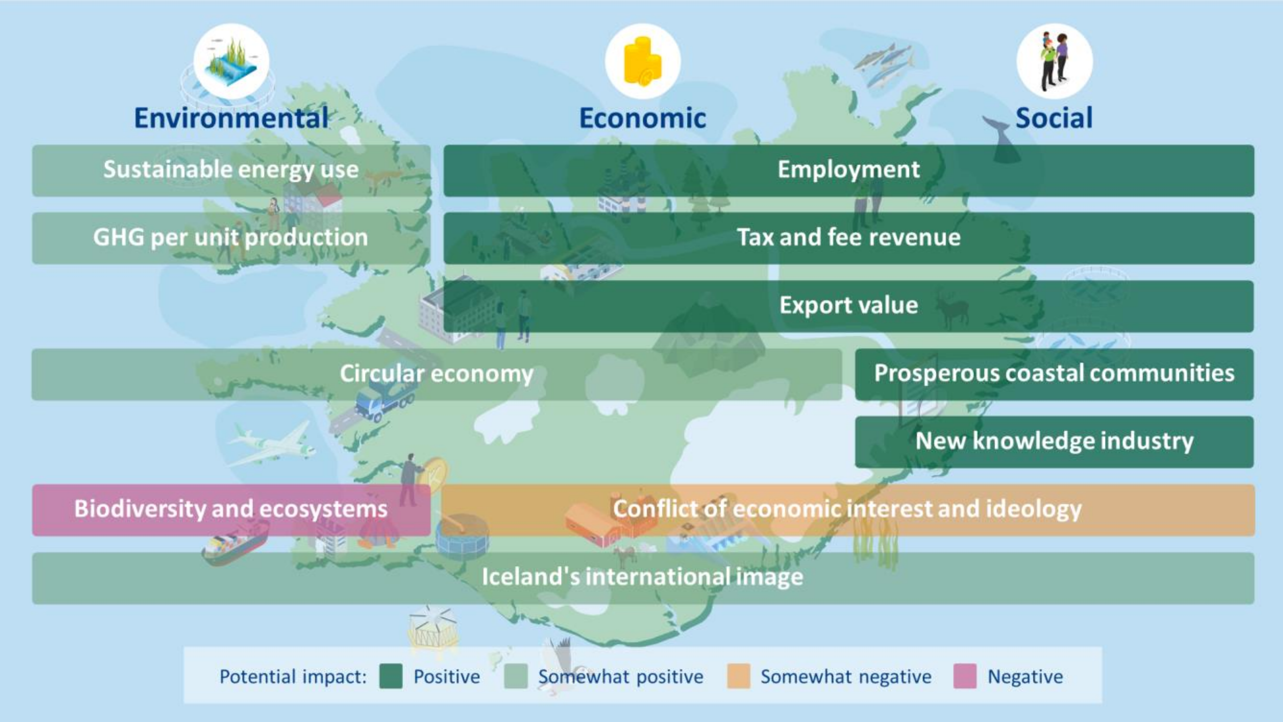
With rapid growth in traditional aquaculture over the last decade, Iceland is witnessing the emergence of a large-scale industry. As global demand for aquaculture products is expected to rise, Iceland's natural endowments positions it well for continued growth. Across the four aquaculture sectors, Iceland's economic value potential over the next ten years is significant in relation to the overall economy. This potential is illustrated in Figure 2.1, showing projected growth in three key value drivers in the base case scenario of this report.

FIGURE 2.1: ICELAND'S AQUACULTURE POTENTIAL (BASE CASE SCENARIO)



The economic value of aquaculture is likely to grow even further beyond the next decade as the sectors included in the analysis reach maturity. Achieving maturity typically grows a sector's tax footprint, as operations become profitable and corporate tax income grows. However, if not managed carefully, industry growth can also have less desired impacts, primarily on the environment. All in all, a growth of this scale will have wide ranging impact on Icelandic society. These impacts are summarized on a high level in Figure 2.2.

FIGURE 2.2: POTENTIAL IMPACT PROFILE OF GROWTH IN AQUACULTURE IN ICELAND



Sustainable food production is a major global challenge, one that aquaculture can play a significant role in addressing. Greenhouse gas emissions from farmed fish and the unit of feed required to produce a unit of protein for human consumption are favorable when compared to other sources of protein. This, coupled with Iceland's abundance of sustainable energy creates ideal conditions for sustainable food production through Icelandic aquaculture. Algae farming in Iceland can operate at net zero carbon emissions and algae inputs to feed have also been shown to reduce emissions from other types of animal protein production. All in all, emissions relative to value creation are also very favorable.

Aquaculture produces biproducts that are well suited as inputs to other industries, promoting the circular economy. Iceland is a global front-runner in 100% fish utilization, and there are already plans and projects in place use biproduct from land-based farming to create fertilizer for use in agriculture.

The largest challenge for aquaculture is its impact on the environment and sea-based lifeforms. This pertains first and foremost to open sea pens, currently the dominant production method used in traditional aquaculture. A special concern is the impact open sea pens have on wild salmon stocks, where escapes cause the risk of genetic introgression with the North Atlantic Salmon stock, endangering its future as a species. Organic load is discharged from production sites in large quantities with impact on the seabed. The use of chemicals used to shield nets is also harmful for other sea-based organisms. Emerging technologies such as closed sea pens hold the promise to limit this impact, but these are not yet in widespread use. As the industry grows in Iceland, a special focus needs to be placed on limiting negative environmental impact.

The environmental impact of the industry will furthermore influence the level of friction it causes with other industries, conventions Iceland is a part of, and overall public ideology. Recent debate has surfaced over the legitimacy of production site placement with regards to sailing routes. Tourism has grown to become a pillar of the Icelandic economy, and many travelers choose Iceland to experience its untouched nature. The emergence of a new industry that relies on access to common natural areas may impact this experience. Iceland is considered one of the best places in the world for angling, which is a source of economic and emotional value for both Icelanders and foreigners. Angling in Iceland is dependent on the prosperity of the North Atlantic salmon and thus at risk from negative impacts from aquaculture. Many claim that it is a moral imperative that Iceland eliminates any man caused danger to its existence.

As illustrated by Figure 2.1, aquaculture can create significant economic value through employment, tax and fee revenue and exports. Relatively, the highest value is captured by the municipalities where aquaculture is operated. Aquaculture has already in the last decade helped reverse trends of population and economic stagnation or decline in several smaller municipalities in the West- and East-fjords.

A key factor for growing aquaculture as an industry is access to local expertise and knowledge. This creates an opportunity to develop a local knowledge industry driven by a thriving research community and educational institutions.

Iceland's aquaculture strategy and resulting policy should seek to amplify positive impacts while limiting negative impacts. This involves prioritizing and making trade-offs that may also impact other industries. Done right, this will result in a balance where economic value is captured through sustainable industry growth that occurs in harmony with the environment and society. Achieving this also has the potential to elevate Iceland's international image as a producer of high-quality sustainable seafood.

The rest of this chapter summarizes the main findings of the report. It begins by looking at aquaculture from a global perspective and then continues to cover Iceland's current and potential future role. Iceland's competitive position is considered across the four aquaculture sectors in focus: traditional, land-based, offshore and algae farming. Projected growth in production and value creation over the coming decade is thereafter presented across three future scenarios, followed by considerations on how to unlock that potential. Finally, risks and uncertainties for Icelandic aquaculture are discussed. For more details on findings presented in this summary, please refer to respective chapters in the report.

2.1 Global aquaculture

As world populations continue to grow, global demand for food, both animal- and plant-based, also continues to grow. The key drivers of this demand are population growth and the rising middle class. Aquaculture is well-positioned to serve this growth in demand, both from an environmental and economic perspective.

With a rising middle class, fish protein demand is expected to grow faster than overall food demand. Global fishery production (fisheries) has not grown since early 2000s and has likely reached its limits. Therefore, that the future supply of fish protein needs to come from farming in order to meet demand. Farmed salmonids have been and are expected to play a significant role in serving this increasing demand. Historically, growth in salmonoid aquaculture has been driven from Norway, Chile, Scotland, and the Faroe Islands, the four largest global producers. Iceland, despite significant growth since 2016, currently only supplies ~2% of global volume.

In addition to fish farming, algae aquaculture holds great potential to sustainably serve future plant-based protein demands. Macroalgae farming is not constrained by arable land, as there is an abundance of habitat in the ocean. Microalgae technology and production has also developed considerably, efficiently creating highly nutritious products in controlled environments.

Today, the world is faced with many challenges. With continued technology advancement, aquaculture of both fish and algae holds potential to sustainably address them. Iceland, with its natural resources and human capital, can play an important role.

Aquaculture can also be significant for the Icelandic economy. With the introduction of new farming sectors, e.g., land-based, and offshore, advancement in technology, and strengthening of policy and regulatory environment, aquaculture can sustainably grow to become one of the pillars of Icelandic economy.

2.2 Iceland's competitiveness

The following section outlines the state of four aquaculture sectors of current or potentially future relevance for Iceland. It considers the advantages and challenges facing each Icelandic sector's competitive position, compared both to other supply markets and to other sectors. This informs the sizing of potential impact, which follows in section 2.3.

2.2.1 Traditional aquaculture

Icelandic salmon production in 2022 through traditional aquaculture, in which fish are raised in seawater pens during the grow-out phase, amounted to ~43kT, or ~96% of total salmon output in Iceland. Traditional salmon farming has grown at a ~35% CAGR since 2016 and holds the potential to grow towards ~100kT within current regulation and technology. Further growth beyond that will require changes in regulation and/or technological improvements.

FIGURE 2.3: ADVANTAGES AND CHALLENGES FOR TRADITIONAL AQUACULTURE (ICELAND-SPECIFIC)

Advantages

- ✓ **Fjords well suited** for traditional aquaculture
- ✓ **Biomass availability**
- ✓ Highly **developed seafood industry** including developed **seafood technology** sector
- ✓ Low water temperatures expected to contribute positively to **lower sea lice issues**
- ✓ **Diseases not as common** as in other markets today
- ✓ **Clean waters** ocean and Iceland's positive image for pure nature

Challenges

- ÷ Nascent industry with **limited scale** and **less mature value chain** compared to other markets (e.g., limited feed production)
- ÷ Less favorable **water temperatures** than in competing markets and currently **low production efficiency**[1]
- ÷ **Regulatory framework and resourcing** have not followed industry growth with challenges in **licensing processes** and **surveillance**
- ÷ **Research and education are behind** leading peer countries

FIGURE 2.4: ADVANTAGES AND CHALLENGES FOR TRADITIONAL AQUACULTURE (SECTOR-SPECIFIC)

Advantages

- ✓ **Economically efficient** with current technology
- ✓ **Proven technology** relative to other production methods

Challenges

- ÷ **Sea lice** risk
- ÷ **Disease risk expected higher** vs. other production methods
- ÷ Escapes' impact on wild salmon stocks, **risking genetic mixing** (introgression) as well exposing them to sea lice and disease
- ÷ **Environmental impact** from the release of **organic load** and in some instances, **chemicals** used in the production

Overall, Iceland is an attractive location for traditional farming due to its naturally suitable conditions and availability of capacity in fjords. Further growth would be supported by increasing the overall maturity of the supply chain and strengthening the regulatory system. Iceland is still expected to double production from traditional farming within the limits of current regulations. This in contrast to the other major salmon farming countries, where future growth from traditional farming is constrained by natural capacity and must be driven primarily by efficiency-enhancing technology.

Iceland has experienced rapid growth in production fueled by private investment since 2016, demonstrating Iceland's attractiveness as a site for traditional salmon farming. However, the existing methods used for traditional farming in Iceland face key environmental challenges and are unlikely to propel the Icelandic salmon industry much beyond two times its current economic size. Economic growth can also be driven through the value chain, e.g., with domestic feed production and increased processing. In addition, technological solutions with potential to mitigate environmental risk and/or expand capacity do exist. Examples include closed and semi-closed pens, sterile salmon, improved surveillance tools, larger smolt, and increased use of digitization to enhance operational efficiency. Beyond these, methods beyond traditional farming offer alternative avenues for mitigating these challenges. The following sections therefore investigate respectively land-based and offshore farming, both of which hold promises for additional growth as well as *potential* remedies to environmental risks.

2.2.2 Land-based

Land-based aquaculture is a nascent sector, currently with a relatively small global output[2] (~0.3% of global fish farming aquaculture). However, in the last few years, land-based aquaculture has received growing attention and significant investment, not least in Iceland. Ongoing projects in Iceland have plans to deliver ~105-125 kT of output across four companies, but most of these projects are in their early stages. Land-based salmon farming in Iceland at the planned scale is therefore yet to be proven successful.[3] The below defined advantages from technology should therefore be seen in this light; they are expected, based on theory and early operational trials, yet none are tested and proven at scale or through time. Thus, new challenges as well as advantages may also arise as technology matures and output scales.

[1] Maximum allowed biomass (MAB) utilization in Iceland is 0.6 vs. e.g., Troms and Finnmark in Norway where MAB utilization is 1.2-1.5 with water temperature conditions similar to Iceland's

[2] Iceland produces ~8kT today, but less than ~1.5kT is salmon; the remainder is primarily Arctic char (~5.5kT) and Rainbow trout

[3] There has been, however, more experience in Arctic char: in 2021, over 5kT were produced; see Food and Veterinary Authority in Iceland

FIGURE 2.5: ADVANTAGES AND CHALLENGES FOR LAND-BASED AQUACULTURE (ICELAND-SPECIFIC)

Advantages

- ✓ **Clean, abundant** underground **seawater** at favourable temperatures
- ✓ **Affordable, renewable energy**

Challenges

- ÷ **Higher transportation costs, emissions and lead time** vs. producers located closer to end-markets (e.g., continental Europe, US East Coast)

FIGURE 2.6: ADVANTAGES AND CHALLENGES FOR LAND-BASED AQUACULTURE (SECTOR-SPECIFIC)

Advantages

- ✓ **Less constraint by natural environment** (access to fjords)
- ✓ **Decreased risk of environmental impact** from organic load (directly) as well as **eliminated risk of escapes**
- ✓ Opportunity to locate **production closer to end-market**s reducing transport and lead time
- ✓ Highly **controlled environment** may provide growth advantages and lower mortality (***to be proven***)
- ✓ Improved **fish health** with **no exposure** to **sea lice** (***to be proven***)
- ✓ Ability to capture and create value from **biproducts**, e.g., as fertilizer[4]

Challenges

- ÷ **Unproven technology at scale**
- ÷ **Higher risk profile for investment:** Technological development and construction are multi-year endeavors requiring significant investment
- ÷ **Technological failures** can lead to mass mortality
- ÷ **Environmental challenges**, e.g., related to water usage, **filtration of discharge water,** and **collection of waste**

Land-based holds potential for considerable operational advantages. Furthermore, the abundance of potentially available capacity is attractive. This advantage will only increase in importance as the demand vacuum arising from traditional farming's constrained supply increases. Iceland is likewise expected to hold key sustained advantages towards other locations, the magnitude of which depend on

[4] Also possible for traditional aquaculture employing closed- and semi-closed pens

the attractiveness of a hybrid flow-through system (HFS) utilizing underground seawater compared to a recirculating aquaculture system (RAS). RAS systems provide more geographical flexibility, but this is counterbalanced by higher energy requirements and more complex technology (the recent technological challenges of players such as Atlantic Sapphire, for example, stemmed from RAS tanks. Overall, Iceland's affordable, clean energy will remain an advantage regardless of technology used.

In sum, Iceland's advantages combined with land-based aquaculture's low maturity and lack of dominant technology may provide an opportunity for Iceland to establish itself as a leader in the market. The relative attractiveness of land based may even increase if potential future regulation makes traditional less attractive from a producer perspective (e.g., proposed taxes or further capacity restrictions).

2.2.3 Offshore

Offshore aquaculture, which involves raising fish further out to sea than in the fjords used for traditional aquaculture, is an emerging sector. Offshore facilities are being developed across several projects, primarily driven by large Norwegian operators.[5] The sector is even younger than land-based, with only around eight projects worldwide, and several technologies are being tested with challenges remaining to be solved. Large scale operations are thus expected to emerge throughout the coming decade as the dominant technological solution(s) emerge. Given the sector's lack of maturity, the below advantages and challenges are primarily expected and indicated from early trials. They therefore include considerable uncertainty.

FIGURE 2.7: ADVANTAGES AND CHALLENGES FOR OFFSHORE FARMING (ICELAND-SPECIFIC)

Advantages

- ✓ **Suitable ocean conditions,** with preliminary study showing no obvious natural constraints of establishing offshore aquaculture in Iceland

Challenges

- ÷ **Lack of offshore infrastructure** (offshore supply vessels, labor, port facilities)
- ÷ **Legislation and planning** not in place, including assessment of suitable production areas, design of licensing structure, and how to manage risk assessments

[5] E.g. SalMarAkerOcean

FIGURE 2.8: ADVANTAGES AND CHALLENGES FOR OFFSHORE FARMING (SECTOR-SPECIFIC)

Advantages

- ✓ **Additional capacity potential** from new, non-fjord locations
- ✓ **Potential operational advantages** to traditional, including more stable sea temperatures and potential fish health advantages (***to be proven***)
- ✓ Potential for **less impact for wild salmon stocks** due to greater distance to salmon rivers (***to be proven***)

Challenges

- ÷ **High risk profile for investments:** Technological development and construction are multiyear endeavors and require significant investment under considerable uncertainty
- ÷ **Harsher environmental conditions** from e.g., waves and currents call for special infrastructure such as offshore vessels and specially trained labor; conditions may impact **fish health**
- ÷ Current risk of larger volume **fish escapes**
- ÷ **Biological threats, sea lice and seabed impact** will likely continue to be challenges

In sum, Iceland is an attractive location for offshore farming. However, supportive regulation and infrastructure currently lag Norway, where a development license scheme has spurred several projects and suitable locations for commercial operations have recently been defined. However, as the frontrunner, Norway still has not finalized its regulatory framework. This leaves room for Iceland to become another leader in this space.

2.2.4 Algae farming

Algae aquaculture is still a nascent industry in Iceland. Microalgae has grown considerably in the past ten years, with plans to scale in the near term. Macroalgae production currently relies on wild harvest. Macroalgae aquaculture has received significant interest in recent years but lacks regulation to allow for commercial cultivation.

FIGURE 2.9: ADVANTAGES AND CHALLENGES FOR ALGAE FARMING (ICELAND-SPECIFIC)

Advantages

Microalgae:

- ✓ **Cool climate,**[6] **clean freshwater** and **affordable energy**
- ✓ **Market leading companies** within specific products (e.g., astaxanthin) quickly scaling and **attracting investment**[7]

Macroalgae:

- ✓ **Cold water** delivering favorable conditions for nutrient-dense species, ideal for value adding processing

Challenges

Microalgae:

- ÷ **Dependency on energy,** unlikely a challenge until production scales

Macroalgae:

- ÷ **Lack of regulation** allowing for commercial farming, also stifling investment by preventing current experimental projects to scale
- ÷ **Lack of scale** relative to sectors in other countries (e.g., large Asian producers)

Across:

- ÷ **Lack of research institutions** and **common knowledge base**
- ÷ **Labor cost** and **limited** pool of **specialized workers**

In sum, Iceland holds several attractive properties for algae farming, particularly in microalgae, driven by natural resource advantages (energy, water). Iceland's high costs and relatively small labor force will likely require producers to focus on high-value products with complex production requirements. Macroalgae farming has not yet been produced at large-scale in Iceland, creating uncertainty around its economic viability. That said, private actors have been working to develop solutions to cultivate and commercialize macroalgae. As commoditized algae products compete with market prices, value-added products and use for environmental remediation may be the most attractive avenues.

Overall, Iceland has the potential to build a competitive position for algae aquaculture, to be realized through use of natural resources, commercial focus (high-value products), building on existing infrastructure, and establishing regulatory clarity.

[6] Advantage varies by specie

[7] E.g., Algalif, Vaxa

2.2.5 Sub-conclusion: Iceland's competitiveness in aquaculture

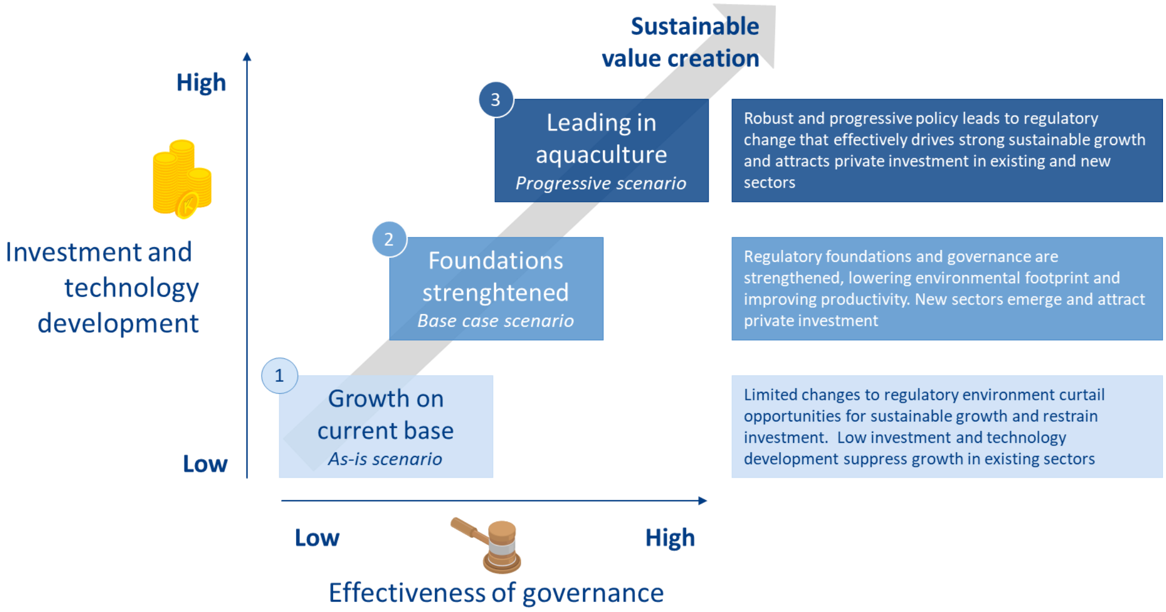
The outline here provided across the four sectors shows that Iceland has meaningful sustained competitive advantages in aquaculture. These primarily relate to Iceland's natural endowments and include affordable green energy, geothermal heat, fjords suitable for fish farming, and access to high-quality underground fresh- and saltwater. On the other hand, there are also natural challenges, such as seawater temperature in the fjords and geographical location with respect to market access. Other challenges can be addressed, such as the effectiveness of regulatory and surveillance frameworks and access to skilled labor and local infrastructure. Addressing this group of challenges can augment Iceland's competitive position.

2.3 Value potential

To frame the potential of aquaculture in Iceland over the next 10 years, three different scenarios are presented: *Growth on current base*, *Strengthened foundations*, and *Leading in aquaculture*. Each provides a different view of aquaculture's potential development. This reflects the inherent uncertainty of the future as well as the fact that Iceland's strategy and policy will have a large impact on future outcomes. The following section seeks to shed light on the potential impact and value generation of aquaculture to support such strategic policy decisions.

Each scenario consists of assumptions that are driven by progress on two growth vectors. The **effectiveness of governance** measures the authorities' ability and actions to support sustainable growth. **Investment and technology development** measure industry investment and progress and adoption of new technology mostly driven by private actors. The two vectors are related in the sense that effective governance generally supports investment and technology development. Therefore, scenarios are not considered where low effectiveness of governance is combined with high investment and technology development and vice versa, as these are seen as unlikely. Figure 2.10 gives an overview of the three scenarios used for evaluating Iceland's aquaculture value potential.

FIGURE 2.11: OVERVIEW OF THREE FUTURE SCENARIOS FOR AQUACULTURE IN ICELAND



A short description of the underlying assumptions for each scenario follows. For a detailed view on these assumptions, see section 8.2. Figures 2.11 to 2.14 that follow, show the projected production volume and how this translates into economic value across each of the three scenarios.

2.3.1 Growth on current base (As-is scenario)

The as-is scenario assumes no significant strengthening of regulatory and surveillance frameworks. This is reflected in no growth in overall traditional aquaculture MAB compared to today and limited changes to MAB utilization. Technological challenges and lack of financing also limit production growth across all sectors. Lastly, neither offshore nor macroalgae farming establish operations on a commercial scale over the next 10 years.

2.3.2 Foundations strengthened (Base case scenario)

The base case scenario assumes that growth is enabled by strengthening regulatory and surveillance frameworks. Furthermore, technological development, improved operations and availability of funding are conducive to growth. During the 10-year timeframe, offshore farming as a sector is established, and projects are operating at a commercial scale by the end of the decade. Licensing framework for macroalgae farming is also established. Over all sectors, this is the scenario considered most likely and therefore most indicative of the value potential of aquaculture in Iceland in the next 10 years.

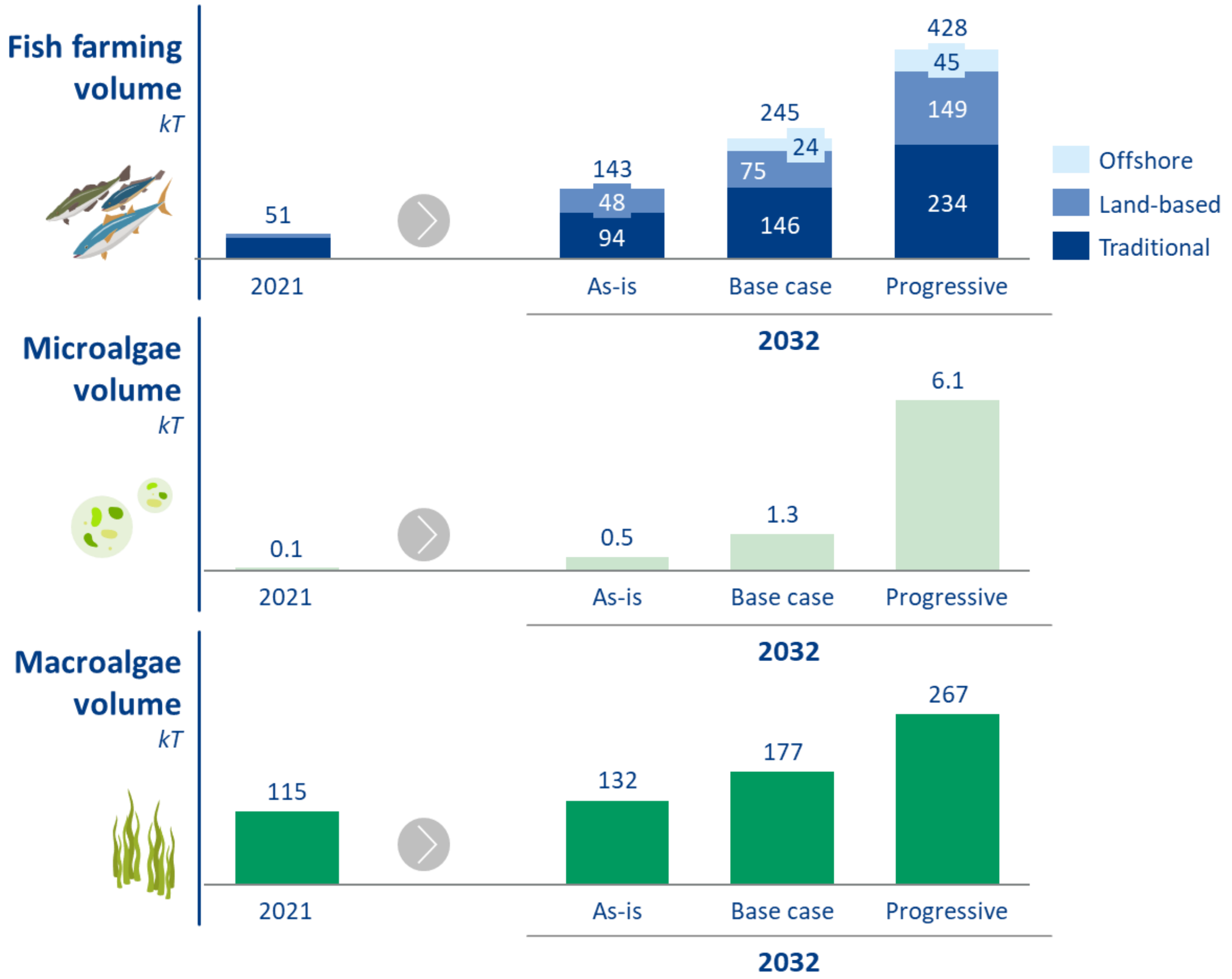
2.3.3 Leading in aquaculture (Progressive scenario)

In the progressive scenario, regulatory, surveillance and strong technological developments boost production in traditional aquaculture. Research and surveillance show that technological developments limit environmental impact, in turn allowing for sustainably increasing the licensed MAB. Farmers furthermore increase their utilization of the MAB to amplify overall production. Ample access to funding, technological success, and favorable regulatory conditions enables strong growth in land-based and algae farming. The regulatory conditions to operate offshore farming are quickly established, and strong investment results in several projects operating commercially by the end of the decade.

2.3.4 Volume

The overall findings show that salmonoid output holds potential to grow from ~51kT in 2022 to ~245kT in the base case scenario (~140kT in as-is scenario and ~440kT in progressive scenario). In all scenarios, traditional remains the largest producing sector by 2032, driven by both technology and capacity expansion. However, land-based is expected to contribute with ~50-150kT, depending on technology and access to funding. Offshore on the other hand will only deliver production in the base and progressive scenarios, in both cases commencing commercial production around 2030 and delivering ~25-45kT, depending on the amount of biomass licensed and investments made.

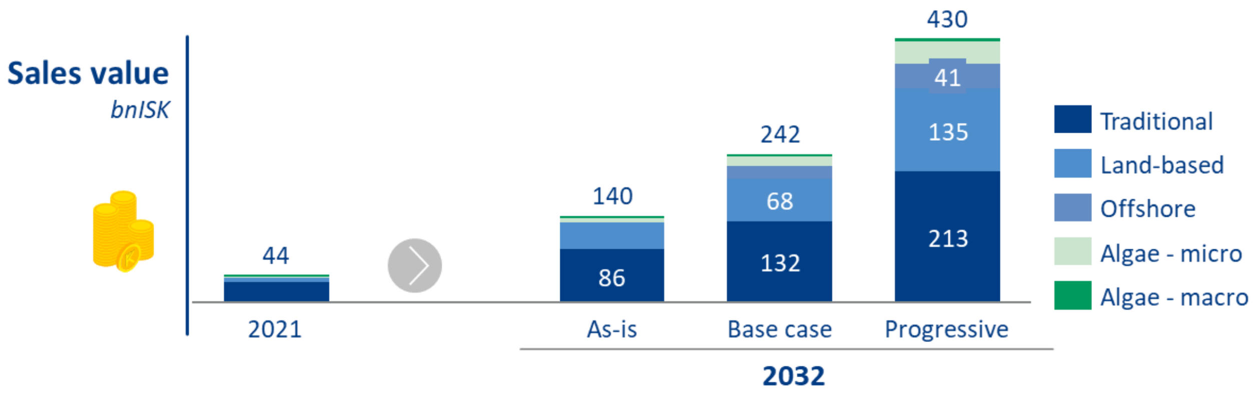
FIGURE 2.11: VOLUME ACROSS AQUACULTURE SECTORS, SCENARIOS AND TIME



Given the assumptions, presented in Chapter 8, microalgae will grow from 0.1kT output today towards 0.5-6kT, increase volume significantly from today. The range for microalgae volume is the largest of all sectors. This is due to plans already underway of significant increases compared to today and limited constraints for scaling production across several species (such as Spirulina) that are typically produced in high volumes. Macroalgae is likewise assumed to grow materially cases from ~115kT today (mostly wild harvest) towards ~130-270kT in the base case and progressive scenarios.

2.3.5 Value

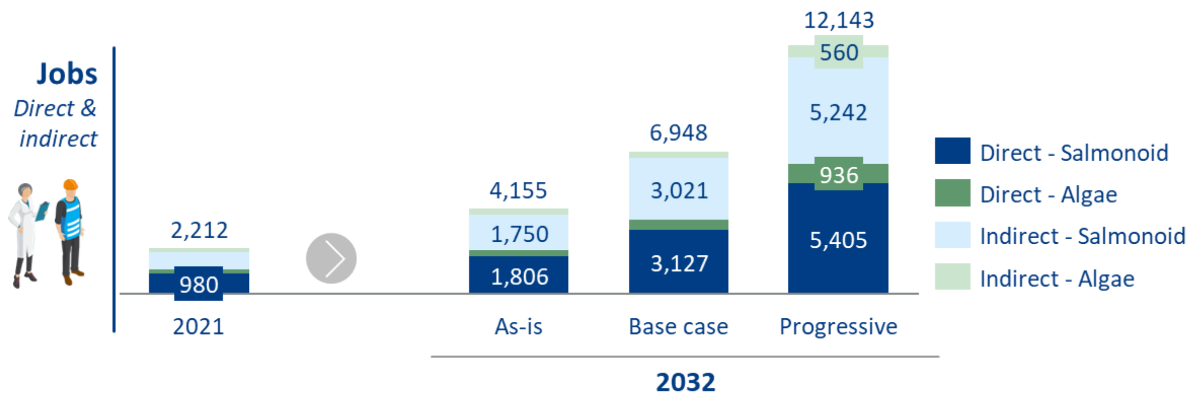
FIGURE 2.21: SALES VALUE ACROSS SECTORS, SCENARIOS AND TIME



In terms of sales value, the base case scenario assumes a growth from ~44bn ISK (310m EUR) in 2021 to ~240bn ISK (~1.7bn EUR) in 2032. To place that number into perspective with the overall economy, ~240bn ISK could make up for as much as ~6% of GDP in 2032.[8]

2.3.6 Jobs

FIGURE 2.13: JOBS CREATED ACROSS SECTORS, SCENARIOS AND TIME

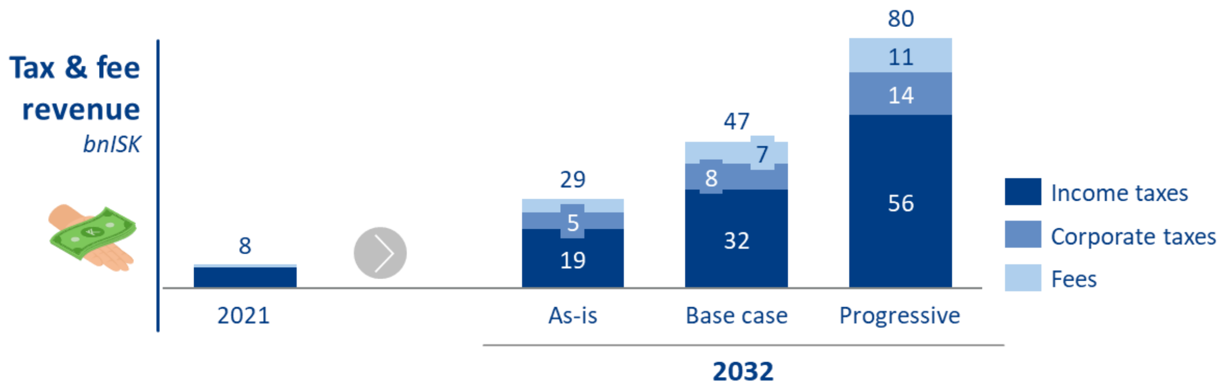


Increased volume also translates into employment, both directly and indirectly arising from the needs of the aquaculture sector. These are assumed to reach around 7,000 in the base case scenario (~4,000 in as-is, ~12,000 in progressive). If realized, these jobs could make up ~3% of the Icelandic work force today (~2% in as-is, ~6% in progressive). However, the net effect of these new jobs is unclear as they depend on where they are sourced from among new local entrants to the labor market, migration from other sectors, and imported labor.

[8] Applying total 2021 GDP for Iceland of ~3,200bn ISK and assuming 3% annual nominal growth

2.3.7 Taxes and fees

FIGURE2.14: TAXES AND FEES PAID ACROSS SECTORS, SCENARIOS AND TIME



Tax revenue includes value from both income taxes from industry laborers (direct and indirect), direct corporate tax of the aquaculture farmers as well as special fees related to the aquaculture industry. In 2032, the projected total taxes and fees sum to ~47bn ISK (~335m EUR) in the base case scenario. If the base case is realized, ~47bn ISK could amount to as much as ~4% of total tax revenue in 2032. Traditional aquaculture is expected to deliver most of the tax revenue in this next decade, both because there are additional fees tied to traditional production volume, and because traditional companies are reaching the stage of generating profits, resulting in corporate income tax revenue. Income tax from individuals carries most of the tax and fee revenue in 2032. It has been noted that a significant share of employment in the industry today is procured through staffing agencies and that in such instances income taxes are not incurred in the same way as when employees are directly employed. No specific adjustment has been made for this in the analysis but is worth investigating further including considering mitigating actions if this development continues.

2.3.8 A new pillar of the Icelandic economy

Purely considering the economic value potential derived from the growth of aquaculture in Iceland, it is poised to become a substantial part of the Icelandic economy. Yet to unlock this opportunity by way of sustainable growth, environmental, and societal implications are equally important to consider. Throughout this report, attention is paid to the environmental impact of aquaculture, both on the local ecosystem and wild salmon population, and in terms of greenhouse gas emissions. Yet this report should be treated only as a preliminary overview, to be validated and deepened with thorough environmental and biological studies. Beyond the environment, interviews with numerous diversified stakeholders have underscored the wide-ranging impact of aquaculture on society, from stimulating growth in small coastal communities to creating an opportunity cost of the use of fjords as a common resource. Yet by ensuring that these are accounted for in Icelandic policy, aquaculture has the potential to become a sustainable pillar of the Icelandic economy.

2.4 Unlocking Iceland's potential

The following section will consider how to enable this potential. Policy decisions can do much to influence future scenario realization, despite uncertainty and external influences. The latter include technological development both inside and outside of Iceland, as well as both micro- and macroeconomic development. The following section outlines key considerations for Icelandic policymakers within each sector, as well as enablers that span the industry.

2.4.1 Traditional aquaculture

The main driver of the economic potential is the volume of production, which in turn drives sales value, jobs, taxes, and fees. Most volume in all scenarios comes from traditional aquaculture. This is volume regulated by the carrying capacity and risk assessments, established to limit environmental impact. Changes to the current MAB for traditional aquaculture require research and thorough environmental assessments, especially with regards to the impact on wild salmon stocks. Prior to such research taking place, many of the following enablers should not be read as recommendations, but as levers to be considered and analyzed for potential application. A prerequisite for these levers is a scientific and political process with the aim to optimize the sector's sustainable value generation.

A. Increase transparency related to the auction process, including more details around the parameters applied and the weight they carry in the decision process.

B. Consider offering special green licenses that incentivize the development and application of technology with lower environmental impact, e.g., minimizing escapes, sea lice, and organic load discharge.

C. Consider increasing the MAB if a farmer uses more sustainable methods such as semi-closed or closed pens.

D. Holistically revisit the license allocation with the aim to maximize MAB under the constraints of the risk assessment and offer operators to relocate their sites.

E. Support increased MAB utilization by allowing biomass migration between defined regions, within farmers' MAB limits per production area. This requires adjusting the carrying capacity and licensing regimes to link MAB to a larger geographic region (e.g., South-Eastfjords) and the carrying capacity assessment of each production area.

F. Increase resourcing for industry regulation and surveillance.

G. Strengthen surveillance regime (e.g., weekly reports of escapees and sea lice vs. monthly; periodic inspections with drones) and implement stricter regulations such as seasonally lowering sea lice threshold (e.g., 0.5 to 0.2 during warmer months) for faster activation of contingency plans; decrease pen density to limit disease risk (e.g., 25 kg/m^3 to 20 kg/m^3); require monthly samples to investigate diseases; and ensure surveillance of smolt facilities and wellboat transport.

H. Streamline medicine approval process, e.g., by pre-approving one sea lice treatment per production cycle to allow for a faster response with the aim to limit outbreaks.

I. Adjust the current distribution of taxes and fees to grow the investment capacity of municipalities for supporting the industry and its workers.

2.4.2 Land-based

Land-based is a sector with large-scale projects being planned in Iceland. These projects are, however, in their early stages, and operations at a large (10kT+) scale are yet to be piloted. The regulatory actions to consider are primarily concerned with enabling growth and creating a predictable regulatory system better catered to land-based operations:

A. Assess creating an independent licensing structure optimized for land-based aquaculture, including technical operating standards and fish welfare requirements, with licensing fees primarily covering surveillance costs.

B. Ensure sufficient resourcing to manage new regulatory work and surveillance for land based. Define overlaps and synergies with traditional aquaculture, e.g., disease surveillance, and ensure resourcing for new surveillance requirements, e.g., of filtered run-off water.

C. Assess policy options to support land-based growth, e.g., through further innovation support, marketing assistance, and other means of encouraging of private investment.

D. Ensure energy supply, including transmission for land-based operations. Less of a concern in the short term but likely to become a constraining factor as scale grows.

2.4.3 Offshore

Offshore is a nascent sector from a technology perspective and requires high investments over a long-time horizon before reaching commercial operations. If Iceland desires to establish an offshore sector, the key role of the government will be to create certainty around its future intentions. Much can be learned from recent developments in Norway, where several projects are already underway or in planning. To become one of the front runners in offshore aquaculture, Iceland should also consider ways to incentivize private investment:

A. Include offshore in the wider aquaculture strategy for Iceland to clearly communicate intentions to the market as well as set off open water planning work across industries, including what areas are to be set aside for preservation.

B. Launch research to validate suitable locations that can be used to advise on location of potential developmental licenses, support work on open water planning, and eventually form the basis for commercial licensing.

C. Consider issuing developmental licenses at low or no cost with conversion optionality to commercial licenses, which can help attract investor interest and build the required capabilities while long term regulation is formed.

D. Fund research to investigate the environmental impact profile of offshore, with special focus on risks associated with escapes and impact on local species such as coral.

E. Consult with the market in identifying suitable areas prior to licenses being auctioned.

F. Consider how to balance the overall tax and fee burden, including commercial license costs, in a way to counter the significantly higher investments required in comparison with traditional.

G. Consider potential constraints on operations e.g., with respect to where production is brought onshore ensure adequate value generation for Iceland.

2.4.4 Algae

Algae farming consists of micro- and macroalgae. Microalgae production has limited regulatory requirements, with key enablers focused on securing affordable energy supplies. Conversely, macroalgae cultivation has higher regulatory requirements due to its use of common resources and potential environmental impact. Currently, there is no licensing systems for macroalgae cultivation, resulting in production limited to wild harvest and smaller experimental projects. The segment therefore requires regulatory support to expand, including key considerations such as the following:

A. Fund research to identify optimal locations for macroalgae aquaculture, including environmental assessment to ensure minimal impact to native algae species and ecosystems.

B. Create a development licensing system, to enable players to develop capabilities and technology, while simultaneously developing a comprehensive regulative framework for commercial production.

C. Assess options around financial support, e.g., special research grants to stimulate further innovation across micro- and especially macroalgae.

D. Limit the tax and fee burden, e.g., surveillance fees for smaller macroalgae farmers and projects during developmental stage to support commercial viably until scale is reached.

2.4.5 Enablers across sectors

Icelandic aquaculture is still in a growth phase while Iceland holds natural endowments that can create sustained competitive advantage. Under these conditions, there is much that governments can do to accelerate industry development and the timeline to economic value. To enable the sustainable growth of aquaculture in Iceland, several enablers should be considered:

A. Consider aquaculture specifically in the prioritization of energy. Sustainable food production with green energy is an essential part of addressing major world challenges. Predictability around access to energy will facilitate investment in the industry. It moreover creates a highly valued product that is likely to fetch premium prices, helping Icelandic aquaculture companies grow and prosper.

B. Increase funding for research facilities, e.g., building a basin for growing fish and algae in collaboration with an educational institution, invest in laboratories and equipment.

C. Increasing educational capacity and build practical education pathways to cater for student interest and fulfill the needs of the industry. Plan longer term to cater for increased technical requirements for industry workers and focus on enabling scientists and research scholars to conduct research to advance knowledge. Look at opportunities in combining current centers of educational excellence across the Iceland from secondary to tertiary education to harness current capabilities.

D. Increase resources for governance and surveillance to enable sustainable growth. Resourcing has not followed production growth (~5x since 2016) nor increased complexity with the emergence of new sectors and rises in diseases and sea lice.

E. Look at actions to strengthen the value chain. To serve aquaculture production in the 2032 base case scenario, ~320kT feed and ~60m smolts are required. Benchmarking with feed mills in Norway, this can be delivered in Iceland with a single feed mill and ~8 smolt production facilities (~8m smolt capacity annually). Both requirements can reasonably be expected to be delivered by private players, given that required approvals are issued by regulators.

F. Creating a single point of entry in terms of managing regulatory affairs related to aquaculture. This can increase oversight, drive the speed of decision making, and make processes smoother and easier to navigate for private players

2.5 Risks and uncertainties

To unlock Iceland's sustainable aquaculture potential, key risks and uncertainties must be considered. In the following sections these are outlined for each of the sectors across relevant dimensions.

2.5.1 Traditional

Production methods in the traditional farming sector are well established and have historically been economically feasible once maturity is reached. This leaves primary risks centered around regulation and environmental challenges.

FIGURE 2.15: SUMMARY OF KEY RISKS TO TRADITIONAL FARMING

1 Environmental

- High concentration of open pens can place pressure on the seabed due to excess organic load and chemical discharge
- Escapees from pens can risk genetic introgression with wild salmon stocks and they can be exposed to disease and sea lice from open sea pens

2 Commercial

- Commercial risk is generally lower in traditional vs. other fish farming sectors, license and production fee costs, an economic downturn, biological challenges and falling salmon prices can all impact earnings significantly

3 Operational

- Access to skilled labor and supply-chain inputs such as feed and smolt may restrict ability to produce
- Human error may lead to biological challenges and restrict output
- A decrease in sea temperatures, already low in Iceland compared to other farming areas, can have significant impact on production, due to lower growth rates and mass mortality

4 Regulatory

- Changes to licensing costs, fees and taxation
- Changes to carrying capacity and risk assessment may restrict production capacity
- Regulatory changes in other countries may affect Iceland's competitive position

2.5.2 Land-based

Land-based salmon production is based on a relatively new technology which, despite promising results from pilot projects in Iceland, creates a level of uncertainty around its ability to be applied on an industrial scale. Impact on the environment also needs further research.

FIGURE 2.16: SUMMARY OF KEY RISKS TO LAND-BASED FARMING

1 Environmental

- Uncertainty regarding the impacts of large-scale ground saltwater extraction
- Wastewater treatment and impact of salinity on land

2 Commercial

- A lack of funding to develop technology and scale operations
- Ability to attract price premiums due to high land-based supply or sustainability advances across sectors
- Benefits from controlled environment operations are not realized

3 Operational

- Energy supply including transmission may impair ability to scale operations
- Human error or technology failures leading to lower yield than expected

4 Regulatory

- Lengthy license approval process impairs ability to scale in line with plans
- Changes to regulation, taxes and fees that may limit output or impact profitability

2.5.3 Offshore

Offshore is the most recent sector in fish farming to emerge, making key risks around technology, funding, and regulatory uncertainty.

FIGURE 2.17: SUMMARY OF KEY RISKS TO OFFSHORE FARMING

1 Environmental

- Early state of technology development may increase risk of large fish escapes, especially in harsh ocean conditions, unless mitigated by new technology, e.g., such as double nets
- Location needs to account for potential impact to vulnerable ecosystems
- Organic load from high biomass production may intensify impact on seabed although dispersal is expected to be higher in open waters

2 Commercial

- Lack of regulatory clarity and planning may slow sector investments
- High investment needs may impair ability to deliver profitable operations, although possible to mitigate with licensing costs and production fees
- Lack of clarity around operational benefits e.g., lower mortality, cost of health management etc.

3 Operational

- Technology to be proven at scale under harsher ocean conditions
- Operations in harsher conditions may increase risk of human error and distance from coast lead to longer reaction times if events occur e.g., due to biological challenges
- Access to infrastructure enabling operations in Iceland (e.g., port-side, vessels, labor)

4 Regulatory

- Surveillance more challenging due to distance from coast and requires new capabilities
- Risk assessment requires further research
- Delays in achieving regulatory and planning clarity may lead to private actors choosing other locations

2.5.4 Algae

The algae sector is in early developmental stages in Iceland, building local knowledge and capacities. Microalgae faces uncertainties around securing energy supply while macroalgae cultivation is challenged by a lack of legislation and local biological data.

FIGURE 2.18: SUMMARY OF KEY RISKS TO ALGAE FARMING

1 Environmental

- Macroalgae: Ocean-based macroalgae farming may risks altering natural ecosystems dynamics

2 Commercial

- Competitive market, with mass scale producers, puts pressure on scale and/or intellectual property
- Macroalgae: Commercial viability of unclear due to low margins

3 Operational

- Lack of local sector knowledge, experience and limited size of specialized labor pool
- Microalgae: Key inputs are energy and freshwater, although neither a challenge at current scale

4 Regulatory

- Macroalgae: Lack of special regulation, planning and licensing, limits commercial attractiveness

2.5.5 Across sectors

Macro trends do and will continue to impact aquaculture with various external factors creating uncertainty about the future of the industry:

FIGURE 2.19: KEY RISKS ACROSS SECTORS

1 Demand

- Although global demand for protein is growing and salmon has been considered a healthy option, plant-based proteins or other low-carbon alternatives are increasingly seen as viable options. Nutritional value, costs, and consumer acceptability are not yet on par with salmon, making it likely that this risk will not materialize in the medium term. Algae farming may however benefit from these developments

2 Supply

- Growth in traditional aquaculture is relatively constraint by natural conditions, industry players are looking towards new production methods, i.e., land-based, and offshore aquaculture. Breakthroughs in technology may lead to significant global production growth and impact market prices
- Climate change can impact ocean conditions on which some sectors depend and hence their ability to supply products

3 Inputs

- Salmon industry is reliant on the input of local eggs and imported feed. If local inputs are not able to scale fast enough, and competition for feed intensifies, it may impact growth and profitability
- Climate change can impact ocean conditions on which some sectors depends

4 Economy

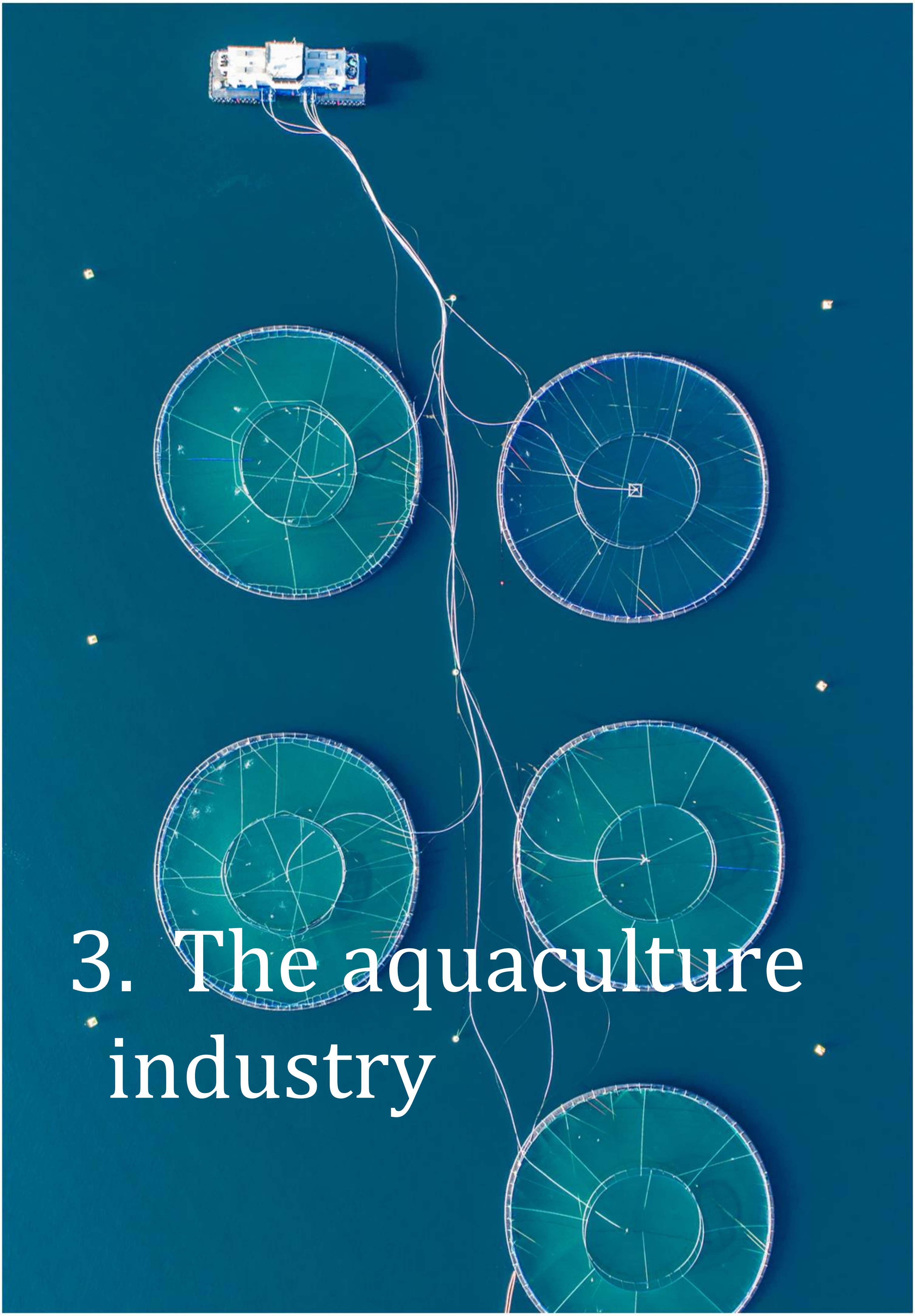
- ISK volatility may impact value of production although possible to hedge
- Economic downturn may limit funding and impact demand and pricing

2.6 Conclusion and the road ahead

The above summarizes the status of the aquaculture industry and future opportunities and challenges for Iceland. Overall, aquaculture holds the potential to grow into a substantial part of the Icelandic economy, with base case scenario sales value correspond to ~6% of Icelandic GDP in 2032, jobs occupying ~3% of the Icelandic work force, and industry taxes and fees accounting for ~3% of total tax revenue.

Unlocking this potential for Iceland requires several regulatory considerations. Of primary importance is to adapt the current regulatory and surveillance environment with focus on limiting environmental impact and facilitating the sustainable growth of the industry. Additionally, the relatively more nascent industries (primarily land-based, offshore and macroalgae) require new, comprehensive regulatory frameworks to enable long-term planning and investment.

The potential economic value to be created by aquaculture poses a great opportunity for Iceland, but left unattended, this growth will also intensify aquaculture's total environmental impact. To achieve the value potential in harmony with the environment and society, policy must balance growth with care for the environment and overall welfare of society. This balance needs to be based on solid scientific grounds, which Iceland has the institutions and expertise to build. The considerations laid out in this report should therefore not been seen as direct recommendations, but instead as levers to unlock Iceland's value potential that require further analysis and research before being reflected in Iceland's aquaculture strategy and policy.



3. The aquaculture industry

The objective of this chapter is to provide a general introduction to the aquaculture industry, covering farmed species, environments, and technologies, as well as its role in food security and sustainable development.[9] This chapter therefore lays the groundwork for defining both the current and future market dynamics facing the Icelandic aquaculture industry, each sector of which will be described in turn in Chapters 4 through 8.

3.1 Industry overview

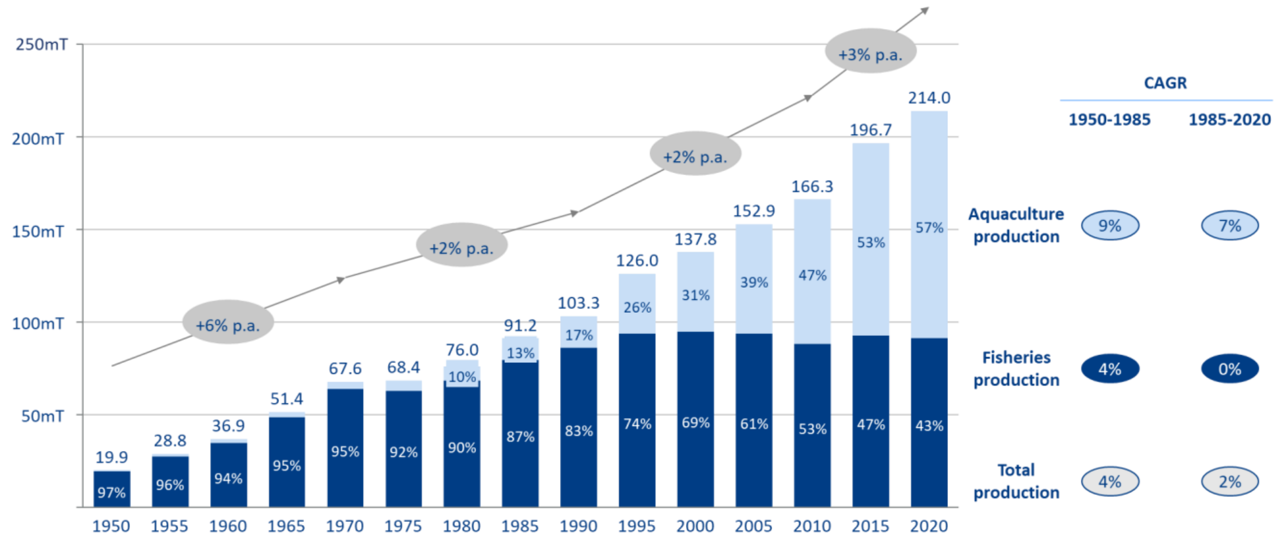
The Food and Agricultural Organization of the United Nations (FAO) defines aquaculture as the farming of aquatic organisms with some form of human intervention to enhance production, such as regular stocking, feeding, and protection from predators.

Aquaculture production also implies the control and private ownership (individual or corporate) of the organisms being cultivated in a controlled environment. Conversely, fisheries account for the harvesting of wild aquatic stocks that are under common ownership.

3.1.1 Aquaculture production volumes have surpassed those of fisheries

Historically, the catch of wild fish has dominated the seafood sector. Over the past century, fisheries grew, especially between 1950 and 1970. However, growth gradually slowed during the 1970s, with volume peaking in the 1990s. Since then, volume from fisheries has remained stable around an annual production of ~90 million metric tons (mT) globally. In turn, global aquaculture production has grown from ~10mT in 1985 to over 120mT in 2020, surpassing fisheries volumes in 2013. Aquaculture, including aquatic plants, has thus taken over as the key growth driver of global seafood production.

FIGURE 3.1: GLOBAL SEAFOOD PRODUCTION 1950-2020 (MT)[10]



[9] Sustainable development is defined by the UN as a long-term strategy to drive growth, meeting present needs without compromising the ability of meeting future needs

[10] FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ), BCG analysis

Aquaculture can be segmented by species, their growing environment, and the production method.

FIGURE 3.2: AQUACULTURE SEGMENTATION

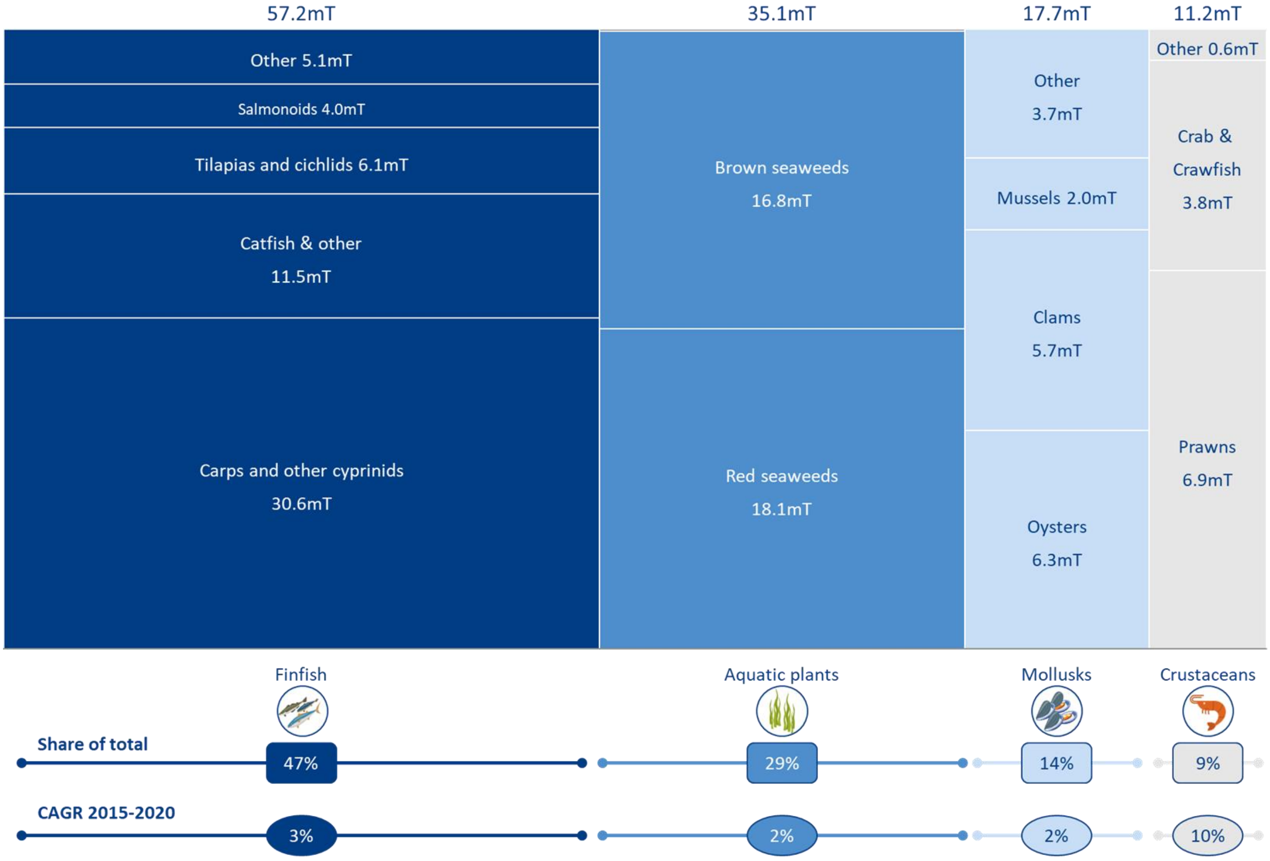
Aquaculture	Biological species	Finfish	Fish species without shell (e.g., carp, tilapia, salmonoids, bream & bass)
		Aquatic plants	Aquatic vegetation (e.g., seaweed, wakame, kelps)
		Mollusks	Shellfish subset with two-part shell (scallops, oyster, mussel)
		Crustaceans	Shellfish subset with segmented body (e.g., shrimp, crab, crawfish)
	Growth environment	Freshwater	Rivers, lakes and ponds Species include carps, trout, catfish, among others
		Marine	Coastal and offshore marine areas Species include Salmon, seaweeds and mussels
		Brackishwater	Water with higher salinity than freshwater Species include shrimp, seaweeds, milkfish and tilapias
	Sector	Traditional	Growing system in a natural marine coastal or freshwater environment
		Land-base	Growing system on land in a man-made controlled environment
		Offshore	Growing system in an exposed marine water environment

This report covers aquaculture production across sectors that utilize different production methods (Chapters 4-7), while focusing on the most attractive finfish and algae species for Icelandic conditions.

3.1.2 Salmonoids are attractive to farm

Aquaculture production is mainly focused on finfish and aquatic plants, which account for around 75% of total global volumes.

FIGURE 3.3: GLOBAL AQUACULTURE PRODUCTS IN 2020 (MT)[11]



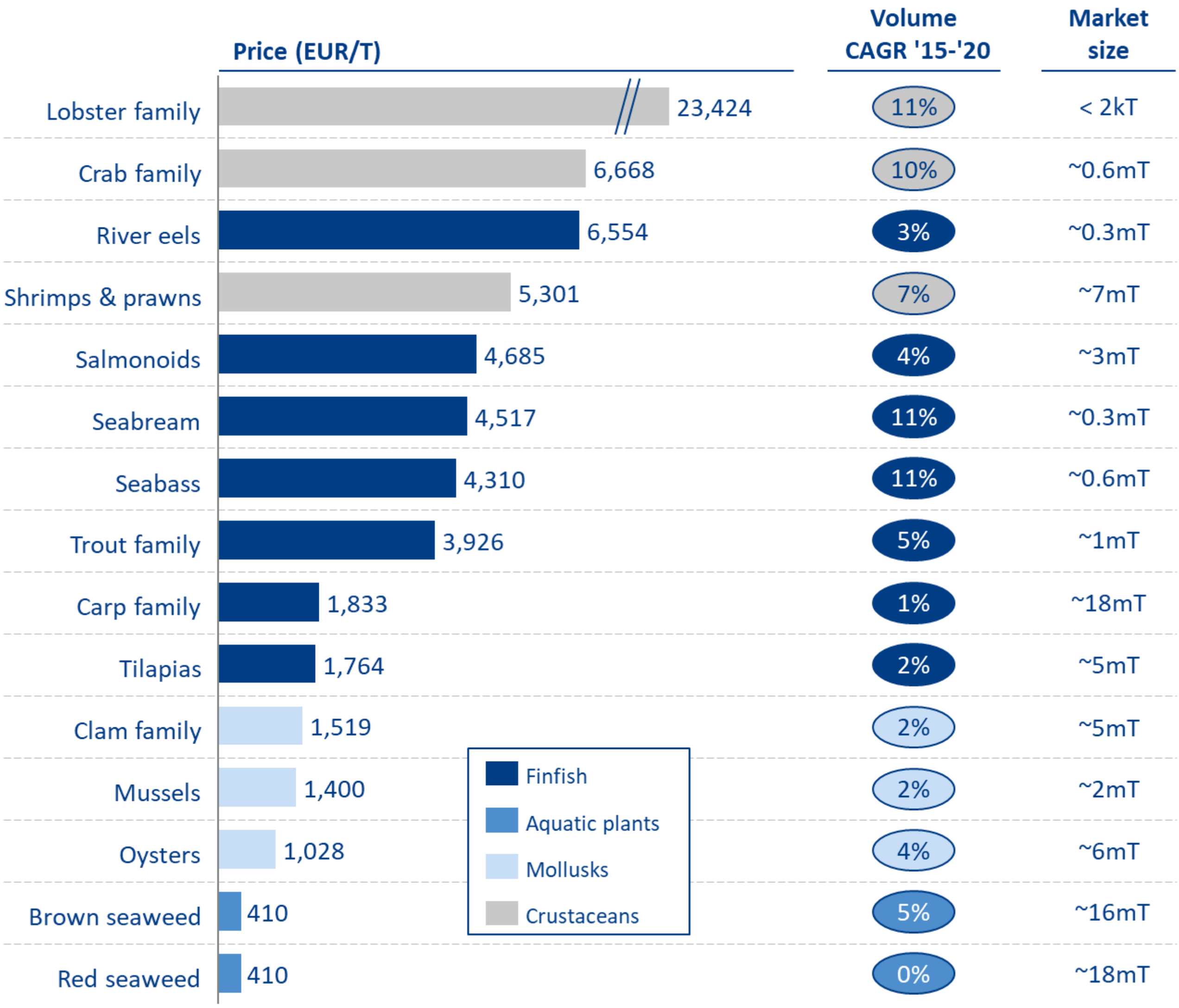
Finfish are the largest group of farmed species, with nearly half of total volume. Freshwater fish (including carps, catfish, and tilapias) make up the majority, and salmonoids are the fourth largest sub-group.

Farmed aquatic plants are the second largest group, with around 30% of total production. This volume is made up of brown and red seaweed such as Japanese kelp and Wakame. Mollusks account for around 15%, comprised of relatively low-value and low-growth species such as oysters and clams. Lastly, crustaceans total around 10% of total production and are the smallest but also the fastest growing of the groups, with 10% CAGR between 2015 and 2020. Crustaceans include shrimps and prawns, seacrabs, lobsters, and freshwater crustaceans (crayfish and crab).

Considering only market value, size and recent growth, finfish and select crustaceans have historically been the most attractive for farming.

[11] FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ), BCG analysis

FIGURE 3.4: MARKET DYNAMICS OF AQUACULTURE PRODUCTS[12]



Finfish include several high-value species historically priced at over 4k EUR/ton, with attractive market sizes and growth. Among these, salmonoids and seabass have been the most attractive families due to high price, a relatively large market size, and being easy to cultivate in comparison to many other finfish.

Crustaceans have had both the highest value and the highest production growth. The shrimp and prawn market is relatively large and has seen strong growth. Crab has a higher price point but a degree of magnitude smaller market size. Finally, lobster aquaculture is still in its infancy with very limited production. It does however fetch the highest price of all farmed species so might grow in the future.

[12] FAO. 2022. Fishery and Aquaculture Statistics. Global aquaculture production 1950-2020 (FishStatJ), BCG Analysis

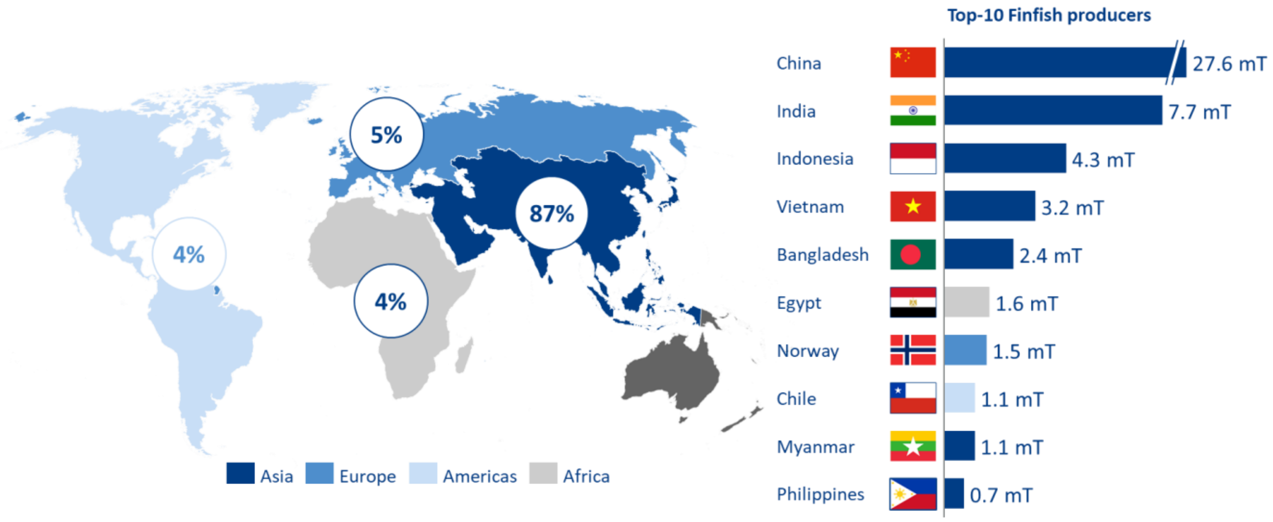
Historical information does not guarantee future attractiveness, but it is relatively safe to assume that finfish and crustaceans will continue to be highly attractive farming alternatives. As finfish are currently most relevant to Iceland, a deep dive is provided from a global producer perspective.

Finfish

The term finfish is commonly used to distinguish the biological group of fish from other aquatic species referred to as fish (e.g., cuttlefish, jellyfish, and shellfish).

Asia has a long-standing tradition for freshwater fish farming. Most finfish production takes place there (87%), with seven of the top-10 largest producers in Asian countries: China, India, Indonesia, Vietnam, Bangladesh Cambodia, and the Philippines.

FIGURE3.5: MAIN PRODUCERS OF FINFISH IN 2020 (MT)[13]



Finfish are biologically segmented by their natural habitat into three main types: freshwater, diadromous and marine fish.

Freshwater fish are the main fish farmed, with Grass carp (5.8mT), Silver carp (4.9mT) and Nile tilapia (4.5mT) as the largest species. Freshwater species are typically harvested in natural environments with rivers, lakes, and reservoirs of mild to warm water temperatures, ~15-30°C.[14] Ponds and floating cages are the most common growing techniques.

Diadromous fish include species that can adapt to fresh and saline water conditions and that transition between seawater and freshwater to spawn. Salmonoids are the most harvested species within this group (~4mT) and thrive in cold waters under 20°C.

[13] FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ), BCG analysis

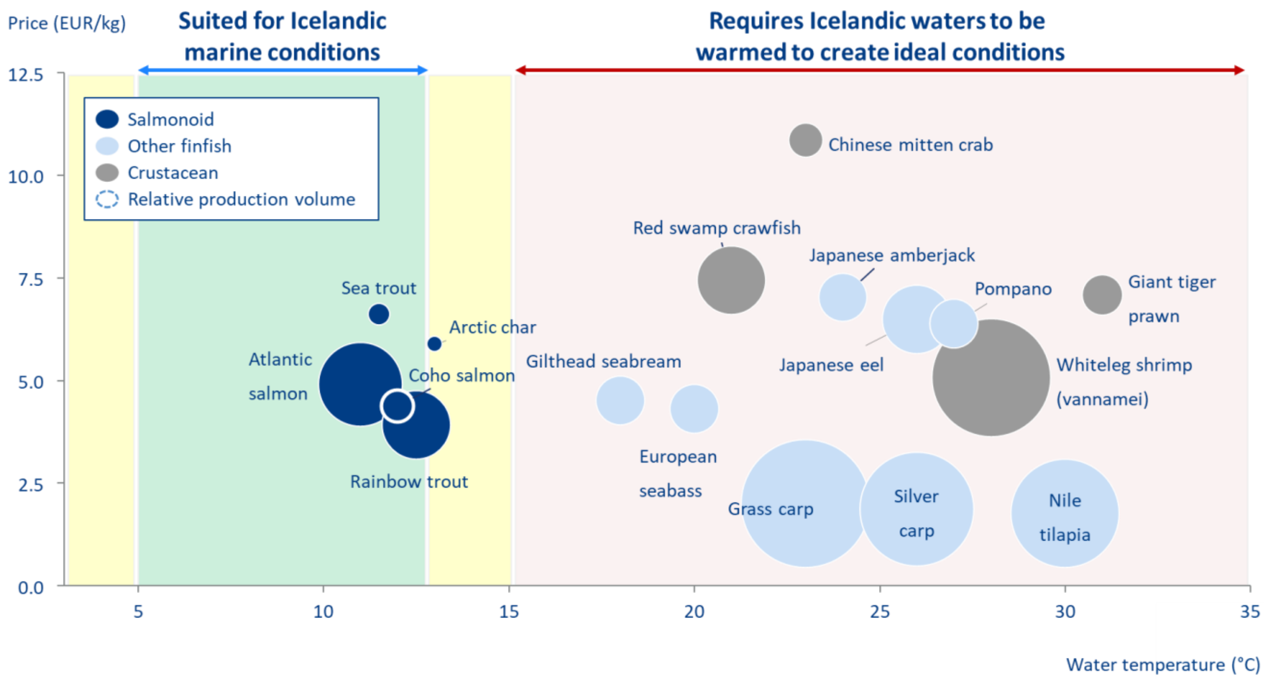
[14] Some species like tilapia thrive at water temperatures of up to 30-36 °C

Lastly, species living uniquely in marine waters account for 3mT, with Seabream and Seabass being the most farmed species. Marine fish are highly sensitive to low temperatures and produced exclusively in warm tropical waters between 20 and 30 °C in pens or sea cages by the ocean.

3.1.3 Salmonoids best suited for farming under Icelandic natural conditions

From the Finfish group, the salmonoid family is best suited for farming under Icelandic conditions. It is also relatively attractive to produce as a high-value species with a sizable market. Crustaceans are also attractive to farm but are not ideally suited for Icelandic conditions since these species require warm temperatures for growth. Crustaceans are typically produced in the Asia (e.g., Vietnam, China, Thailand) and in the Middle East. In addition, other high-value finfish (e.g., Japanese amberjack) are not suited for Icelandic cold-water conditions.

FIGURE 3.6: FEASIBILITY OF AQUACULTURE PRODUCTION IN ICELAND[15]



Certain conditions along the Icelandic coast, such as mild currents and fjords that provide shelter benefit sea-based farming. Sea temperature is however not ideal for growth. The optimal growth conditions for the salmonoid species are temperatures ranging from 8-14°C, with higher temperatures increasing the risk of diseases and temperatures below 0°C increasing the likelihood of mass mortality. As shown in Figure 3.6, this temperature range is much lower than the optimal ranges of other finfish and crustaceans. Other species have historically been farmed in Iceland such as Cod and Halibut. Plaice is still produced and recently experiments with seabream started. While species that thrive at higher temperatures can be farmed in Iceland, it would require technical solutions for warming up water, with the associated energy costs.

[15] FAO, European Central Bank, Nationalbanken. BCG analysis

3.1.4 Sub-conclusion

Annual demand growth for seafood products has been around 3% over the past 10 years. Production from fisheries has not grown since the 1990's, and growth in aquaculture production has met new demand.

Within farmed fish, salmonoids are best suited for farming in Iceland and are currently also the most produced species. Salmonoids hold attractive characteristics compared to the rest of fish species due to their large market, high value, and growing demand. In light of this, the rest of this chapter will primarily focus on salmonoids, with algae covered in more detail in Chapter 7.

3.2 Demand, supply, and sustainability

The world population is expected to grow to over 10 billion by 2060.[16] To feed the global population, food production needs to grow as well. Left unchanged, this implies drawing more on natural resources and ecosystems, which will lead to further deterioration of the earths biosystems and biodiversity. New and more sustainable ways of food production are therefore required to address this challenge.

To limit environmental impact from growth in food production, aquaculture can play an important role, having relative advantages compared to many other currently produced sources of protein. More broadly, aquaculture can support achieving the sustainable development goals of the United Nations.

FIGURE 3.7: HOW AQUACULTURE CAN CONTRIBUTE TO THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

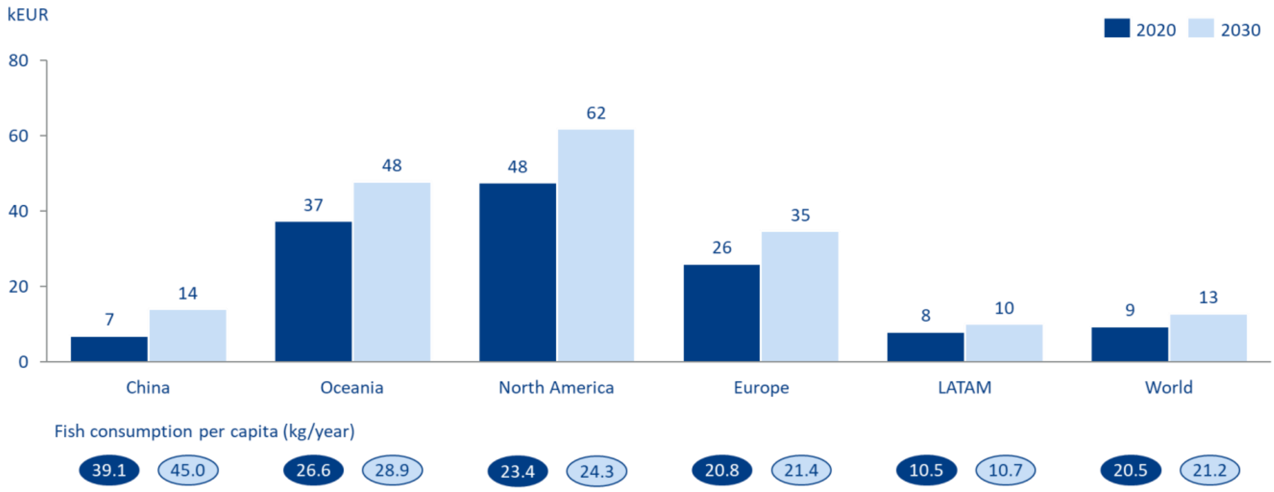
Algae farming is especially well suited to support the goals as it does not rely on protein based inputs for its production. In the ambition to contribute to the goals, continued research, and development, across aquaculture production sectors, is still needed to improve the sustainability of aquaculture production.

[16] UN World Population Prospects 2022

3.2.1 Global demand for fish protein is growing

Daily protein consumption per capita is expected to grow from 81g in 2020 to 87g by 2030. Fish currently constitutes ~7% of protein consumed. Protein composition is heavily dependent on income level, where higher income correlates with higher protein intake from animal sources. The same applies to the level fish consumption as a proportion of that protein intake. Demand for fish protein is therefore expected to grow between 2020 and 2030.[17]

FIGURE 3.8: EXPECTED INCOME AND FISH CONSUMPTION PER CAPITA BY 2030[18]

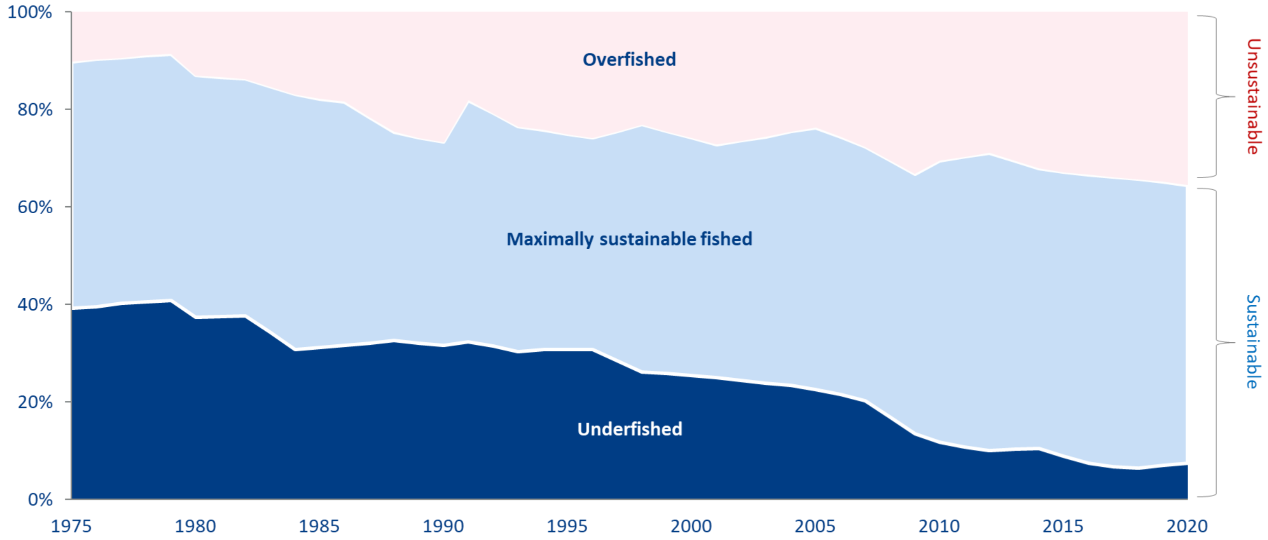


The catch of wild fish is limited by the natural fish stock. FAO estimates that currently over 36% of marine stocks are overfished, up from 10% in 1975. Similarly, the estimated levels of underfished stocks are now 8% compared to around 40% in 1975, see Figure 3.9. This development implies that current levels of fisheries production are not sustainable in the long term. Consequently, aquaculture production is required to meet expected growth in fish demand.

[17] FAO

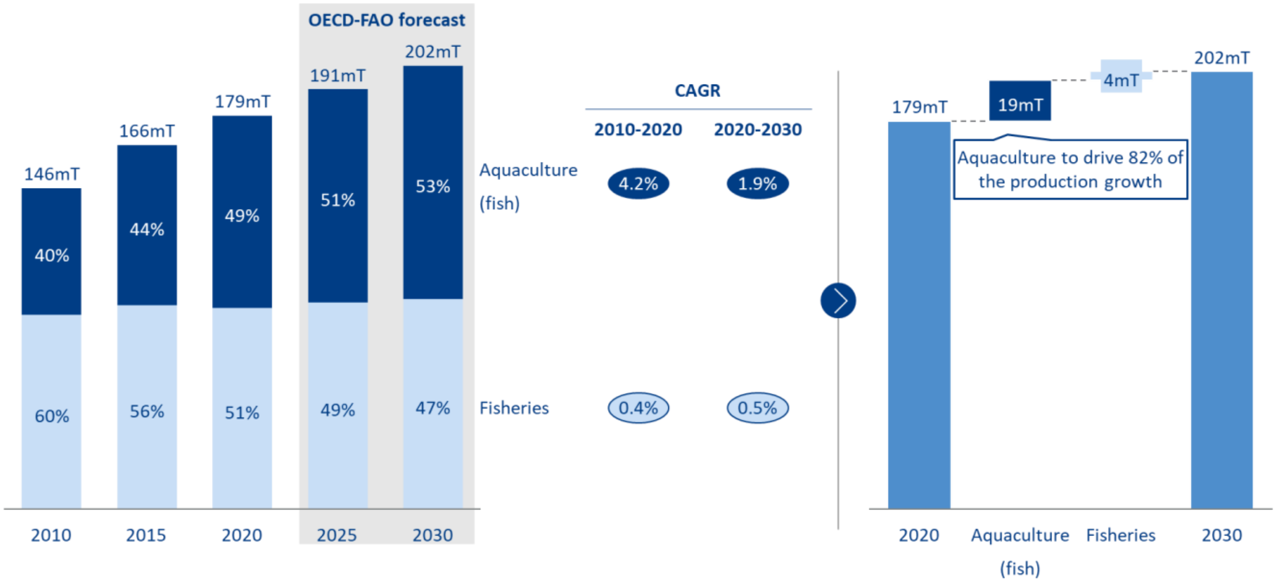
[18] OECD-FAO Agricultural Outlook, European Central Bank, Nationalbanken; BCG Analysis

FIGURE 3.9: STATE OF MARINE STOCKS FOR FISHERIES[19]



Through 2030, production of seafood is expected to grow by around 23mT, reaching total global production of more than 200mT. From this growth, aquaculture is expected to contribute 82% or ~19mT, see Figure 3.10.

FIGURE 3.10: FISH PRODUCTION GROWTH UNTIL 2030 (MT)[20]



3.2.2 Salmonoid farming is resource-efficient relative to other farmed protein

The current global food system, including the production and consumption of food, contributes to some of the world's major challenges, including climate change and a decline in biodiversity. With that,

[19] FAO

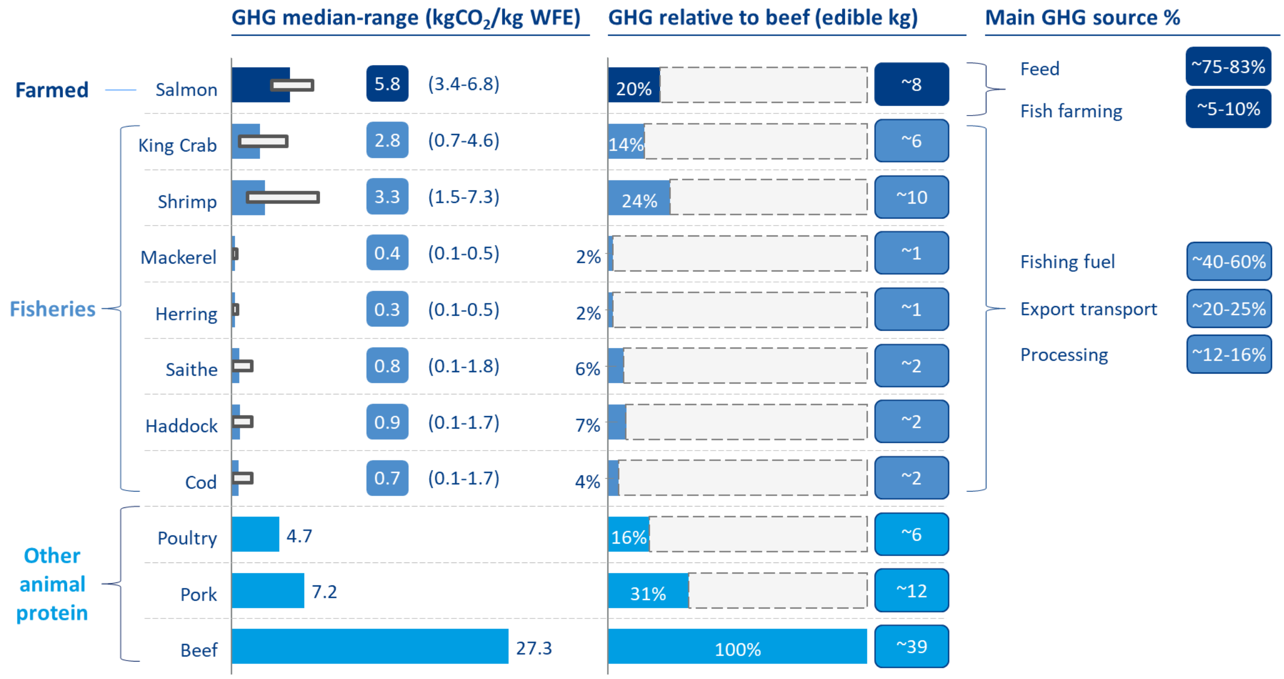
[20] OECD-FAO Agricultural Outlook

aquaculture as a source of protein-based foodstuff has the potential to be relatively sustainable as aquaculture generally has a lower carbon footprint and a higher feed conversion ratio compared to other methods for animal protein production. If well-managed aquaculture can be well positioned to meet the increase in demand for animal-based proteins in a way that minimizes impact on the food supply chain, ecosystems, and the climate.

Environmental impact

The global food supply chain accounts for over a third of greenhouse gas emissions caused by humans.[21] Generally, feed and fuel constitute the largest sources of emissions in the production phase, while transportation and export make up most of processing and distribution emissions.

FIGURE 3.11: GREENHOUSE GASSES (GHG) FROM ANIMAL-BASED PROTEIN PRODUCTION[22]



Salmon farming has been estimated to have greater greenhouse gas emissions compared to fisheries. This is primarily due to the production of fish feed for aquaculture, which accounts for over 75% of emissions, while fisheries' emissions are primarily due to fuel burned by fishing vessels. Comparing emissions with land-based animal protein sources, poultry emits less than farmed salmon, but pork and beef emit considerably more.

In addition to greenhouse gas production, food production also impacts natural resources in various ways. It occupies ~43% of habitable land (excluding ice and deserts) and over 70% of the world's freshwater resources are used for agricultural purposes.[23] Fish farming uses significantly less land

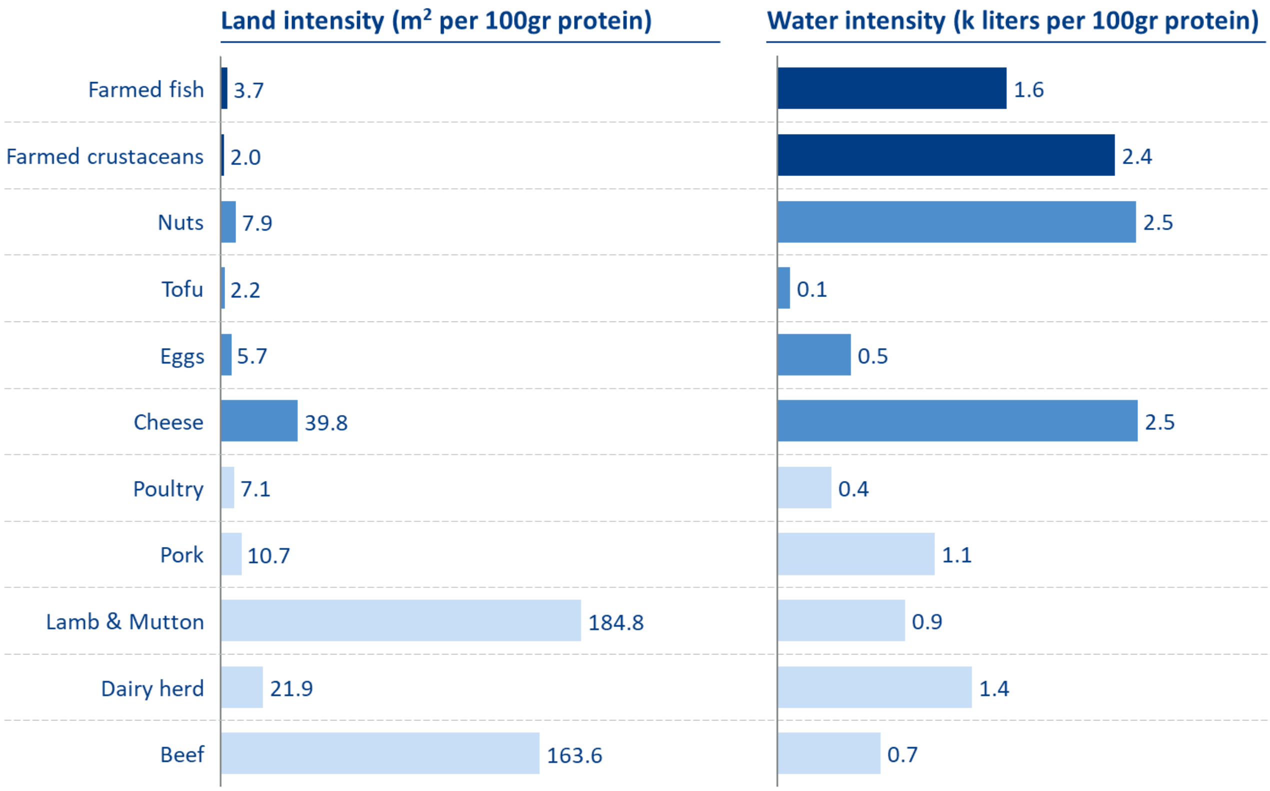
[21] Crippa et al. 2021

[22] Stiftelsen for industriell og teknisk forskning (SINTEF)

[23] World Bank

(~4m² per 100g of protein produced) than other animal proteins such as lamb and beef production. However, this may increase with a shift to more land-based fish farming. In general, aquaculture is freshwater intensive, with fish farming using ~4x more freshwater than poultry and around ~1.5x more than pork. That said, depending on the method and species of fish produced, freshwater use can be comparable or even lower than competing animal-based protein production.[24]

FIGURE 3.12: LAND AND WATER INTENSITY FROM PROTEIN PRODUCTION[25]



Feed efficiency

When examining greenhouse gas emissions production and use of scarce resources, feed efficiency in the production of animals is a key consideration. The rise in demand for animal-based proteins, accelerated by the rising middle class, has resulted in a growing share of agricultural output being used as feed. According to the FAO, one third of croplands are used for livestock feed production. In 2020, total feed production amounted to 1.7bnT, and is expected to reach 2bnT by 2030. This growth is likely to impact the environmental, e.g., increase in agricultural emissions, deforestation, and strain on soil and water resources.

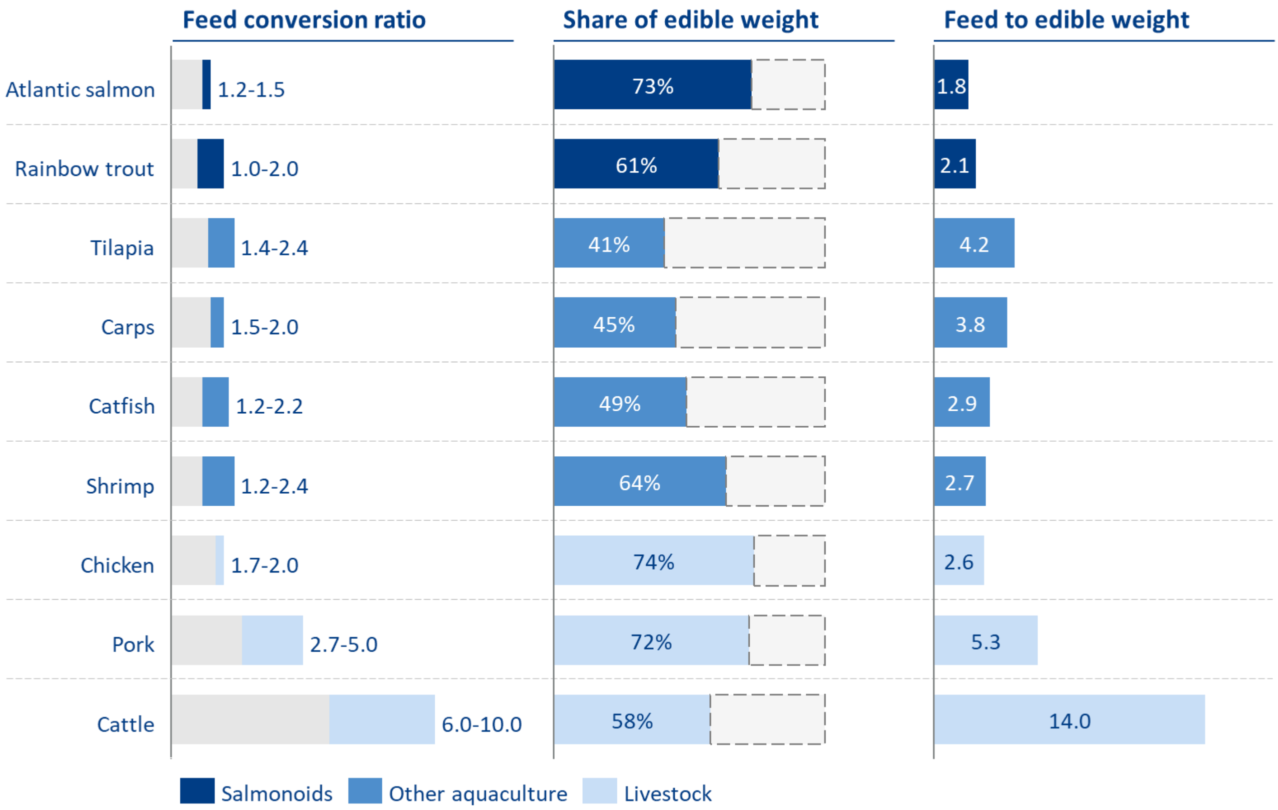
Reducing the feed intake per unit of outputted animal protein therefore becomes important. The feed conversion ratio is often used as a measure of feed efficiency in animal production. It measures the weight of feed intake divided by the weight of the animal. Aquaculture products are more feed efficient

[24] Poore, J, MOWI industry report

[25] Poore, J. and Nemecek, T (2018)

than other animal protein sources, partially due to their reduced energy requirements and cold body temperatures. Another measure of feed efficiency is the conversion of animal's biomass to edible food. Salmonoids are highly efficient in turning feed into biomass (1.2-1.5), with a high percentage of their weight (73%) turned into edible food for human consumption. Combined, this makes salmonoids more feed efficient than most other animal products.

FIGURE 3.13: FEED CONVERSION RATIO AND EDIBLE EFFICIENCY[26]



Feed conversion ratio is an essential feature of efficient aquaculture management. It constitutes the largest share of both production costs (~40-50%)[27] and environmental footprint. Hence, feed optimization has a significant impact on profitability and the environment.

Aquaculture feed has historically included fish meal and oil from wild fisheries. Therefore, growth in feed volumes can place increased demand on wild fish populations. In 2020, over 20mT of fishing and aquaculture production was used for non-food purposes, with fishmeal comprising the largest share.[28] Of all fishmeal, 85% is used as feed in aquaculture, with the remaining used for pigfeed and petfood.

The aquaculture industry has been working on innovative vegetable feed substitutes to reduce the fishmeal share in fish feed, thereby reducing cost and environmental impacts. According to the

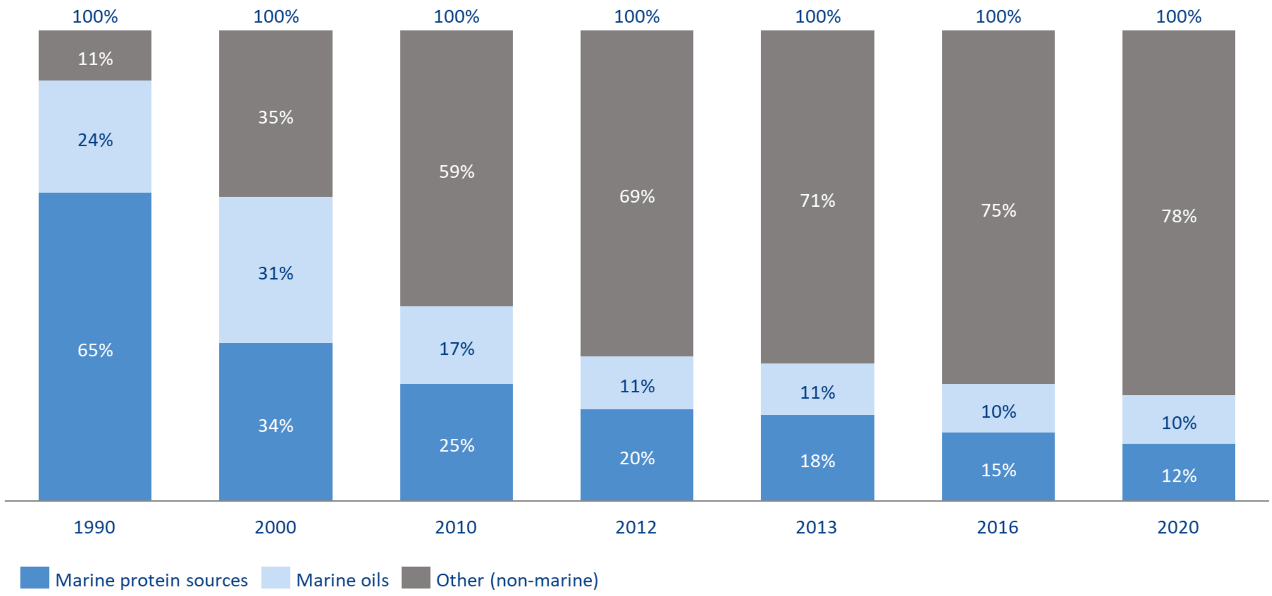
[26] John Hopkins University (Center for a Livable Future): Feed conversion ratio in aquaculture, BCG analysis

[27] Kepler Cheuvreux

[28] FAO

Norwegian food research institute (NOFIMA), from 1990 through 2020, marine protein in Norwegian fishmeal has been reduced from 65% to 12%.

FIGURE 3.14: USE OF MARINE PROTEIN IN NORWEGIAN FISHMEAL[29]



Notwithstanding these developments, aquaculture still has challenges to address to increase the sustainability of production, such as the reduction of organic load released in the world's seas, ensuring animal welfare, and limiting impact on wild fish stocks and other marine life.

3.2.3 Sub-conclusion

The demand for fish-based proteins for human consumption is expected to increase, and aquaculture is expected to be the primary source for meeting that demand. Salmon farming is a relatively sustainable method for producing animal protein, relative to other sources. It has a relatively high feed conversion ratio, low greenhouse gas emissions per unit output and currently uses limited land for its production.

Salmon demand is therefore expected to be supported by several macro trends, such as population growth leading to an increased protein demand, higher fish consumption and consumer preferences for protein with a reduced environmental footprint.

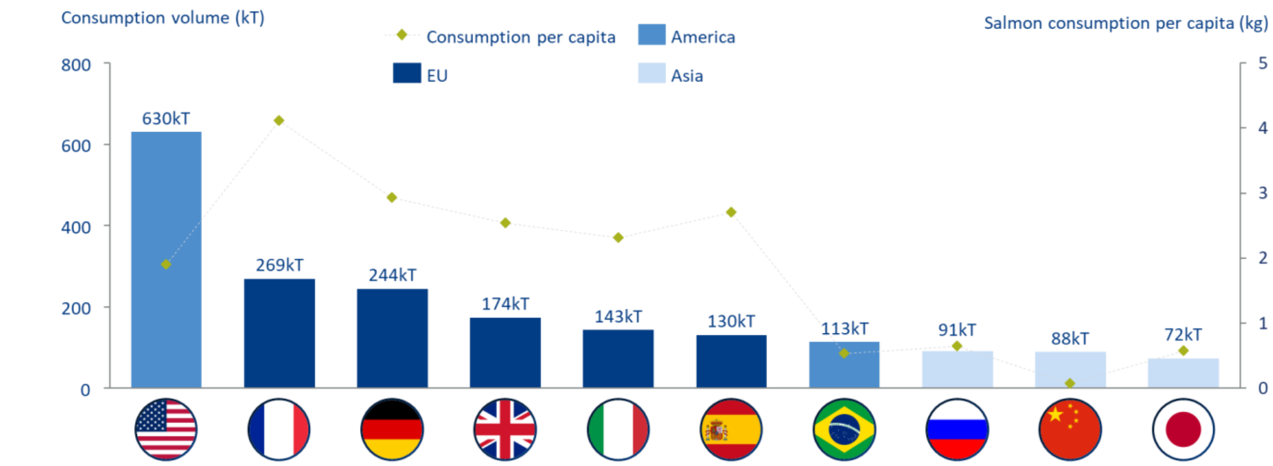
[29] Utilization of feed resources in the production of Atlantic salmon (Salmosalar) in Norway (NOFIMA): An update for 2020

3.3 Global aquaculture – demand and supply

3.3.1 USA and Europe are the largest markets for aquaculture products

The largest market for Atlantic salmon is the US, with a consumption volume of over 600kT, accounting for 44% of global consumption. The US is followed by five European nations (France, Germany, UK, Italy, and Spain), with consumption volumes of 130-270kT each, see Figure 3.15.

FIGURE 3.15: LARGEST MARKETS FOR ATLANTIC SALMON AND CONSUMPTION PER CAPITA[30]



Annual consumption per capita (kg)

Atl. Salmon	1.9	4.1	2.9	2.5	2.3	2.7	0.5	0.6	0.1	0.6
Fish (Total)	22.1	34.2	12.6	18.5	29.8	42.4	9.0	20.1	38.5	46.1
Salmon share	9%	12%	23%	14%	8%	6%	6%	3%	0%	1%

Despite lower volumes than the US, European nations have the highest Atlantic salmon consumption per capita. Japan has the highest fish consumption per capita, but a low share of this is Atlantic salmon.

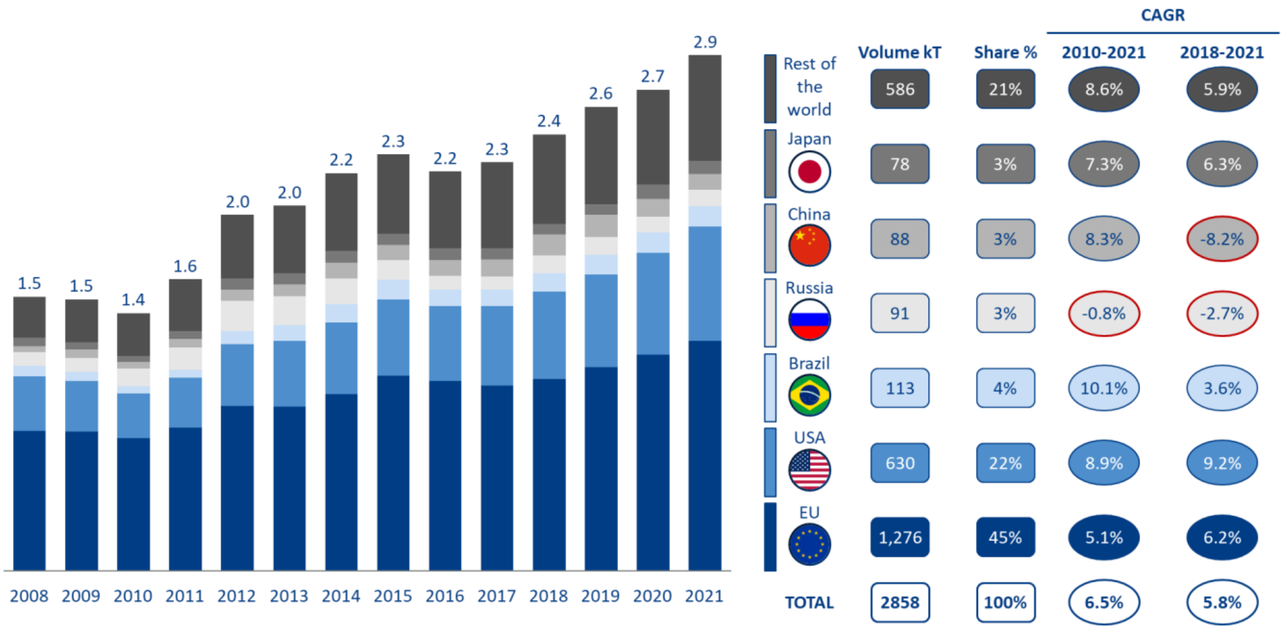
Demand for Atlantic salmon has grown at 6.5% CAGR in past decade, with a short-lived fall in 2016, partially due to the production disruptions in Chile caused by HAB disease.[31] Growth has been strong among the top consumer markets over the last decade, especially in the EU and US. However, the COVID-19 related disruptions slowed the pace of global growth between 2018 and 2021.

Historically, the EU and US have been the largest consumer markets for salmon, with a joint volume of nearly 2mT accounting for around 67% of the total market, see Figure 3.16.

[30] FAO STAT Food balances, MOWI industry report, BCG analysis

[31] A harmful algal bloom (HAB) disease killed over 100kT fish

FIGURE 3.16: CONSUMPTION OF ATLANTIC SALMON ACROSS LARGEST MARKETS (MT)[32]

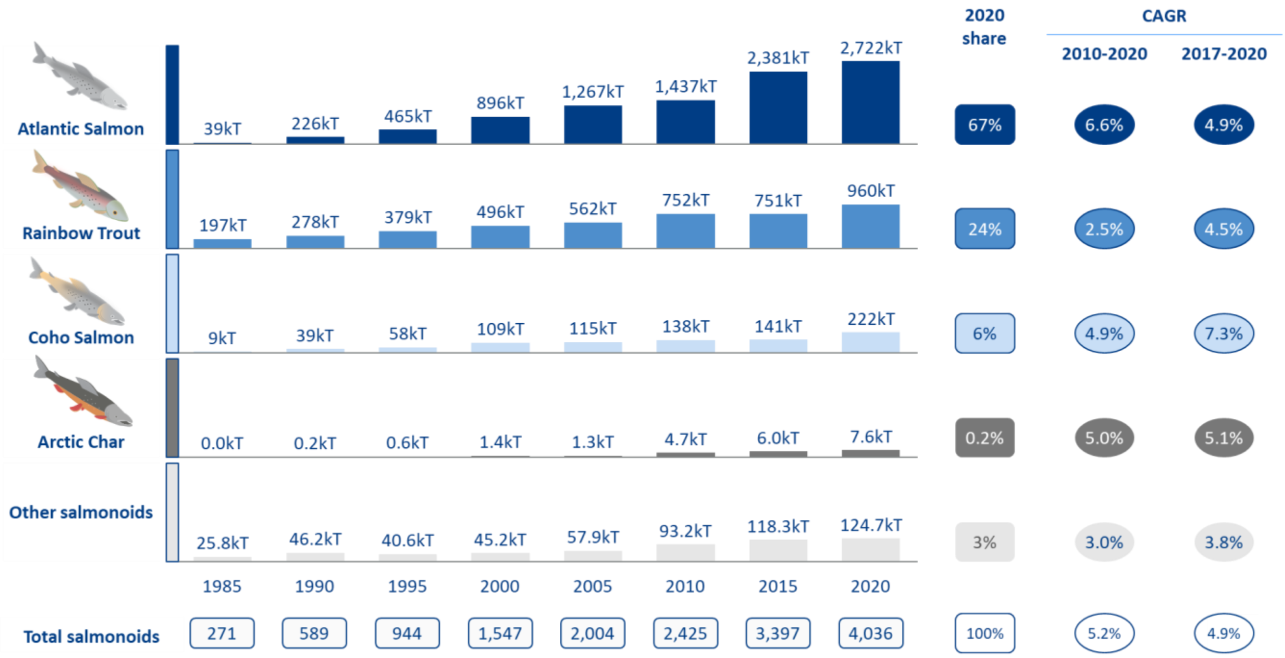


3.3.2 Norway and Chile supply most of the world's salmonoids

The global production of salmonoids has been growing significantly over the past decades, with 2020 volumes reaching 4mT, a 15x increase in volume since 1985. Salmonoid production has seen stable growth, primarily driven by the Atlantic salmon. Combined, Atlantic and Coho salmon account for nearly 75% of production, or 3mT. Rainbow trout is the second largest salmonoid produced at 1mT. Other smaller salmonoid species include Arctic char and Clearhead Icefish.

[32] Kontali, BCG analysis

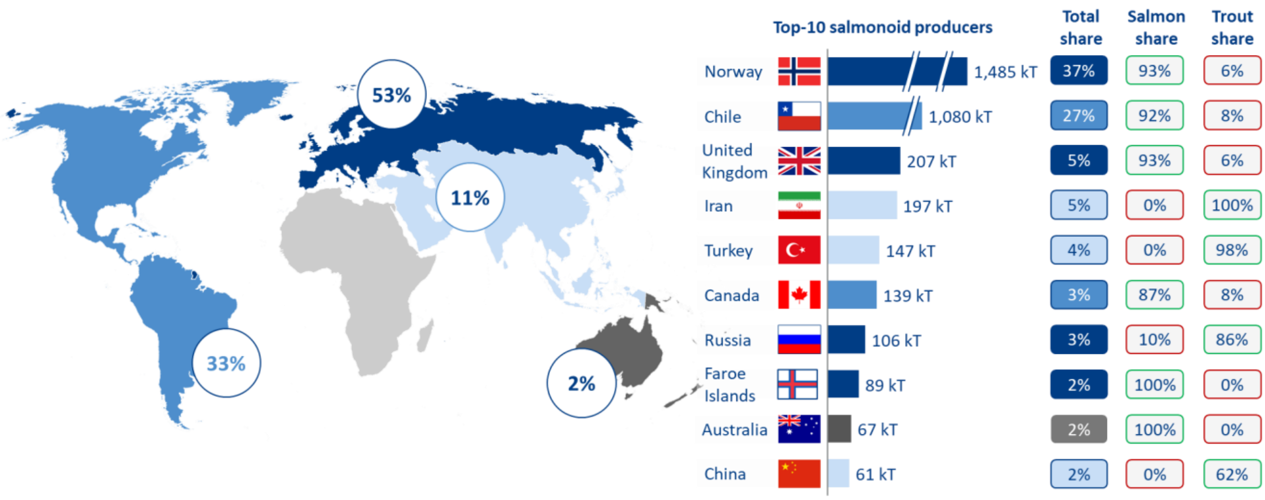
FIGURE 3.17: SALMONOID PRODUCTION DEVELOPMENT BY SPECIES (KT)[33]



Over half of global salmonoid production takes place in Northern Europe, and the Americas follow with a third of global production, see Figure 3.18. Norway and Chile are the largest suppliers benefitting from access to a large coastline, ideal water conditions and a developed infrastructure for fish farming. Among the top 10 salmonoid producers, differences exist in terms of species and methods. Salmon-heavy producers (Norway, Chile, UK, Canada, Faroe Islands) focus on marine sites with pens in coastal areas. Conversely, the trout-heavy producers (Iran, Turkey, Russia, and China) rely on cage production methods in freshwater sites.

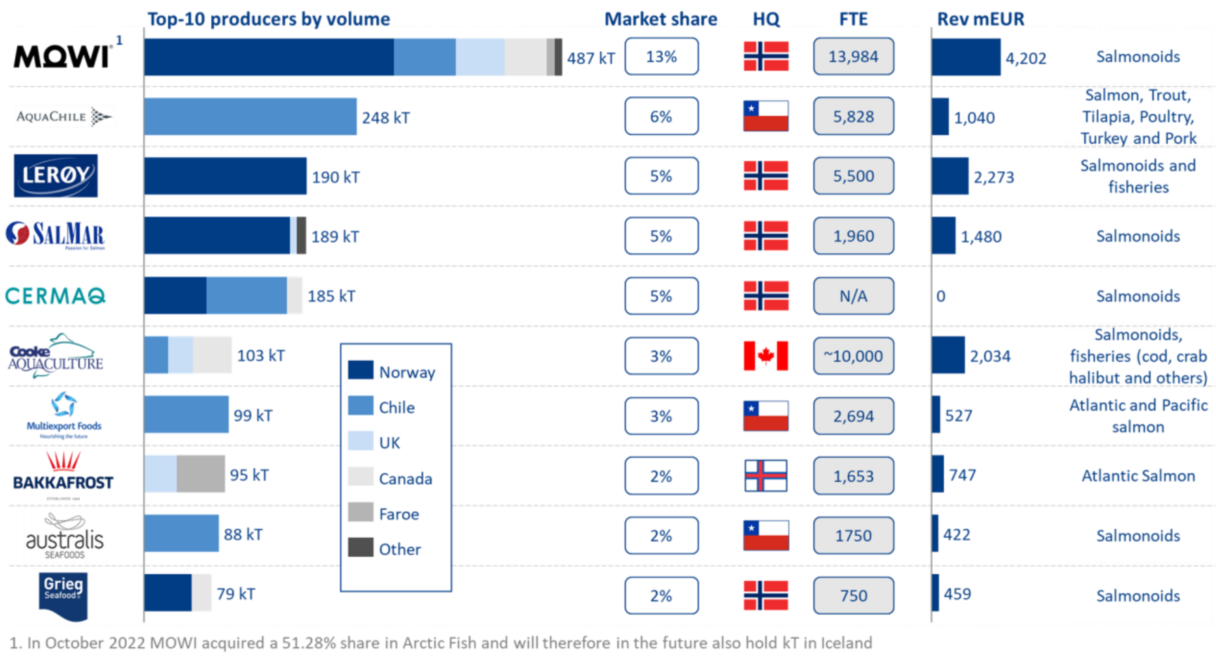
[33] FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ)

FIGURE 3.18: SALMONOID PRODUCTION BY COUNTRY AND REGION[34]



The top 10 farmers produce around 2mT, equivalent to around 50% of global volume. Amongst the top 10 farmers, there are five Norwegian companies. The largest salmon producers are vertical integrated, leveraging scale across the value chain (from smolt growth to salmon production and processing). Some of the companies specialize in salmon farming, while others are seafood groups that also include a fisheries business.

FIGURE 3.19: TOP-10 GLOBAL SALMONOID PRODUCERS[35]



[34] FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ), BCG analysis

[35] Kontali, MOWI industry report, companies' annual reports, FAO, BCG analysis

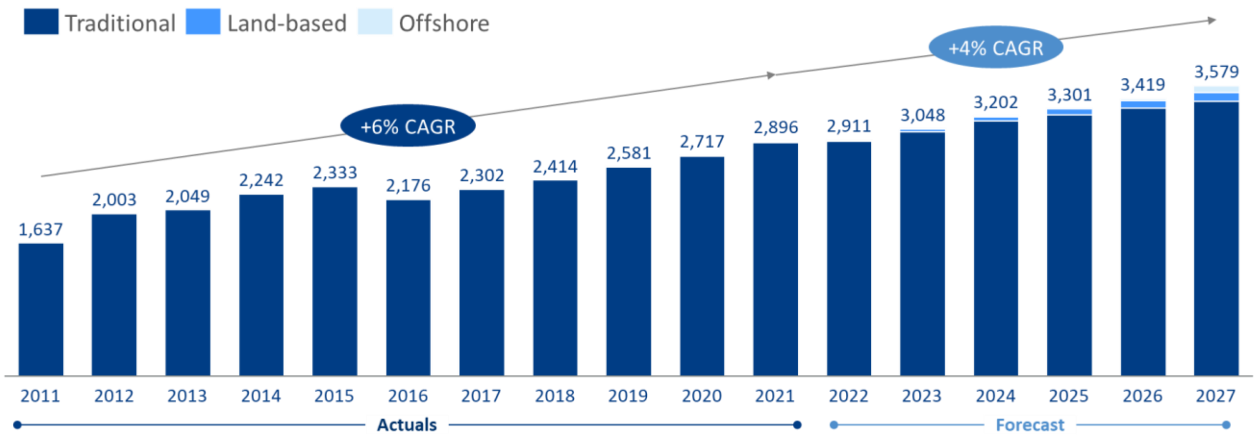
The global leader MOWI is Bergen-based but has wide-spread operations across Norway, Chile, UK, Canada, Ireland, and the Faroe Islands. In 2021, MOWI produced 465kT of salmonids. MOWI specializes in Atlantic salmon, with sales targeting the European market (67%). MOWI has shifted its operations from whole fish to value-added production: whole fish was over 60% of production in 2013, but this figure has decreased to 36% in 2021. In October 2022, MOWI acquired a 51.28% share in Arctic Fish and will therefore in 2023 also through its ownership produce Salmon in Iceland.

AquaChile is the largest salmon producer in Chile, with 21 farming sites yielding 248kT in production. AquaChile focuses mostly on Atlantic salmon but also produces Coho salmon, trout, and tilapia. The company was acquired in 2018 by Agrosuper, the Chilean leading animal protein producer. AquaChile is a vertically integrated company across feed, smolt production, and processing, as well as distribution and sales under proprietary brands. Over 95% of production is exported, with Atlantic salmon production mainly exported to the US (48%), Brazil (15%) and Russia (11%), and Coho salmon mainly exported to Japan (85%).

The third-largest global producer is Bergen-based Lerøy, an integrated seafood group with fisheries, whitefish and aquaculture production. The latter includes salmon, trout, and shellfish. The group has a fully integrated value chain for salmon and trout production. Lerøy specializes in Atlantic salmon, which yields nearly 60% of its revenue, with the EU and Asia as the main markets.

Nearly 100% of today's production is traditional, that is, with fish raised in pens in coastal areas protected from adverse offshore conditions. Nevertheless, natural limits to new production areas are expected to reduce the pace of growth. Many of these firms are therefore experimenting with new technologies such as land-based and offshore farming to drive further volume expansion.

FIGURE 3.20: HISTORICAL AND EXPECTED GROWTH OF ATLANTIC SALMON (WFE) BY FARMING SECTOR (KT)[36]

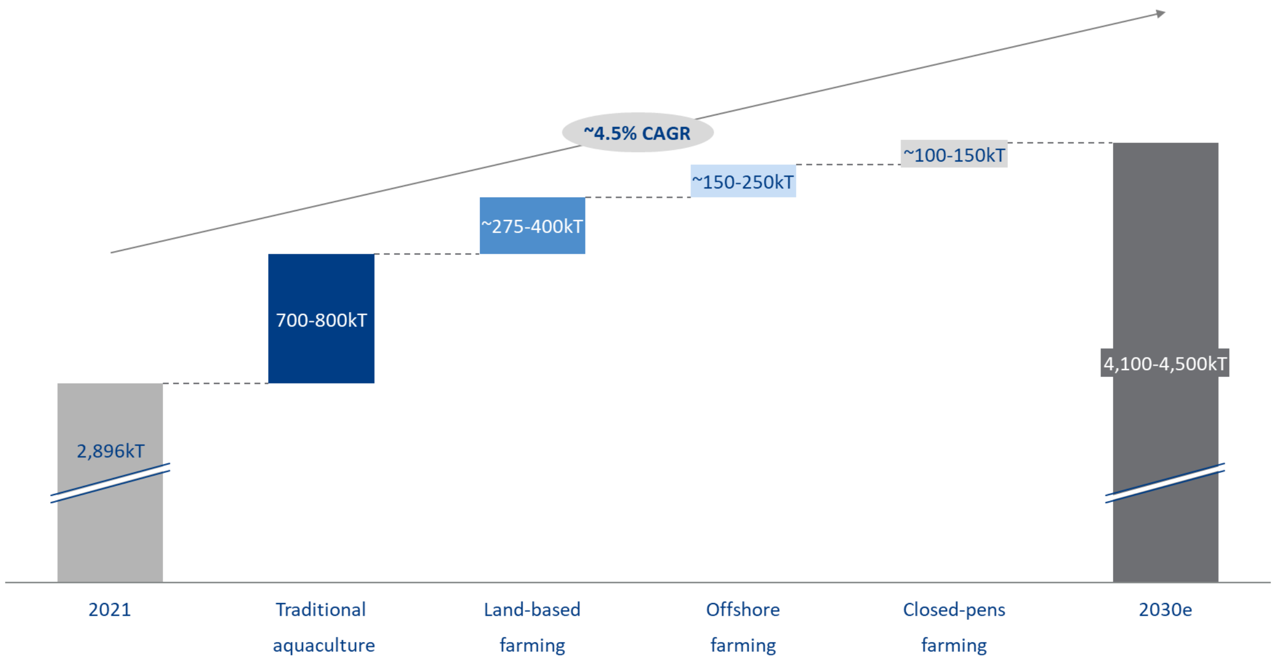


Note: Market share considers only salmon (Atlantic and Coho) and Rainbow trout. Volume refers to salmonoids, while revenue and FTE for the whole aquaculture segment. Lerøy and Cooke Seafood include figures for fisheries. Cemaq is owned by Mitsubishi Group with annual reports neither available for calendar year nor for the Cemaq global business

[36] Pareto Securities

Non-traditional sectors are expected contribute to the salmon production growth in the global industry, with an expected volume contribution of up to ~0.8mT, see Figure 3.21.

FIGURE 3.21: ATLANTIC SALMON GROWTH CONTRIBUTION PER FARMING SECTOR, 2020-2030[37]

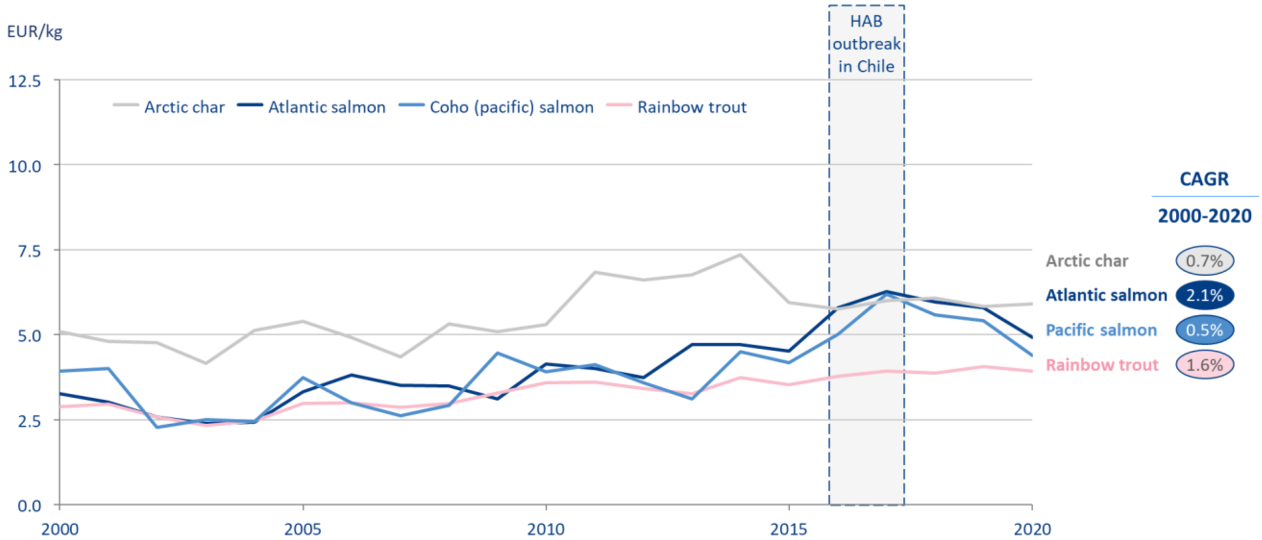


3.3.3 Salmonoid prices have followed an upward trend appearing to continue

The global price of salmonoid species has grown during the past two decades, with Atlantic salmon prices growing more than other salmonoid species. Fluctuations in price can be attributed to multiple factors, including production cycles and shocks to the supply side (such as the 2016 HAB disease outbreak in Chile) or to demand shocks. In the past two decades, salmon has on average fetched around a 20% premium compared to trout. Over the same period, the Coho salmon price has followed the Atlantic salmon price closely, with an average discount factor of 2.5%.

[37] Pareto Securities

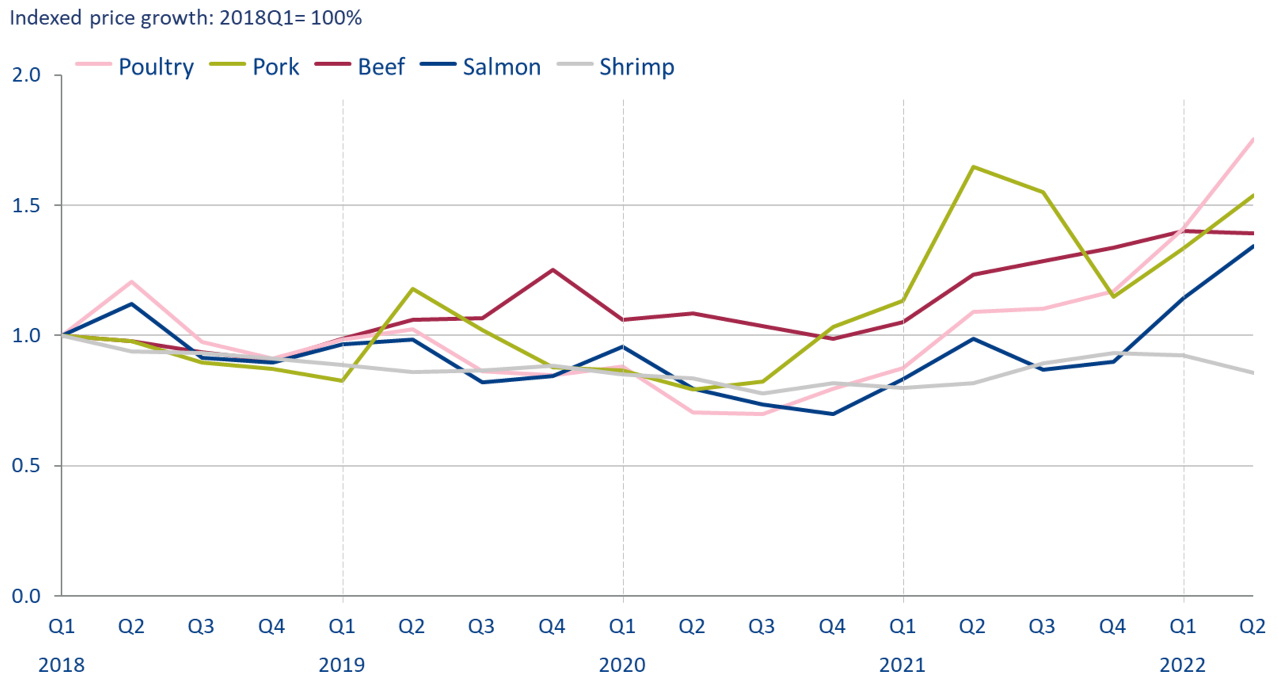
FIGURE 3.22: PRICE DEVELOPMENT OF SALMONOID SPECIES (EUR/KG)[38]



An additional factor affecting salmon is the price of competing animal protein food sources such as cattle, pork, and poultry. In the recent past, COVID-19 has impacted the food industry by reducing income levels and disrupting supply chains. In 2021, increases in commodity prices drove a general price increase across these protein substitutes. Salmon price did not grow as rapidly first but caught on towards the end of the year and has grown in tandem in 2022. In the short to medium-term, salmonoid prices are expected to follow this upward trend due to a growing demand and relatively stable supply.

[38] FAO, European Central Bank, Nationalbanken, BCG analysis

FIGURE 3.23: PRICE DEVELOPMENT IN ANIMAL PROTEIN SOURCES (INDEXED Q1 2018=100)[39]



3.3.4 Sub-conclusion

Key markets for salmonoid demand are the US and Europe, both in terms of current size as well as in terms of growth, while main supply markets are Norway and Chile. Given Iceland's geographic positioning, it may have a location-based advantage in terms of distance to demand markets, especially the US Northeast.

Chile and Norway are mature supply markets with highly developed infrastructure and large firms (eight of the top 10 globally). These are important factors for Iceland to replicate in order to strengthen its competitive position.

New farming technologies are emerging (land-based, offshore) that have attractive attributes such as lower environmental impact and that are less limited in capacity than coastal fjords. Given how nascent these sectors of aquaculture are, Iceland has the potential to become a leading producer in applying these new sectors.

Salmonoid prices have followed an upward trend over the past 20 years and are expected to continue increasing along with other animal protein sources. Expected relative long-term price stability contributes to the appeal of growing the aquaculture sector in Iceland.

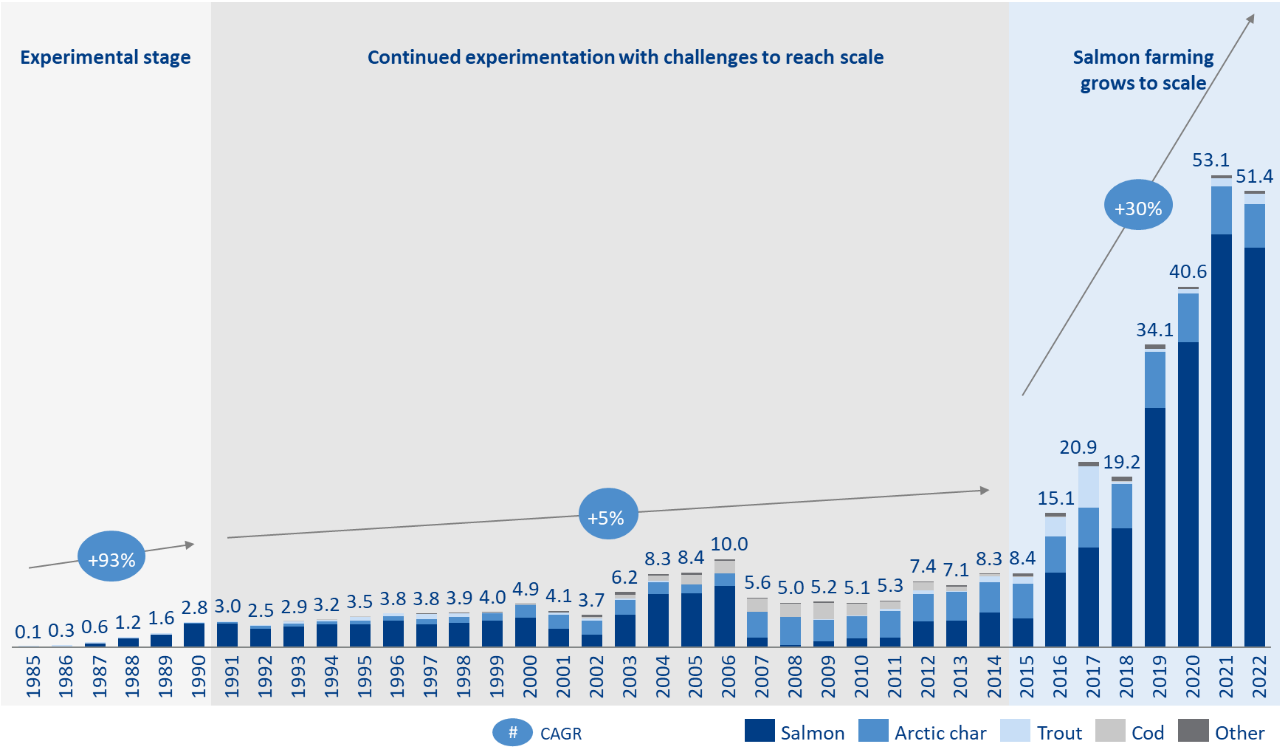
[39] International Monetary Fund, Federal Reserve Bank of St. Louis, BCG analysis

3.4 Aquaculture in Iceland

The history of fish farming can be traced back to the winter of 1884 and 1885, when salmon and trout hatcheries were established in Iceland with the intent to release hatchlings into lakes and rivers. Fish farming for direct consumption was first established with trout farming in Kelduhverfi in Öxarfjörður between 1942 and 1945, followed by Rainbow trout farming in 1951 at Laxalón in Reykjavík. In 1952, Reykjavík Energy (Rafmagnsveita Reykjavíkur) started a salmon hatchery at Elliðaár. Smolt production was established in 1961 by Fish farming Iceland (Laxeldisstöð Ríkisins), and the first smolts released at sea in 1963. In the 1970s, advancements were made in land-based farming, using a mix of sea and geothermal water to achieve an ideal level of salinity and regulate water temperature. In the mid-1980s, interest grew significantly, and many fish farming facilities were built that contributed to an increase in production from 150T to 3kT over five years. During this period, farming was mostly focused on salmon and Rainbow trout, but operations were generally challenging due to low market prices, high capital, and investment costs. In the 1990s until the early 2000s, production grew in land-based farming, and the farming of Arctic char gained foothold. Farmers and scientists also piloted production under brackish water conditions of non-salmonoid species (cod and halibut, among others), including the introduction of warm water species under geothermally controlled environments, without considerable commercial success. After a slowdown, salmon production grew again in the period 2003 to 2006, contributing to the highest volume ever recorded in 2006 of 10kT. The production of salmon then dropped to low volumes until growth returned in 2012. In 2015, the era of industrial scale fish farming started with very rapid growth until 2021 (36% CAGR), driven by traditional salmon farming. This growth can be attributed to licensing being awarded for production areas in fjords and the entrance of Norwegian investors with knowledge, experience, and capital.[40] Production however dipped in 2022 mainly due to biological incidents in the Eastern fjords, leading to a CAGR of 30% in the seven-year period from 2015-2022.

[40] Staða fiskeldis á Íslandi: Framtíðaráform og stefnumótun, Landssambands fiskeldisstöðva í rannsókna- og þróunarstarfi 2010-2013

FIGURE 3.24: FISH FARMING PRODUCTION IN ICELAND (KT)[41]

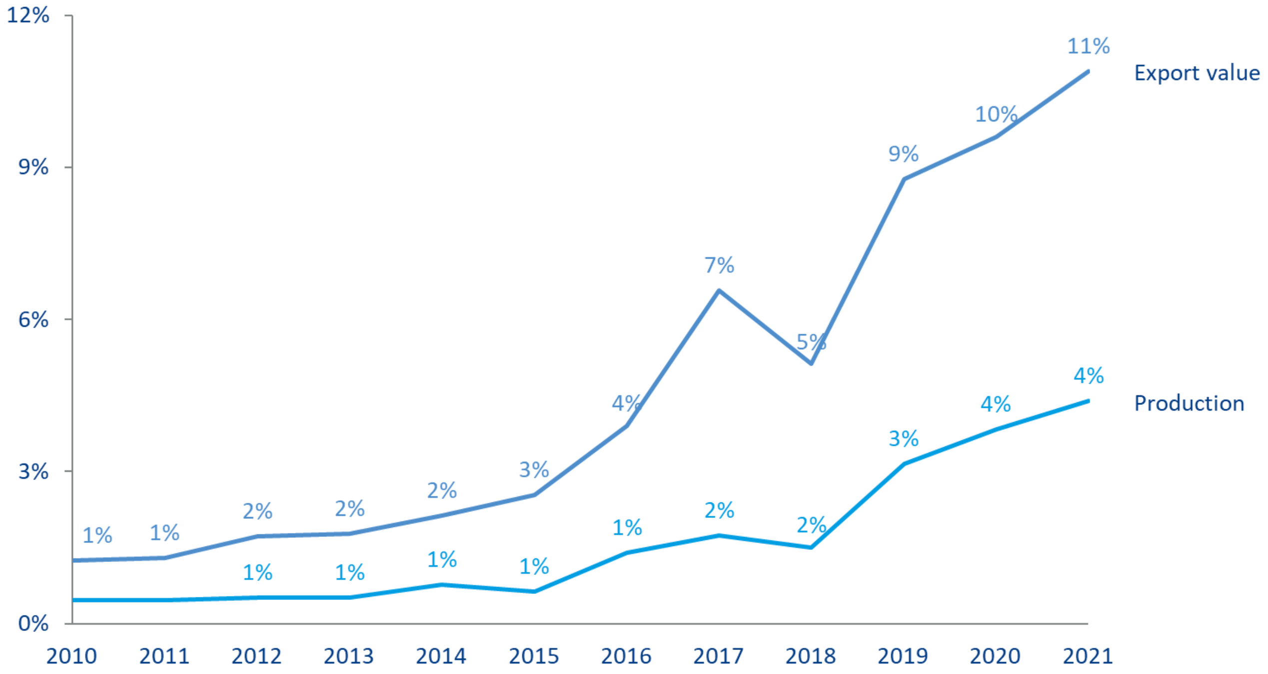


3.4.1 Aquaculture's significance in Icelandic seafood has grown since 2015

The seafood industry is one of the pillars of the Icelandic economy, historically driven by fisheries. Icelandic vessels have fished over 1mT in recent years. Fisheries' volumes have, however, contracted from the period 1995-2003, where they often reached beyond 2mT. As mentioned before, aquaculture has however been in rapid growth, especially since 2015. Since 2010, aquaculture's share of total seafood production in Iceland has increase from insignificant to currently being around 4%. Salmonoids are furthermore a high-value species, which has resulted in the export value of aquaculture production reaching 11% in 2021.

[41] Icelandic Food and Veterinary Authority, FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ), BCG analysis

FIGURE 3.25: AQUACULTURE SHARE IN PRODUCTION AND EXPORT VALUE OF ICELANDIC SEAFOOD (%)[42]



3.4.2 Fishing and aquaculture are the fifth largest GHG emitter in Iceland

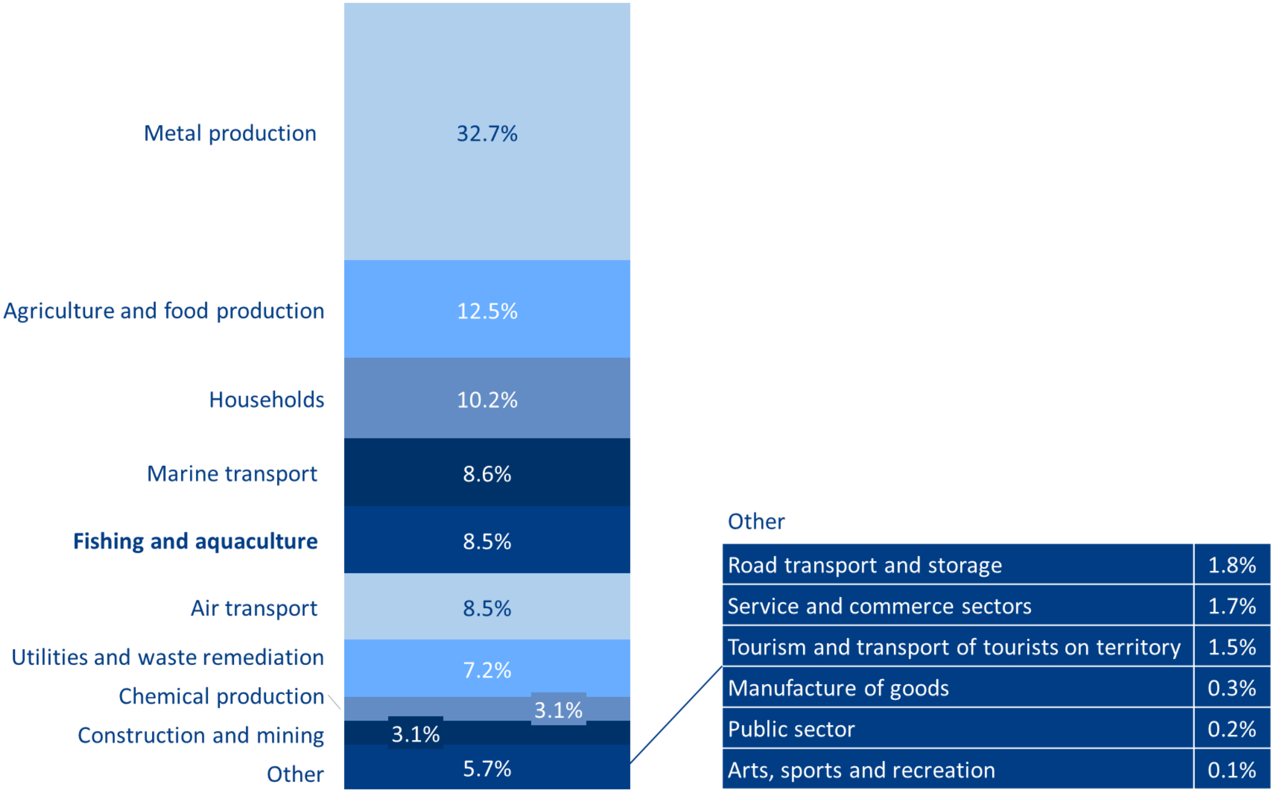
The fishing and aquaculture industry in Iceland has had many positive impacts on the Icelandic economy. However, it has also led to impacts on the natural environment. As with many other activities in the food supply chain, production releases of greenhouse gasses. The fishing and aquaculture industry is the fifth largest emitting industry in Iceland, following emissions-intensive industries such as metal production and land-based agriculture. Farmed salmon has generally been found to be more emissions intensive than seafood from fisheries, depending on production method and the end market. While emissions from fisheries are dominated by fishing fleet fuel consumption, aquaculture emissions stem primarily from the production of feed, due to associated agricultural emissions from crop production. That said, studies have shown that emissions can be reduced by 40-50% for farmed salmon with improved efficiencies in the supply chain.[43] For example, synthetic pigments make up the largest share of emissions in feed, with possibilities to reduce emissions by using natural pigments such as astaxanthin produced in microalgae farming.[44]

[42] Statistics Iceland (Hagstofa Íslands), FAO, BCG analysis

[43] Ziegler & Hilborn (2022)

[44] Stiftelsen for industriell og teknisk forskning (SINTEF)

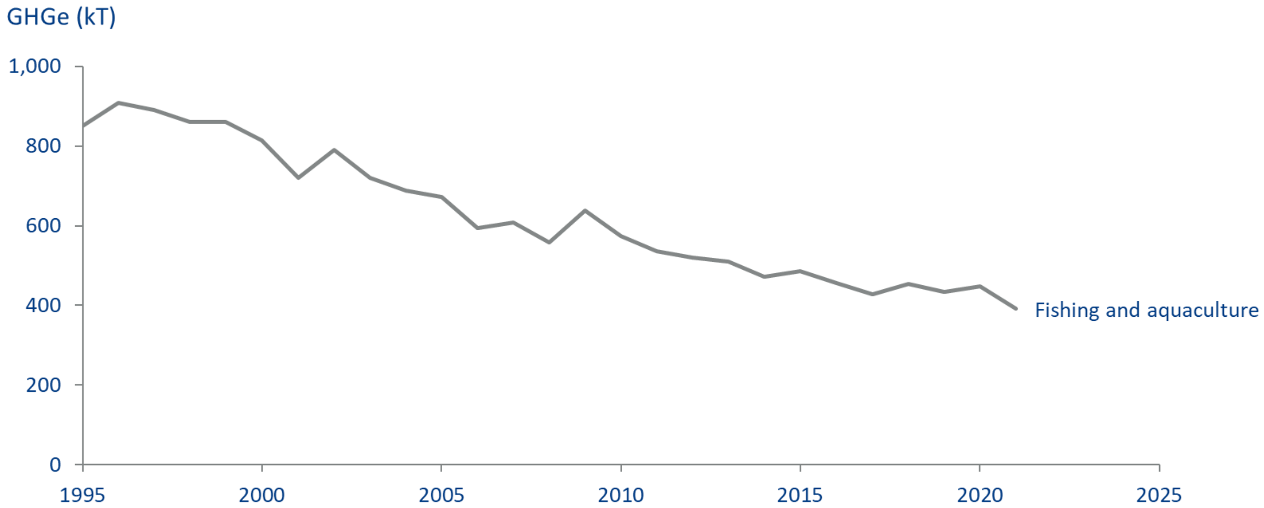
FIGURE 3.26: BREAKDOWN OF ICELAND'S EMISSIONS BY INDUSTRY IN 2021[45]



Total emissions in the fishing and aquaculture industries have been decreasing. This is likely mostly driven by changes in emission intensities from fisheries as they are responsible for the lion share of production.

[45] Statistics Iceland (Hagstofa Íslands)

FIGURE 3.27: HISTORICAL EMISSIONS FROM THE FISHING AND AQUACULTURE INDUSTRIES IN ICELAND[46]



National reporting of GHG emissions has its limitations. Specifically for aquaculture due to being reported in aggregate with fisheries. As the industry grows this is likely to change to enable better monitoring of the industries footprint. Sources do however agree that emissions from aquaculture are relatively small in comparison to other sources of animal-based protein production (see section 3.2.2).

Icelandic salmon producers have varying levels of reported emissions intensities depending on their methods of production and source of feed inputs. Emissions accounting has not yet been standardized, which naturally leads to differences in the way companies report. Over the past few years, emissions per ton of salmon produced in traditional aquaculture have ranged between ~3.2-3.5tGHGe/T[47], which is comparable to emissions profiles of Norwegian salmon producers.[48]

Pressures to limit greenhouse gas emissions will likely continue increase in years to come. Iceland can do much to reduce the emission intensity of its aquaculture industry. This includes localizing more parts of the value chain e.g., feed production and secondary processing to reduce transportation costs. The use of aquaculture biproduct as input to other industries can also lead to positive impact on total emissions from Iceland.

3.4.3 All salmonoid species growing, but salmon dominates

Salmonoids account for nearly 100% of current Icelandic production volume. In 2022 Atlantic salmon (~87%) and Arctic char (~10%) made up the majority. All salmonoid species are growing, but the key driver is Atlantic salmon.

[46] Statistics Iceland (Hagstofa Íslands), BCG analysis

[47] Tons greenhouse gasses emitted per ton salmon produced

[48] Landssamband fiskeldisstöðva, Company reports, Stiftelsen for industriell og teknisk forskning (SINTEF)

FIGURE 18: DEVELOPMENT AQUACULTURE PRODUCTION IN ICELAND PER SPECIES[49]

Although Arctic char production is small compared to salmon in Iceland, Iceland is the global leader, with 72% global market share.[50] Arctic char is farmed in brackish water on land under controlled conditions, generally at a lower scale than salmon in sea pens and at an overall higher production cost. This likely explains the preference among Icelandic farmers to produce salmon.

In comparison to overall production, farming of Rainbow trout in Iceland is much lower than seen in Norway and Chile. Norway and Chile produce 7 and 12 tons of Rainbow trout for every 100 tons of salmon, respectively, while Iceland farmed less than 2 tons for every 100 tons of salmon in 2021. To preserve the Icelandic wild trout stock, Icelandic farmers are not allowed to use Rainbow trout of Norwegian origin for farming. Norwegian trout is used in other countries as it has favorable attributes, mainly that it grows to a large size. Due to this limitation, Icelandic farmers use other genetic strains that do not grow to the same size, making production less commercially attractive.

3.4.4 As scale grows, new opportunities emerge in the Icelandic value chain

Over time, as aquaculture companies have grown larger, they have become more vertically integrated to include more of the value chain's activities within their operations. This is done to secure supply and capture synergies in operations. Most Icelandic aquaculture companies are in early stages of their vertical integration and consume services from either local or foreign service providers. Many of these service providers have been established as specialized entities with a focus on fish farming, while others have emerged as business units of seafood firms with long-standing experience in the fisheries segment.

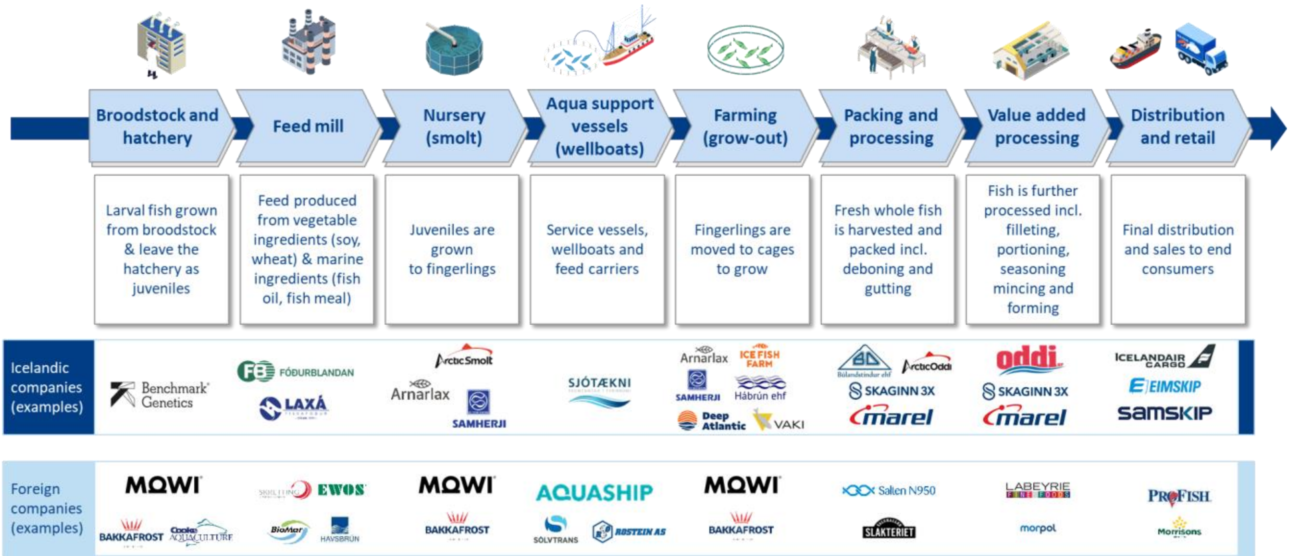
As scale grows in Iceland, the economic feasibility of expanding local service provision grows. This is particularly relevant for feed production and value adding processing, value chain segments that today are mostly sourced outside of Iceland. Establishing these services in Iceland can strengthen supply

[49] Icelandic Food and Veterinary Authority, FAO (2022) Fishery and Aquaculture Statistics, Global aquaculture production 1950-2020 (FishStatJ), BCG analysis

[50] Other producers include Sweden (17%) and Norway (7%)

chains, increase value creation, and reduce environmental impact. The opportunities within each step in the value chain are discussed below.

FIGURE 3.29: FISH FARMING VALUE CHAIN AND SELECT LOCAL AND FOREIGN COMPANIES[51]



Broodstock and hatchery

Eggs from broodstock fish are stripped and produced in freshwater facilities. The majority of fish farming companies purchase eggs from a third party. The industry leaders are Benchmark Genetics in Iceland and AquaGen. Import and veterinary policies in Iceland do not allow import of eggs. Therefore, all farmers in Iceland purchase eggs from Benchmark Genetics. However, several farmers in other markets produce their own eggs internally, such as Mowi, the largest global salmon farming company.[52]

Feed and feed mill

During the smoltification and grow-out phase in the sea, the fish must be fed. Feed is mainly produced from vegetable ingredients (soy, wheat) and marine ingredients (fish oil, and fish meal). As in other animal production systems, feed makes up the largest share of the total production cost. This cost varies based on transportation needs and composition. To limit transportation costs, feed mills are usually located close to production areas. In 2021, Norway was the largest feed supply market, followed by Chile, USA, Scotland, and the Faroe Islands. Feed production in Iceland today is limited, impacting farmers' total feed costs due to transportation needs.[53] Increased interest has been seen from producers to invest in and operate their own feeding mills to decrease costs and have more control over fish health. Síldarvinnslan and BioMar Group have announced intentions to build a feed mill in Iceland in August 2022.[54] Icelandic micro algae producers also produce inputs for fish feed e.g., VAXA and Algalíf.

[51] Expert interviews, Company reports, BCG analysis

[52] Company reports, MOWI industry report

[53] MOWI industry reports, Expert interviews, Company reports

[54] Síldarvinnslan

Smolt and smolt facility

The largest farmers in Iceland and other focus markets are vertically integrated, producing their own smolts in freshwater facilities.[55] Large investments are required to establish smolt facilities, and this has been a production bottleneck for the smaller farmers in Iceland in the past years.[56] The industry is further focusing on increasing the duration of post smolt production to shorten production time at sea. This reduces exposure to sea lice and diseases, and it can also increase productivity given carrying capacity caps by allowing for faster turnaround at production areas.

Aqua support vessels

Service vessels monitor the production areas and transport feed from land. In addition, wellboats transport salmon to and from land. In both Norway and Iceland, most farmers use vessels from third parties.[57]

Production area on sea for salmon grow-out

Salmon is primarily grown out in open pens in the sea in all focus markets. However, large investments have been put into developing other technologies. Traditional farmers are exploring closed pens as well as semi-closed pens, especially in Norway. Production in (semi-) closed pens is expected to have a smaller impact on the environment and to increase salmon health due to, for example, fewer sea lice. Semi-closed pens are currently used in some operations in Norway, but there are no closed or semi-closed pens in Iceland today.[58] Beyond traditional farming, land-based farming already has a foothold in Iceland, building upon a longer tradition of farming other fish such as Arctic char on land. Offshore farming, as another alternative, has been developed in Norway on a small scale but does not yet have a presence in Iceland. Closed and semi-closed possibilities are further discussed in Chapter 4, whereas the land-based and offshore sectors are discussed in Chapters 5 and 6, respectively.

Packing and processing

After the grow-out phase, the fish is slaughtered and gutted as a part of primary processing, after which it can be sold as head-on gutted (HOG). Secondary packing and processing span multiple processes dependent on end-use, from initial pre-rigor fileting to smoking or other ways of cooking. While primary processing (slaughtering and gutting) must take place relatively close to the harvest area, secondary processing can take place both pre- and post-transport and rigor state and is thus less geographically limited, especially if the fish are frozen. This leads to secondary processing most often taking place close to consumer markets. The value of produce generally increases with secondary processing and biproduct can be used for other purposes. Processing fish also decreases weight to be transferred with positive impact on transportation cost and carbon footprint. Growth in the scale of fish farming in Iceland may therefore bring opportunities for increasing secondary processing where synergies can be created with Iceland's high tech processing industry for fisheries.

---

[55] Company reports

[56] Stakeholder interviews

[57] Stakeholder and expert interviews

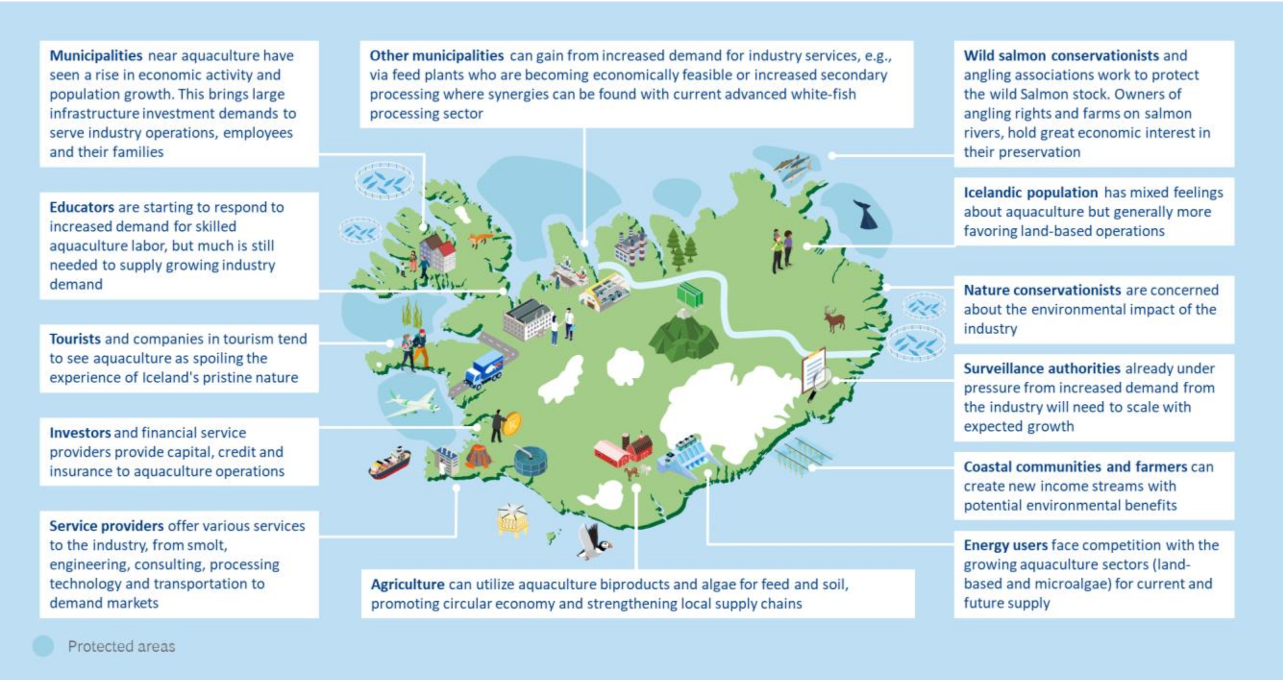
[58] Expert interviews

3.4.5 Aquaculture in Icelandic society

Aquaculture, like most other types of farming on an industrial scale, has complex and wide-ranging societal impacts. Like many commercial endeavors, it creates economic interest from which many benefit but also causes friction with or risks the commercial interest of others. Most aquaculture sectors rely on the use of common resources, with opportunity costs for alternative use.

Societal impacts can be explored by considering the stakeholder groups who are broadly impacted, positively or negatively, by aquaculture activities.

FIGURE 3.30: SELECT STAKEHOLDER GROUPS RELATED TO ICELANDIC AQUACULTURE



Within these stakeholder groups, there are differences of opinions and perspectives, and they are not considered to be uniform in nature. They are also likely to have vary their views between different sectors within aquaculture.

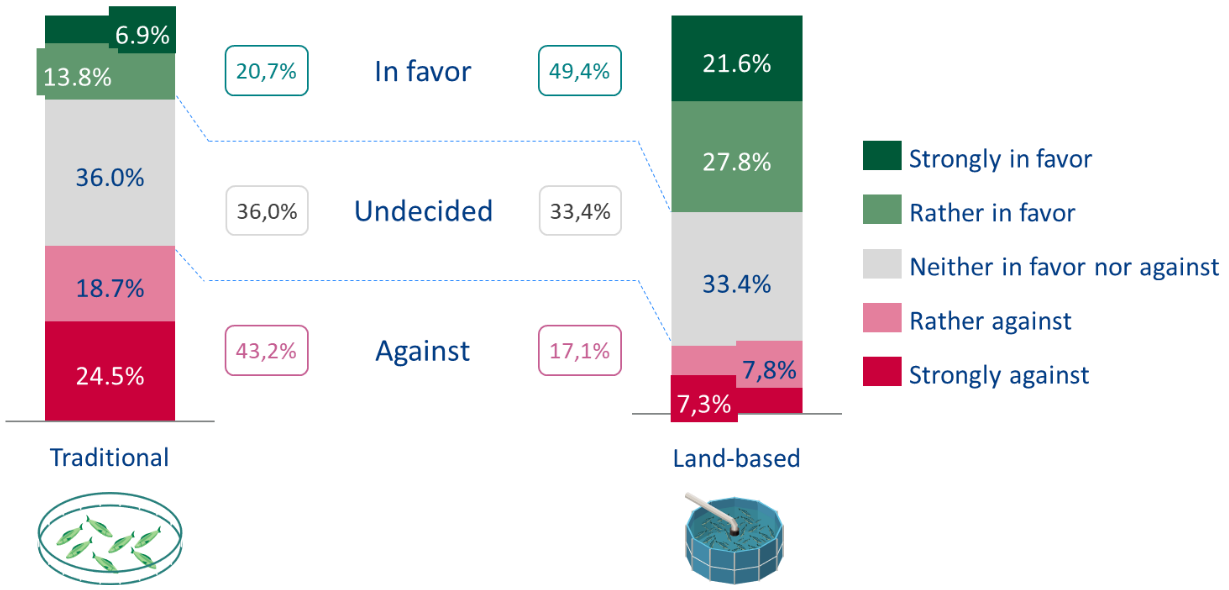
Of the sectors covered by this report, traditional aquaculture is currently the only large-scale aquaculture sector operating in Iceland and the one most largely debated. Several of the sectors have not yet fully entered the public debate. Land-based farming has attracted attention given the number of large-scale projects that are underway, but these projects are at early stages. While recent polls suggest a generally positive attitude towards the sector, it remains to be seen how land-based aquaculture will impact society. Offshore has only recently entered the discussion in Iceland, and limited information exists on public opinion. Preliminary research has been done to investigate its feasibility for Iceland with promising results, included in this report (Chapter 6). Yet more research is needed to validate these findings, and therefore offshore farming has not entered the public debate in full weight. Similarly, algae farming is a small industry in Iceland that has generally attracted positive attention from the public, but more research is needed to understand the true sentiment towards it. The following considerations should therefore, with some exceptions, mostly be viewed as perspectives relating to traditional aquaculture.

In the following sub-sections, general perspectives of select stakeholder groups from Figure 3.30 are considered. Many of these concerns are transferable between stakeholder groups, as people may naturally belong to two or more stakeholder groups. However, for the sake of simplification, they will only be reflected once across the stakeholder groups. The purpose of this section is to give insight into the complex social dimensions and frictions that surround the industry.

The Icelandic population has mixed views on fish farming

Aquaculture on an industrial scale is a relatively new development for Iceland. Rapid growth in traditional aquaculture, along with its opportunities and challenges, have been the subject of public debate. Traditional aquaculture has the most impact in the areas where it currently takes place, that is on the West- and Eastfjords. The population in these areas, a relatively small part of the overall population, experiences the industry firsthand. Yet overall awareness is growing in Iceland as the industry is becoming larger. Recent public polls show that the Icelandic population has mixed views about fish farming. Results also point to traditional aquaculture being seen less favorably than land-based, see Figure 3.31.

FIGURE 3.31: PUBLIC OPINION OF SALMON FARMING AS MEASURED IN MASKÍNA POLL MAY 2022[59]



The results of the Maskína poll from May 2022, show that close to half of the population is in favor of land-based salmon farming, while over 40% of are against traditional salmon farming. For both traditional and land-based aquaculture, men are more in favor than women. Traditional salmon farming has the highest approval rating in the West- and Eastfjords, areas where economic activity is highest. Two other surveys have been run recently covering the whole of Iceland. In 2018, Vestfjarðarstofa commissioned Gallup to explore sentiment towards traditional aquaculture in Iceland. The results in this survey showed that 46.3% were in favor and 29.6% against. In August 2021, the North Atlantic salmon Fund also commissioned a survey from Gallup related to traditional aquaculture. Here, the

[59] Maskína poll May 2022, n=882

results showed 21.1% in favor and 56.6% against. From these results it can be inferred that public opinion towards traditional aquaculture is somewhat fluid. It should also be kept in mind that survey results can be impacted by the questions that are asked and the number of options for answers provided.

Public opinion surveys have also been made periodically only for the Westfjords. In late 2020, Vestfjarðarstofa, commissioned the Research Institute of Akureyri University (RHA) to perform such a survey. This survey covered many dimensions related to traditional aquaculture in the area, including views on environmental and economic impact, and it segregates the result based on residency. Overall, 81% of those surveyed are strongly or rather in favor of traditional aquaculture in their area. Like in the Maskína survey, older residents surveyed (>60 years) and men see traditional aquaculture more favorably. In RHA's survey, younger people surveyed (<30 years) also see it more favorably than those between the ages of 30 and 60. There are also differences in views based on location of residency. Generally, views are less favorable in Ísafjörður, Strandir, and Reykhólar compared to other municipalities in the South and Northwest of Westfjords, where aquaculture is already an established industry.[60]

Based on interviews with the public and information from the public debate, the recognized and expected opportunities and benefits of aquaculture can be summarized into a few categories:

- Supports the preservation of smaller coastal communities.
- Promotes economic activity in adjacent industries.
- Contributes to building a new knowledge industry in Iceland, creating opportunities for high-skilled labor.
- Has potential with a land-based farming sector to use Iceland's natural endowments to create a sustainable low carbon product.

Similarly, concerns around aquaculture can generally be summarized as:

- Environmental impact, e.g., chemical, and organic load on the seabed.
- Animal welfare and impact on wild salmon stocks.
- Lack of fair payment from the use of common resources and limited corporate taxes derived from operations.
- Foreign ownership transferring economic rent from Iceland utilizing common resources without fair payment. The industry currently has limited tax footprint and vertical integration of current players enables them to control to a high degree where profits occur in the value chain.
- Iceland's international image as one offering pristine nature.
- Foreign owners having lower incentives to preserve local nature and contribute to social infrastructure or long-term community building.

[60] Fiskeldi á Vestfjörðum, viðhorfskönnun 2020 – Rannsóknarmiðstöð Háskólans á Akureyri

- Ability to recognize the origins of farmed salmon and how sustainably it has been produced.

Municipalities

Municipalities in the West- and Eastfjords are currently most exposed to aquaculture through traditional fish farming. Reykjanesbær and Ölfus will soon be as well, from large land-based projects ongoing.

The population in the Westfjords had seen a steady decline from the 1940s until 2013, when it stabilized around 7,000 people. Since 2018, the population has grown to around 7,200 people. Between 2013 and 2022, municipalities in fjords with aquaculture have seen an increase in population from 4,096 to 4,470, or an increase of ~9% compared to the ~2% seen for the whole of the Westfjords.

The overall population of Eastfjords has been steadily growing since the early 2000s. Since 2001, the overall population grew from 11,934 people to 13,541 or 12.7%. Viewing only the municipalities where aquaculture is active, the growth from 2001 has been from 2,782 people to 3,815, or 37.1%.[61] Thereof, growth has been 15% since 2011, when aquaculture moved to industrial scale, compared to the 9.9% seen for the total population of Eastfjords. It is important to note that aquaculture is not the only industry that has grown in these areas: there has also been growth activity related to the fisheries and aluminum industries. However, areas with aquaculture activities have seen a relative rise in population compared to the total population in the West- and Eastfjords after reaching industrial scale. Aquaculture has thus most likely contributed to these developments.

Increase in population is seen as one of the main benefits of the emergence of industrial scale aquaculture in these municipalities. There are, however, more realized and expected benefits, which are summarized in the following:

- Positive impact on population growth.
- Increased diversification in economic activity.
- New income streams for municipalities with limited means to invest in societal projects.
- New employment opportunities for the younger generations that also attract local population that has previously left the municipalities.
- Increase in population that strengthens the community and more strongly incentivizes non-aquaculture workers and their families to remain.
- Increased economic activity, development of deep industry knowledge and access to biproduct can spur local innovation and create new jobs, including in the aquaculture service industry.

In addition to these benefits that are generally recognized in municipalities that host aquaculture, the emergence and rapid growth of the industry has also led to challenges and concerns that are summarized as follows:

[61] Includes: Eskifjörð, Reyðarfjörð, Fáskrúðsfjörð, Stöðvarfjörð og Djúpivog

- High investment needs to build local infrastructure to support the industry and its workers; lack of investment in local infrastructure from previous decades significantly aggravates this issue.
- Available income streams not correlated with the extent of operations or the use of common resources in waters along municipality coast.
- Harbor fee laws not being adapted to aquaculture, leading to friction between municipalities and a potential bidding war with a race to the bottom to attract aquaculture operations.
- Limited security regarding long-term income streams from operations, e.g., low barriers for farmers to relocate parts of their value chains (e.g., primary processing).
- Lack of residential housing and other social infrastructure required to house and service workers and their families.
- Work in the industry being to a large degree occupied by migrant workers that do not contribute to municipality taxes and naturally do less to contribute to the community.
- Limited funds to support the adaptation of foreign workers that choose to become permanent residents.
- Opportunity cost and risks for other industries and local livelihoods, e.g., tourism.
- Increased transport on underinvested road infrastructure may constrain aquaculture and other local business activities and lead to further deterioration impacting local population.
- Current government redistribution scheme (Fiskeldissjóður) creating internal competition between municipalities, overburdening already scarce resources, limiting predictability, and not allowing for the long-term investments needed.
- Visual impact from operations including lighting during the night.

To alleviate these concerns and maximize the opportunity aquaculture brings to the municipalities, they generally request for the following actions are to be considered:

- Review industry taxes, levies, and their distribution to reflect actual investment needs.
- Review harbor law and regulation to cater for aquaculture.
- Revisit the education system at the tertiary and university level to create practical educational pathways for students seeking employment in the industry.

Surveillance authorities

Regulatory frameworks and resourcing of surveillance authorities have not followed the rapid growth of the industry. Iceland has far fewer officials managing the industry per kT produced than e.g., Norway and Faroe Islands. This has led to inefficiencies in licensing processes and strained regulatory and surveillance authorities. This strain has furthermore led to employee turnover which further aggravates the problem. Access to employees with the right qualifications and knowledge is limited and the industry in many cases attracts the few that are available. With the foreseeable growth of the industry and introduction of new sectors such as land-based and potentially offshore and macroalgae farming, the situation may lead to yet more constraints than experienced in recent years. This implies that a thorough review of resourcing for regulatory and surveillance authorities is required to enable sustainable growth of the industry.

Wild salmon conservation and angling associations

Iceland is seen as one of the best places in the world for fishing wild salmon and trout in rivers. Amongst Iceland's hallmarks are the clean rivers, pure wilderness, and the abundance of wild fish.

Many Icelanders are avid anglers that spend significant time every season fishing. Foreigners also travel from all around the world to enjoy the Icelandic angling experience. Over the last few decades, the industry grew around managing and selling fishing licenses in Icelandic rivers. Supply of licenses is limited, and licenses are in high demand, which means they are priced accordingly. Licenses in the most prestigious rivers are not within the means of most Icelanders, which has also become a topic of public debate. However, this means that significant economic value is created by Icelandic salmon and trout fishing. Both those who lease the rights to the rivers and sell the licenses as well as the farmers who own the rights are in many instances highly dependent on this income for subsistence. In 2018, the Economics Institute of the University of Iceland performed a study that concluded that the direct economic impact related to angling was 11bn ISK, and the GDP impact, after deducting the value of imported products and services, was 8.7bn ISK.[62] Adjusting for inflation from January 2019 to September 2022, those numbers equate to 13.2 and 10.5 bn ISK today, respectively. Open pen (traditional) salmon farming poses a threat to wild salmon stock as described below. In a worst-case scenario, the Atlantic Salmon can be reduced to extinction with respective impact on angling and the livelihoods of those who on it depend. Wild Atlantic Salmon is already on the list of endangered animals in Norway as the size of its stock has halved in the last 40 years. From 449 populations, only 20% is seen as in good or very good standing.[63]

Associations that work to preserve the wild salmon stocks raise awareness about and demand action to reduce and over time eliminate the impact traditional aquaculture has on wild salmon stocks and the natural habitat of the sea:

- Wild salmon is at the risk of genetic mixing with farmed salmon escapes. Wild salmon have over thousands of generations developed unique attributes that are optimized for survival in the wild, often including traits, specific for the river they originate from. Farmed salmon have been bred to attain other attributes that are suitable for farming but not necessarily survival in the wild. Research has also shown farmed salmon to be disadvantaged for breeding in wild salmon rivers.[64] Moreover research shows farmed salmon migrating long distances into wild salmon rivers.[65] When farmed salmon migrate to wild salmon rivers, they cause genetic blending and dilute the gene pool of the wild salmon, impairing their survival ability of the wild. This can lead to the deterioration and worst case the extinction of the wild Icelandic salmon stocks. Evidence suggests that wild salmon stocks in Newfoundland, Norway and Scotland have been highly impacted by fish farming.

[62] Hagfræðistofnun Háskóla Íslands - Virði lax- og silungsveiða – Report no. C18:07 – October 2018

[63] Status of wild Atlantic salmon in Norway 2021- Vitenskapelig Råd for lakseforvaltning

[64] Lifetime success and interactions of farm salmon invading a native population (Flemming et al, 2000)

[65] Migration and survival of farmed Atlantic Salmon released from two Norwegian fish farms. (Lars P. Hansen, 2006).

- Wild salmon can be harmed by sea lice growing excessively in fish farms. Smolts are particularly vulnerable to sea lice when migrating first to sea.
- Organic load and heavy metal compounds from farming sites can alter ocean conditions to the detriment of other sea-based lifeforms and humans if consuming them.
- Disease from farmed salmon can spread to wild stocks.

Overall, wild salmon conservation and angling associations firmly reject open net sea pens due to the risks it poses to the wild North Atlantic salmon. They point to several past instances of public process where the industry has been unduly favored at the cost of the environment and wildlife. They demand the government to honor current Icelandic law and international treaties it is signatory to.[66] They want to see swift action to facilitate the transition to the more sustainable land-based farming. During the transition, active measures should be taken to control and limit the risks involved with current traditional farming operations. The outcomes of those measures during the transition should be targeted at achieving zero mortality in wild fish from sea lice arising from salmon farms and zero escapes of farmed salmon:

- Stop further allocation of licenses and revoke issued licenses that are not yet utilized.
- Include existing conservation areas in Icelandic law.
- Increase resourcing for industry monitoring bodies, ensure high frequency monitoring that is made publicly available, and segregate monitoring bodies from those who award licenses.
- Increase resources for the Marine and Freshwater Research Institute to better enable it to serve its legal mandate of preserving the wild salmon stock, including furthering research on genetic introgression and disease occurrence derived from fish farms.
- Strengthen regulation through the introduction of consequences for non-compliance to e.g., sea lice levels, escapes, diseases, and stocking standards.
- Include water quality standards in regulation for independent monitoring.
- Tag/clip farmed salmon to increase the ability to identify escapees. Today, visual identification is very challenging, especially if smolts escape, as the farmed salmon will develop similar visual appearance to the wild stock salmon. This will also eliminate the need for costly and lengthy DNA research to validate origins of salmon that is suspected to be farmed.

Nature conservation associations

Icelandic nature conservation associations have also worked to raise awareness around the environmental risks posed by traditional aquaculture. Their key concern is the impact on the sea and its sea-based lifeforms, especially from the organic load discharged from sea pens in traditional aquaculture. Land-based industries are responsible for filtering this organic load out of their wastewater, while the traditional aquaculture has no such regulation. Conservation associations

[66] UN Convention on Biological Diversity, Bern Convention on the Conservation of European Wildlife, OSPAR Convention on the protection of the Marine Environment of the North-East Atlantic, Agreement on the European Economic Area (article 73), Directive 2011/92/EU of the European Parliament (articles 2 and 14), the Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters

additionally a call for increased transparency around the surveillance of traditional fish farming operations, including surveillance data being made public once conducted. They also emphasize Iceland's obligation to adhere to international regulation and international treaties and conventions it has ratified, such as those concerning biological diversity. The limited influence the public has on high-impact decisions made in their areas is regretted, and these organizations ask for further public consultation, as they find the current setup with the Environmental and Natural Resources Board of Appeal (Úrskurðarnefnd umhverfis- og auðlindamála) to be ineffective. Instead, they suggest that the public should have access to legal recourse when there is evidence of malpractice or unlawful action in relation to aquaculture, as is the custom in Norway and Sweden. Imperative for these associations is to create trust in the governing process of the industry, which needs to be managed by strong and independent authorities that follow and enforce the rule of law.

Seafarers

Recently a debate has surfaced in Iceland around the placement of traditional aquaculture sites with regards to sea-traffic. Analysis suggests that some production areas may be positioned inside safeguarded sailing routes, guided lighthouses. Any type of man-made infrastructure is not permitted inside these safeguarded sailing routes according to law (Act on lighthouses no. 132/1999). These matters are under review including in the coastal planning program and may lead to repositioning of some production areas or clarification regarding the placement of pens inside the production areas. Planned production sites in Seyðisfjörður have also faced scrutiny due to proximity to the FARICE submarine cable and that sea-traffic routes in the fjord are already narrow.

3.4.6 Sub-conclusion

The aquaculture industry in Iceland is relatively young and has grown fast. It is already a sizeable part of Icelandic economy and has supported growth in municipalities in the West- and Eastfjords. With these benefits, challenges and conflicts of interest have also emerged. Aquaculture has wide-ranging societal impacts and according to polls, public sentiment towards traditional aquaculture is to a large degree negative. Stakeholder groups express many concerns, most of which can be addressed with effective policy. To achieve a sustainable growth of Icelandic aquaculture in harmony with society, these tensions should be further analyzed, and solutions sought that balance economic growth, societal wellbeing, and environmental impact.

4. Traditional aquaculture

This aim of this chapter is to provide an overview of the traditional aquaculture sector in Iceland, with special emphasis on salmon farming due to its relative weight in Icelandic production. In addition to Iceland, the chapter will examine focus markets, i.e., Norway, Scotland, the Faroe Islands and Chile. The objective is to describe market dynamics, environmental impact, conditions for traditional farming, key trends, and policy frameworks from the perspective of licensing and tax regimes, governance, and surveillance. Due to its relative importance in Icelandic aquaculture this chapter will focus mostly on salmon farming.

4.1 Sector overview

Traditional farming is the oldest and most practiced sector within salmon farming. Salmon farming begins in freshwater facilities on land before salmon smolts are transferred to pens, mainly in fjords, to grow out in the open sea. Salmon farming began as an experiment in the 1960s in Norway and developed into a thriving industry in the 1980s.[67] In the 1990s, the industry also gained foothold in Chile, with Scotland, the Faroe Islands and Iceland following thereafter.[68]

4.1.1 Salmon farming is limited to cold water seas

Salmon farming is performed in relatively cold-water temperatures, ranging between 0-20°C, with an optimal temperature range between 8 and 14°C. Salmon farming is therefore limited to coastlines within certain latitudes in the Northern and Southern Hemispheres.

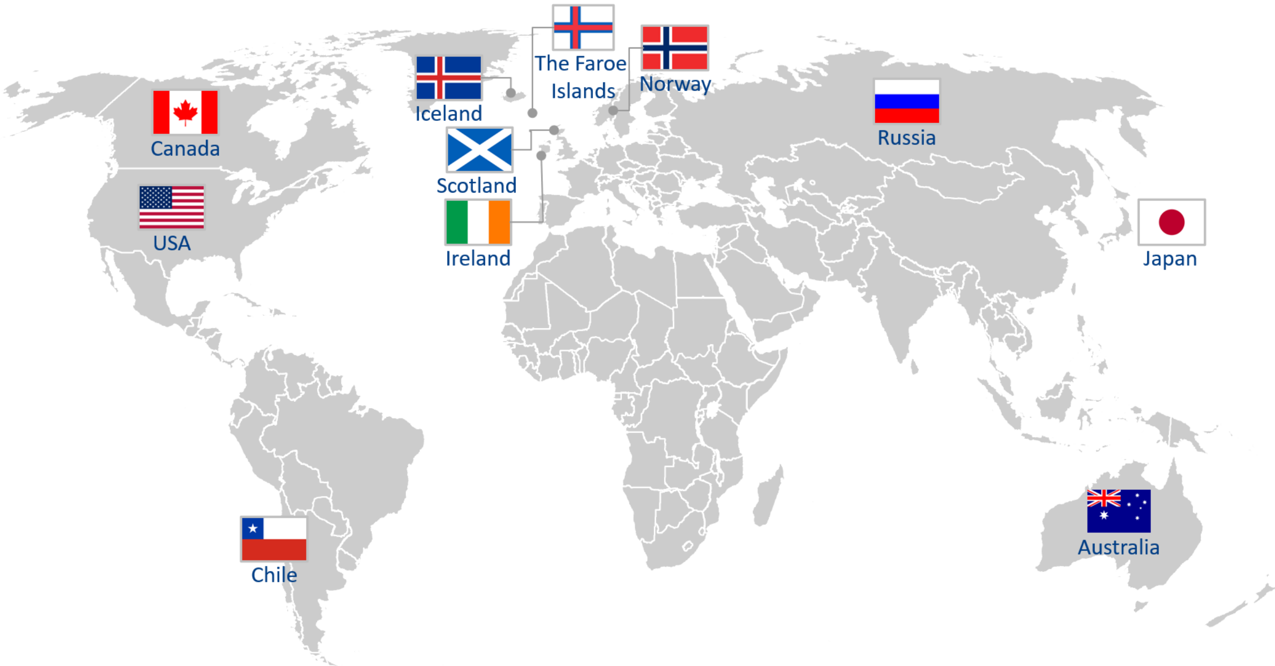
Salmon farming further requires ocean currents with certain strengths to flow through production areas. The currents play a key role in improving conditions, contributing to higher water quality, faster dilution of waste, higher levels of oxygen and less influence from terrestrial runoff. Such conditions are typically found along sheltered coastlines that have appropriate biological environments, such as fjords and other sea areas protected by small islands or archipelagos. Consequently, today, most of traditional salmon farming is performed in ten countries: Norway, Chile, Scotland, Canada, the Faroe Islands, Australia, Iceland, Japan, the United States, Ireland, and Russia.[69]

[67] Statistics Iceland (Hagstofa Íslands) FAO, BCG analysis

[68] Fiskeridirektoratet, FAO, BCG analysis

[69] Countries producing at least 10kT. These represent nearly 100% of global production

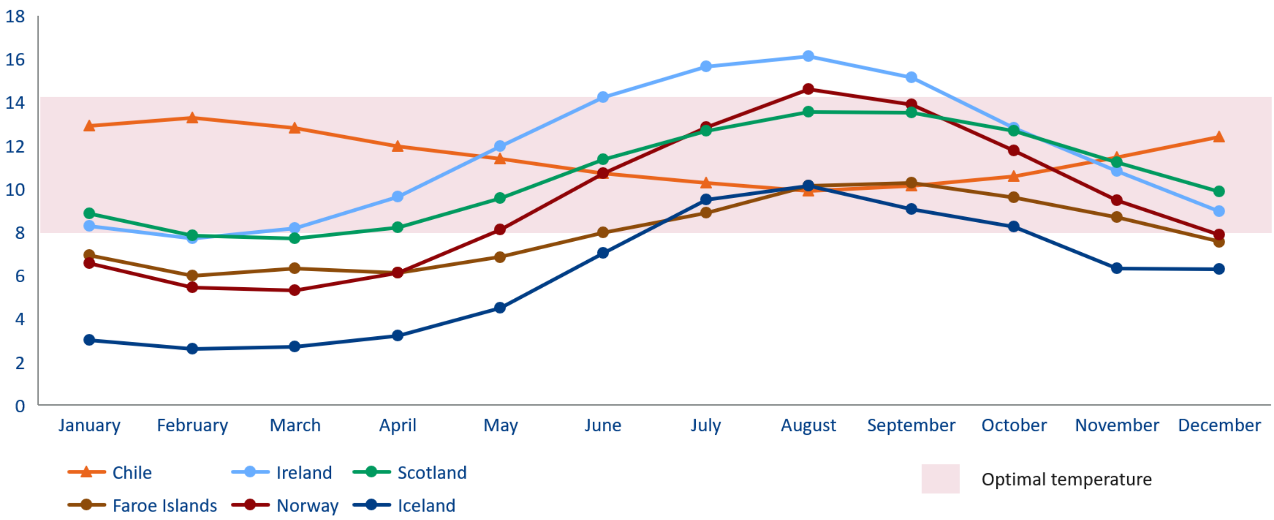
FIGURE 4.1: LOCATIONS SUITABLE FOR TRADITIONAL SALMON FARMING[70]



4.1.2 Icelandic sea temperatures are less then optimal for growth but limit the risk of diseases and sea lice

As noted in the previous section, salmon production time is highly dependent on seawater temperatures, which vary during the year and across regions.

FIGURE 4.2: AVERAGE SEAWATER TEMPERATURE PER MONTH IN FOCUS MARKETS[71]



[70] FAO (2022): The State of World Fisheries and Aquaculture, BCG analysis

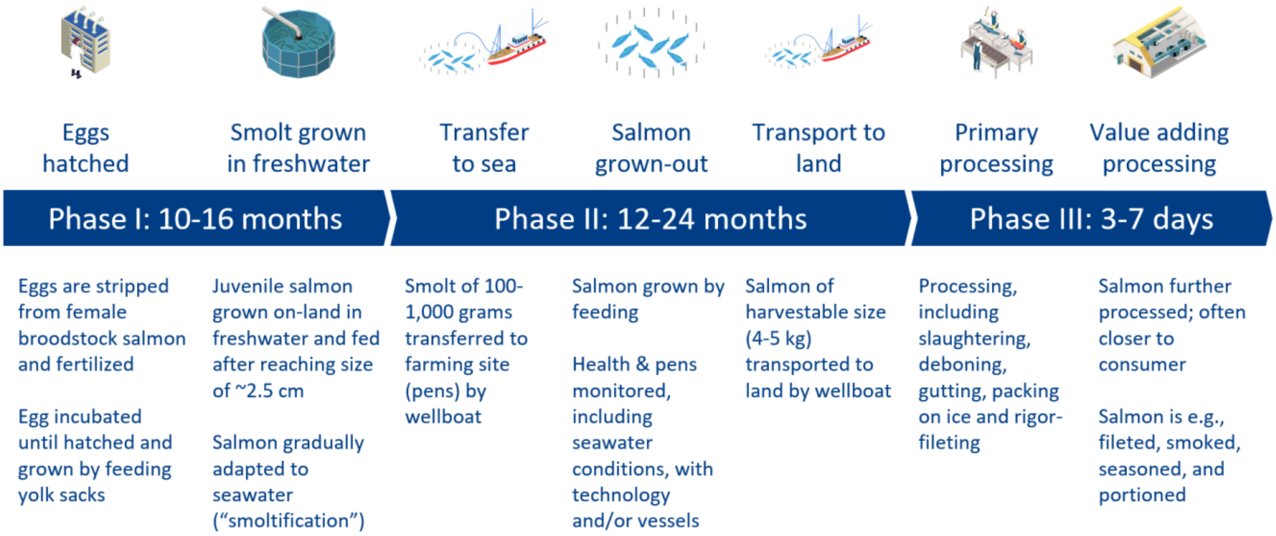
[71] Kepler Cheuvreux, DNB Markets, BCG analysis

The smolt to harvest production time in Chile has historically been shorter compared to other countries due to stable seawater temperatures between 10-12°C. Countries farming in the Northern hemisphere have a temperature fluctuation of up to +/-9°C, resulting in less growth during the winter and stronger growth during the summer.[72] Seawater temperatures also impact production utilization, with high temperatures increasing the risk of diseases and low temperatures increasing the likelihood of mass mortality from cold exposure. Overall, in comparison to other markets, Chile has a natural competitive advantage due to its stable seawater temperatures.

4.1.3 The salmon farming production cycle spans three phases

The production cycle for salmon farming is around 2-3 years and is generally split into three phases.

FIGURE 4.3: TRADITIONAL SALMON FARMING PRODUCTION CYCLE[73]



In the first phase, eggs are stripped and fertilized from broodstock fish, which are mature salmon kept for breeding purposes. Following fertilization, the eggs are incubated in freshwater until hatched. The hatched eggs (fry) feed on yolk sacks until their first feeding. Next, the juvenile salmon are transferred to freshwater tanks and grown for up to 16 months after hatching to an average weight of between 100 and 250 grams. The salmon can be kept in freshwater sites for longer periods of time to increase in size, often referred to as post smolt production. In post smolt production, the smolts usually grows from 250 to 1,000 grams, leading to increased resilience and a shorter grow-out time at sea. During the smolt and post smolt process, the juvenile salmon are introduced to seawater in a process called smoltification, where salinity is gradually increased until it reaches seawater level.

In the second phase, the salmon is transported to sea pens by wellboats to grow until they are harvested. During the grow-out phase, the fish are fed, and their health is monitored. Most pens have automated feed systems that portion the feed. This process is typically overseen by employees on land. Service

[72] Icelandic Salmon Pareto Securities (2021), BCG analysis

[73] Johansson, G. Ø. (2017): Process analysis and data driven optimization in the salmon industry, BCG analysis

vessels visit the production area to monitor the pens, including oxygen levels, current levels, fouling development, and temperature levels. After 12-24 months at sea, the salmon have grown to a harvestable size of 4-5 kg and are transported to land by wellboats.

In the third phase, the salmon is slaughtered, gutted, processed, and packed on ice with output measured in Gutted Weight Ton (GWT) or Head-On Gutted (HOG). Some farmers include value-adding processing (VAP) in their production cycle, while others may ship to processing facilities closer to the end market. Value-adding processing can include fileting, seasoning, portioning, mincing, and forming. Once pens in a production area have been harvested, the site is fallowed[74] for 1-6 months, depending on local regulation, before the next generation is put to sea in the same location.

4.1.4 Sub-conclusion

Salmon farming takes around 2-3 years from the time an egg is hatched to when the salmon is harvested, requiring access to both seawater and freshwater, as well as specific infrastructure at each phase. As salmon farming requires specific seawater temperatures (optimally between 8 and 14°C), locations are naturally restricted to the geographical poles. Consequently, Iceland is well-suited for farming, yet its relatively colder seas compared to other focus countries can result in lower seasonal productivity.

4.2 Supply dynamics

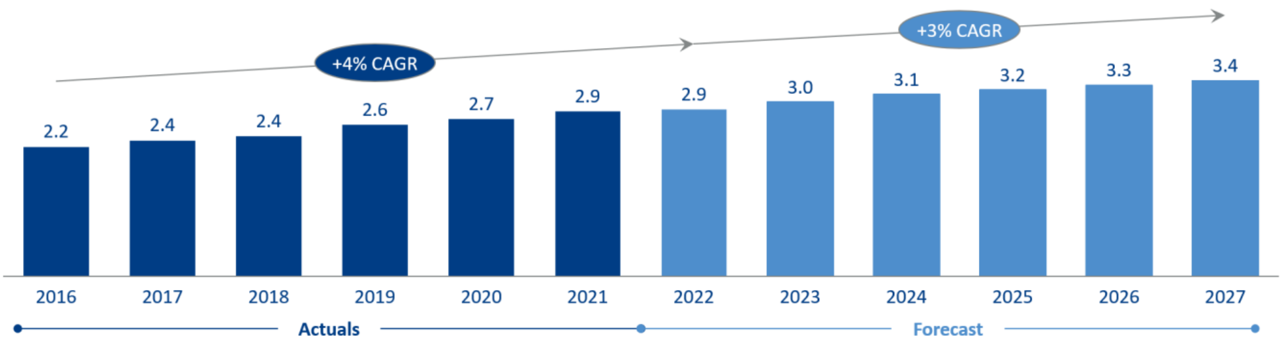
4.2.1 Supply of traditionally farmed salmon is expected to grow modestly

Since 2016, the volume of traditionally harvested salmon globally has been growing at a 4% compound annual growth rate (CAGR), reaching a total volume of ~2.9mT in 2021. Growth is expected to slow to ~3% CAGR for the next five years, with total volume reaching ~3.4mT in 2027. The main reason for slower expected growth is that current licensing regimes are reaching full utilization rates due to biological and environmental boundaries. Furthermore, regulatory measures to mitigate environmental impacts have been implemented, e.g., in Chile and Norway, where license utilization is dependent on the sustainability of each farmers production.[75] Consequently, growth beyond the expected ~3% CAGR until 2027 is unlikely to occur without significant progress in farming and biotechnology or regulatory changes. Growth expectations in Iceland are further described in Chapter 8.

[74] Fallowed is a 'resting period' where a production area is cleaned, and condition of seabed is often assessed before next production cycle starts to limit environmental impact

[75] Note: License regimes further described in Section 4 below

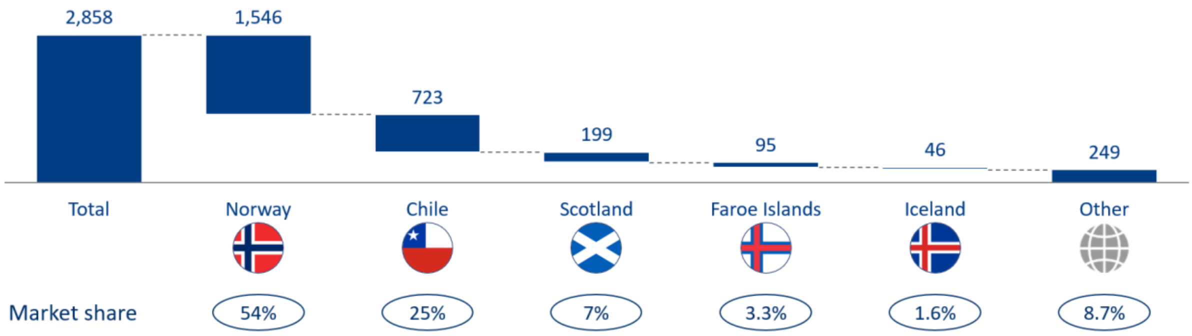
FIGURE 4.4: GLOBAL HISTORICAL AND EXPECTED GROWTH OF TRADITIONALLY FARMED SALMON (WFE IN MT) [76]



4.2.2 Supply is dominated by Norway and Chile

In 2021, Norway and Chile were the largest producers of traditionally farmed salmon accounting for ~54% and ~25% of total volume, respectively. Volumes in Scotland, the Faroe Islands, and Iceland accounted for approximately 7%, 3% and 2%, respectively. Other markets accounted for the remaining ~9%.

FIGURE 4.5: PRODUCTION OF TRADITIONALLY FARMED SALMON (EXCLUDING COHO) PER COUNTRY IN 2021 (WFE IN KT) [77]



4.2.2.1 Iceland is growing faster than leading countries that are constrained by supply

From 2016 to 2021, all focus markets experienced growth in harvested volumes. Difference in growth between markets is mostly explained by new license availability, increases in productivity, and mass mortality due to e.g., algae blooms. All markets experienced slower growth in 2020, with Norway having

[76] Kepler Cheuvreux, Kontali, FAO (2022): The State of World Fisheries and Aquaculture, BCG analysis

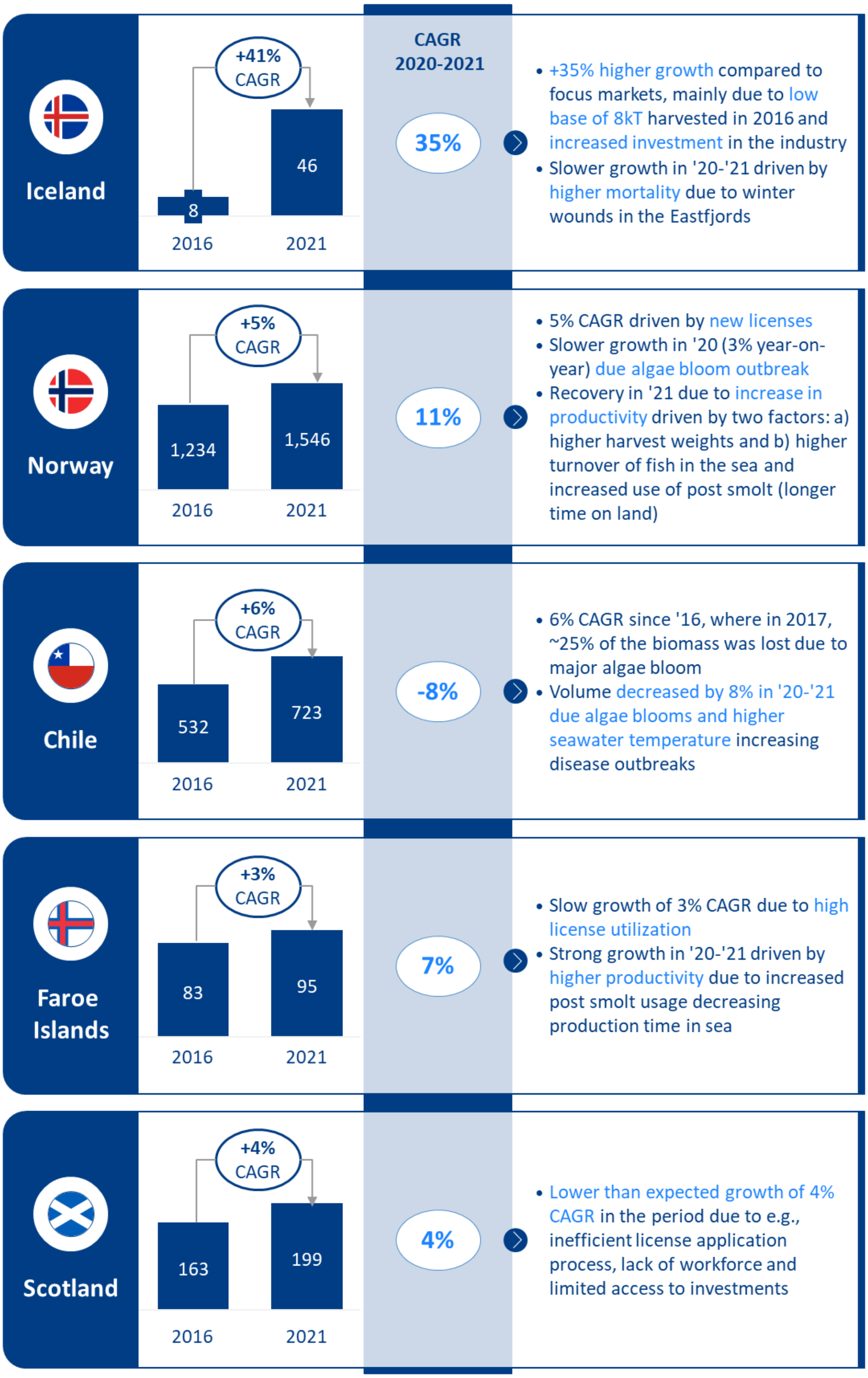
Note: Historical volumes only include traditional farming of Atlantic salmon and forecast is based on Kepler Cheuvreux, Pareto Securities, and experts, excluding land-based and offshore volumes

[77] FAO (2022): The State of World Fisheries and Aquaculture, Pareto Securities, Statistics Iceland (Hagstofa Íslands), Icelandic Food and Veterinary Authority, Fiskeridirektoratet, Faroese Seafood, BCG analysis

an algae bloom in 2019 that reduced harvesting potential into 2020, and Scotland and the Faroe Islands experiencing high biological challenges limiting total growth in 2020.[78]

[78] Pareto Securities, Fiskeridirektoratet, Faroese Seafood, Expert interviews, BCG analysis

FIGURE 4.6: HISTORICAL GROWTH OF TRADITIONALLY FARMED SALMON PER COUNTRY (WFE IN KT) [79]



4.2.3 Trends focus on efficiency and environmental footprint

Growth of traditional farming must consider necessary environmental and sustainability related factors such as wild salmon conservation, which in turn can lead to regulatory limitation on capacity. This is for example the case in Iceland, where growth is capped to limit impact on wildlife and the local ecosystem. Additionally, biological challenges continue to be an issue leading to lower harvest growth and higher production cost. Farmers are thus focused on increasing productivity, lowering costs, and finding alternative ways to grow sustainably. The following trends detail key considerations for the sector.

FIGURE 4.7: OVERVIEW OF TRADITIONAL AQUACULTURE MARKET TRENDS[80]

1. Shift to bigger production areas and pens in more optimal locations

Salmon farmers are moving production areas further away from fjords to locations where conditions are most optimal, such as where sea depth is higher or currents stronger, providing higher biological carrying capacity. Pens used in production areas are also increasing in size to bring scale benefits to operations (e.g., better utilization of investments such as feed barges). This trend has been strong in Norway with pens growing from an average size of 40 to 120 meters in diameter. This trend is also seen in Scotland, where many production areas are located far into fjords with limited currents and exchange

---

[79] FAO, Statistics Iceland (Hagstofa Íslands), Seðlabanki Íslands, Scottish Government, Pareto Securities, Kontali, BCG analysis

[80] Fiskedirektoretet, Expert interviews, BCG analysis

of water. Farmers in Scotland are thus moving further away from fjords to a more exposed areas to improve biology and productivity.

FIGURE 4.8: NUMBER OF PRODUCTION AREAS IN NORWAY BY SIZE IN 2012 AND 2020[81]

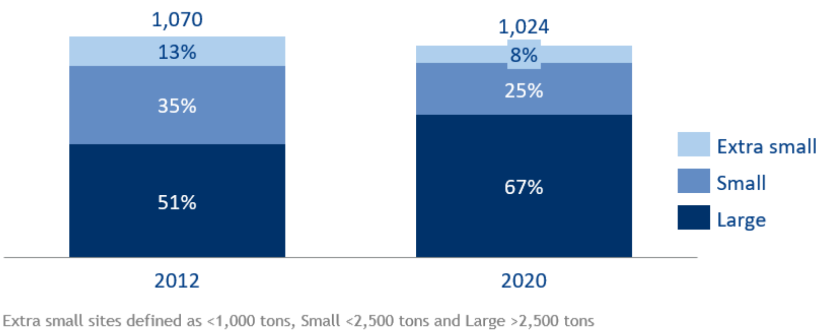
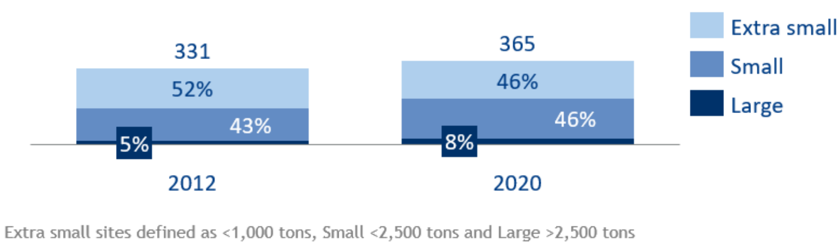


FIGURE 4.9: NUMBER OF PRODUCTION AREAS IN NORWAY AND SCOTLAND BY SIZE IN 2012 AND 2020[82]



2. Exploration of alternative farming methods

Alternative farming sectors such as offshore farming, land-based farming and closed-containment pens are sparking significant interest in all markets. Alternative farming sectors can help navigate challenges linked to traditional farming, such as waste management, escapes, and diseases. Overall, Norway has progressed most across alternative sectors, but other countries are expected to follow suit, and significant land-based projects are already underway in Iceland (discussed further in Chapter 5). Canada has also promised to move the entire industry to closed containments, although this has not yet happened. That said, traditional farming is still expected to drive most of the growth in the medium term, whereas new sectors likely will play an increased role in aquaculture in the next 10 years (Chapters 5 and 6).

3. Focus on limiting environmental impact and improving fish welfare

In parallel with the development of alternative farming sectors, countries are working to reduce the environmental impact of traditional farming. This includes increasing efficiency of the value chain to reduce carbon footprint, supported by many operators' net zero carbon emission targets. Fish farmers

[81] Fiskeridirektoratet, Scottish Government, Expert interviews, BCG analysis

[82] Fiskeridirektoratet, Scottish Government, Expert interviews, BCG analysis

are also focusing on plastic management, decreasing use of copper, escape prevention, effective sea lice management, reducing the use of licensed medicine and other fish health initiatives, waste collection, and limiting feed residue. Closed- and semi-closed pens are being explored to reduce escapes and capture organic load instead of impacting seabed below production areas, with monitors overseeing water oxygen and other water conditions to limit impact on the environment. Biodiversity is also a priority, as healthy oceans are important to drive sustainable fish farming. Some fish farmers have also experimented with integrated multi-trophic aquaculture (IMTA) systems, cultivating different species in a polyculture. Growing fish, mollusks, and algae in proximity to each other (see further in chapter 7).

4. Increasing use of post smolt to increase smolt weight and limit time at sea

The average smolt size today is around 100 grams in Norway, Chile, and Iceland. Most salmon farmers, especially in Norway, Faroe Islands and Canada, are investing in larger smolts with some projects aiming for sizes up to 1,000 grams. With larger smolt sizes, the fish needs less time to reach harvest size in sea pens. With licenses centered around the biomass in the sea, this can significantly increase the turnover at sea and, thus, overall production. An additional benefit is lower mortality, as releasing more resilient fish into seawater reduces the likelihood of disease and lice outbreaks, resulting in lower overall risk in production.

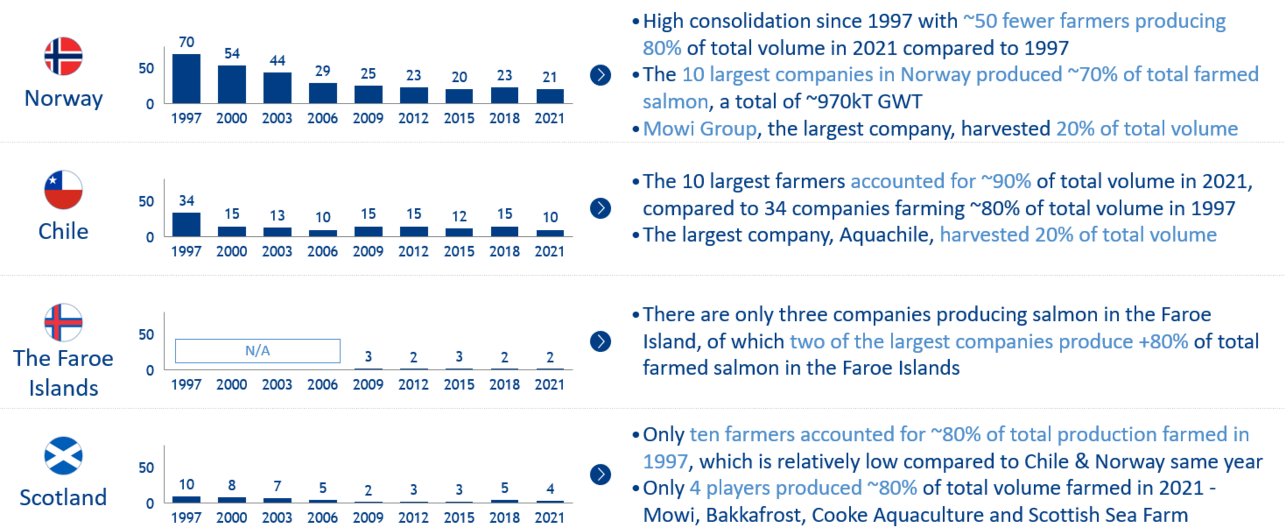
5. Changing feed composition

Today, the key ingredients in commercial fish feed are vegetable products, which often come from unsustainable sources. Historically, fish feed also included fish compounds from fisheries, although this has been greatly reduced. As the farming industry grows, alternative ingredients in fish feed are being investigated such as algae oil and insect meal in the ambition limit environmental impact. In addition to making the feed more sustainable, the industry is also looking for ways to make feed more cost effective, as well as increasing the use of growth feeds aimed at stimulating faster growth and health feeds aimed at lice prevention and boosting the immune system.

6. Industry consolidation

Historically, the salmon farming industry consisted of a larger number of smaller firms, especially in Norway and Chile. During the last decades, the industry has been consolidating in all focus markets, with 80% of volume produced by a small number of companies. Further consolidation is expected, however dependent on current and potential new limitations on anti-trust and ownership.

FIGURE 4.10: DEVELOPMENT AND NUMBER OF FARMERS PRODUCING +80% OF SALMON HARVESTED IN MARKETS[83]



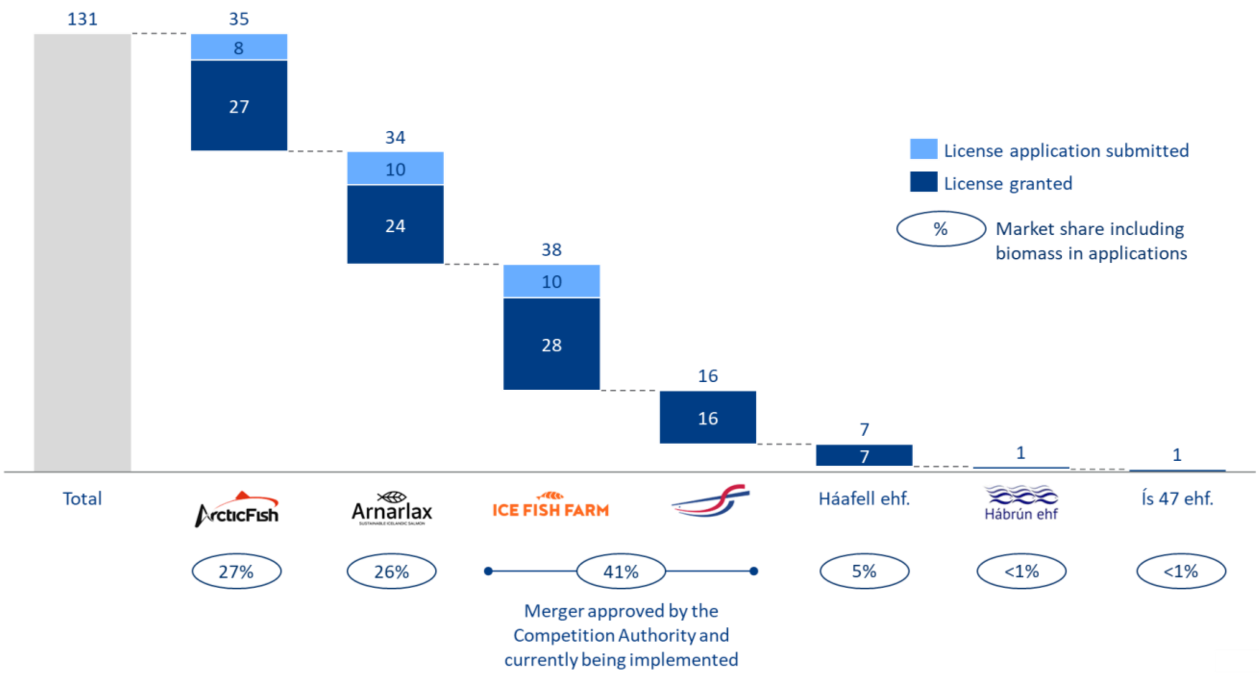
The industry in Iceland is also consolidating. Merging companies must adhere to competition legislation, and as of today all mergers have been approved. Three listed businesses dominate Iceland's salmon farming sector today. In 2021, Ice Fish Farm (Fiskeldi Austfjarða) and Laxar Fiskeldi, who both operate in the Eastfjords, merged.[84] Arctic Fish and Icelandic salmon (Arnarlax), who operate in the Westfjords, were also expected to merge because merger plans between the companies' majority owners, Norwegian Royal Salmon (NRS) and SalMar, announced first half of 2022. In October 2022, MOWI however acquired a 51.28% stake in Arctic Fish from Norwegian Royal Salmon as part of a European Commission ruling to approve the merger of SalMar and Norwegian Royal Salmon. Other traditional farmers in Iceland are Háafell which is licenced to farm salmon, ÍS 47 and Hábrún who are licensed to farm cod and rainbow trout.

Arctic Fish and Arnarlax are therefore likely to operate as separate companies in the Westfjords. Collectively, they presently possess 51kT of MAB and have applications in process for an additional 18kT MAB. This makes up for 53% of licenses currently granted and in application. In the Eastfjords, Ice Fish Farm, which recently merged with Laxar Fiskeldi, currently holds ~44kT MAB and has applications in process for an additional 10kT MAB. If granted, Ice Fish Farm will hold 41% of all licenses. Remaining licenses are held by three companies in the Westfjords, Hábrún, ÍS 47 and Háafell. Consequently, it is possible that all licenses in Iceland will be divided amongst six farmers in 2023, with the three largest holding 94% of MAB.

[83] Pareto Securities, BCG analysis

[84] The Icelandic Competition Authority, company reports

FIGURE 4.11: LICENSE (MAB ALLOWANCE IN KT) PER PRODUCER IN ICELAND[85]



4.2.4 Sub-conclusion

Since 2004, global traditional salmon farming has grown at an annual rate of 4%. While focus markets have grown by 3-6% per year since 2016, Iceland has grown from a low base of 8kT at an average of 41% per year and reached 46.5kT in 2021. Currently, Iceland produces 1.6% of global supply, which is dominated by Norway and Chile with 54% and 25% market share, respectively.

Key trends today mainly focus on mitigating current challenges linked to capacity restraints and reducing environmental impact. Industry consolidation is seen across markets, including in Iceland, where recent merger activity is expected to leave two players with +90% of market share.

4.3 Regulation

Traditional salmon producers in the focus markets are subject to several legislations which are governed and administered by local authorities. Key legislation centers around coastline availability for farming, licenses, taxes and fees, and the environment. Iceland and Norway must also implement and comply with applicable EEA regulations such as the Water Framework Directive[86] and regulations related to animal welfare and diseases.[87] The Faroe Islands and Scotland are not obligated to implement EEA/EU regulations. However, both markets have largely implemented the provisions stated in EU regulations related to salmon farming.

[85] ood and Veterinary Authority, BCG analyses

[86] EU Water Framework Directive 2000/60

[87] Regulation on Animal Welfare, Regulation (EU) 2016/429 on transmissible animal diseases

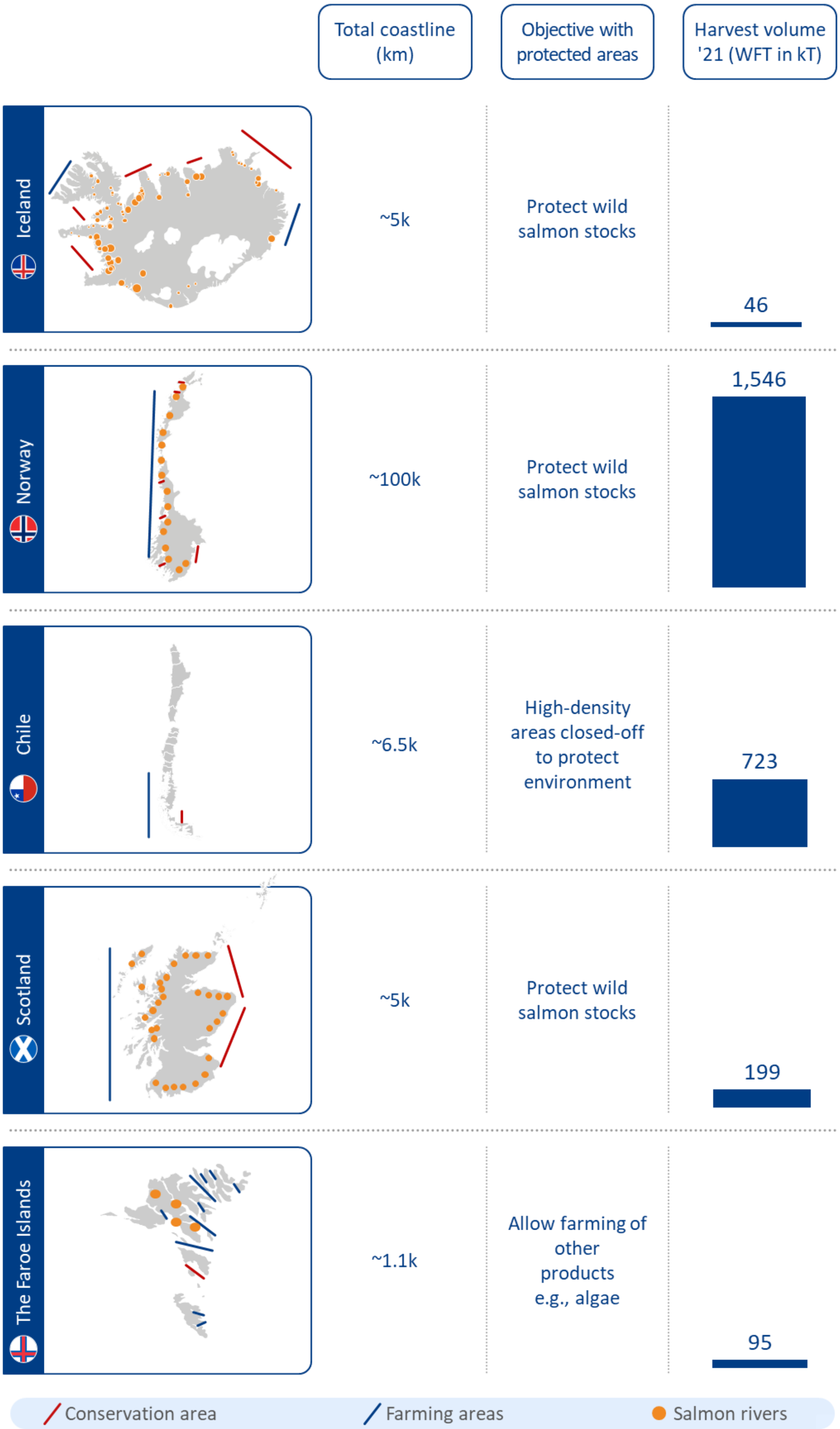
4.3.1 Coastline availability for farming differs in focus markets

In all focus markets, there are limitations on where fish farming can operate, this can be the result of conservation efforts or because environmental conditions are not suitable for farming.

In Norway and the Faroe Islands, most of the coastline is made available for salmon farming, whereas large sea areas are conserved in Scotland and Iceland. Large parts of the Chilean coastline cannot be farmed due to the lack of adequate sea conditions to farm salmon. Of all the markets, Chile has the highest density in terms of harvest per km coastline available for farming.[88]

[88] DNB Markets, Pareto Securities, BCG analysis

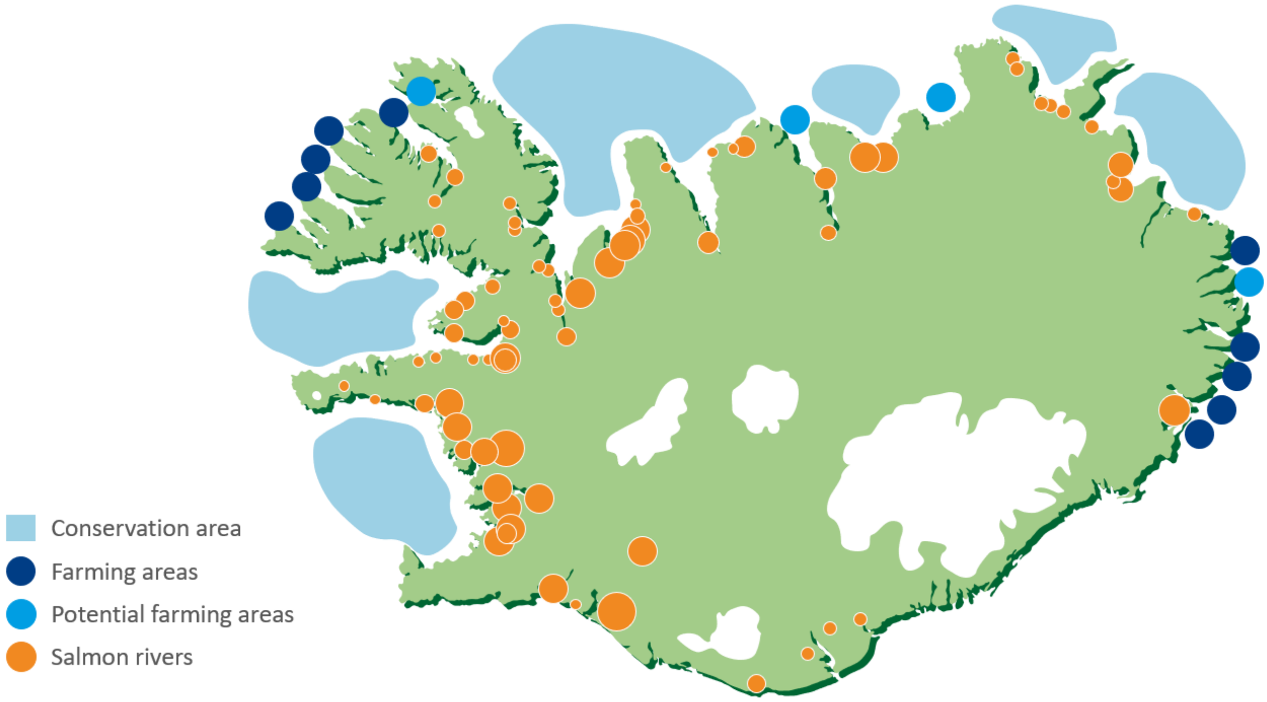
FIGURE 4.12: MAIN FARMING AREAS, CONSERVATION AREAS AND AREAS NOT ADEQUATE FOR FARMING[89]



Farming areas located in the East and West of Iceland; majority of coastline conserved

All production areas in Iceland are located in the West- and Eastfjords. In 2004, areas of the Icelandic coastline were conserved, prohibiting any traditional salmon farming within the boundaries. The objective was to reduce the risk of farmed salmon escaping from pens, migrating to salmon rivers, and genetically mixing with the wild salmon stocks. In addition to this, some fjords are not considered suitable for salmon farming. This has left 14 fjords, of which 10 currently have farming operations.

FIGURE 4.13: CONSERVATION AREAS, PRODUCTION AREAS AND POTENTIAL PRODUCTION AREAS IN ICELAND[90]



Most of Norway's coastline available for farming with limited conservation

Norway has the second largest coastline in the word after Canada, with a length of ~100k kilometers, including its islands and archipelagos. Norway utilizes most of its coastline for salmon farming. Key migration zones in wild salmon rivers are also protected (e.g., Atlafjord and Reisafjorden) to limit the risk of genetic mixing with farmed salmon. In Norway, conservation areas are defined close to the mouth of the wild salmon rivers, whereas in Iceland, much larger areas surrounding wild salmon rivers are closed off for conservation.

Chile has the highest harvest density but has recently closed off areas

In Chile, it is only possible to farm salmon in the middle and southern regions due to sea temperatures. Historically, no restrictions applied in terms of where salmon producers could operate a farm. Production areas are therefore located close to each other, resulting in Chile having the highest density

[90] Auglýsing um friðunarsvæði þar sem eldi laxfiska (fam. salmonidae) í sjókvíum er óheimilt, 27 Maí 2004, nr. 460, Ministry of Food, Agriculture and Fisheries, BCG analysis

of harvest per km coastline available for farming. Due to its high densities, Chile has experienced challenges with diseases (see details in section 4.5). With growing volumes and biological challenges, the government has initiated stricter regulation and control on the sector's environment impact by closing off areas in the South (mainly in the Magallanes region). However, farmers with licenses granted before the closure can continue operations.

Scotland's North and East coast restricted from farming

In Scotland, farms are based in the West and Northwest coasts, as the Scottish Planning Policy restricts salmon farming in the North and East coasts. These restrictions are mainly intended to limit the risk of genetic introgression. The length of coastline available for farming is similar to that of Iceland's, but Scotland produces ~4x more than Iceland due to a higher MAB.

The Faroe Islands' coastline is fully exploited

In the Faroe Islands, all environmentally suitable areas for salmon farming are exploited, with few areas set aside for farming of other products, e.g., macroalgae. Hence, growth in traditional aquaculture cannot be driven by new licenses.

4.3.2 Description of policies and license regimes in focus markets

Beyond the availability of coastlines, the licensing regimes governing farming locations is an important determinant of total production. Each of the focus markets has a distinct licensing system, with multiple governing bodies involved in allocating farming licenses. Generally, licensed production is measured either in maximum allowed biomass (MAB) or in smolt stocking threshold, see Figure 4.14. In either case, the process for approval, and the degree to which a license's capacity can be changed once issued, varies by market.

The location in which licenses are linked to differs between markets. For guidance, the following terminology is used:

TABLE 4.1: LOCATION TERMINOLOGY USED IN LICENSING DISCUSSION

Term	Description
Geographical area	One or more fjords or bodies of water in which farmers operate[91]
Production area	A specific location within a geographical area where farmers operate
Pens	Pens placed within a production area where salmon are grown out

[91] Different from the definition used in Icelandic law on fish farming.

FIGURE 4.14: HIGH-LEVEL OVERVIEW OF LICENSE REGIMES IN FOCUS MARKETS

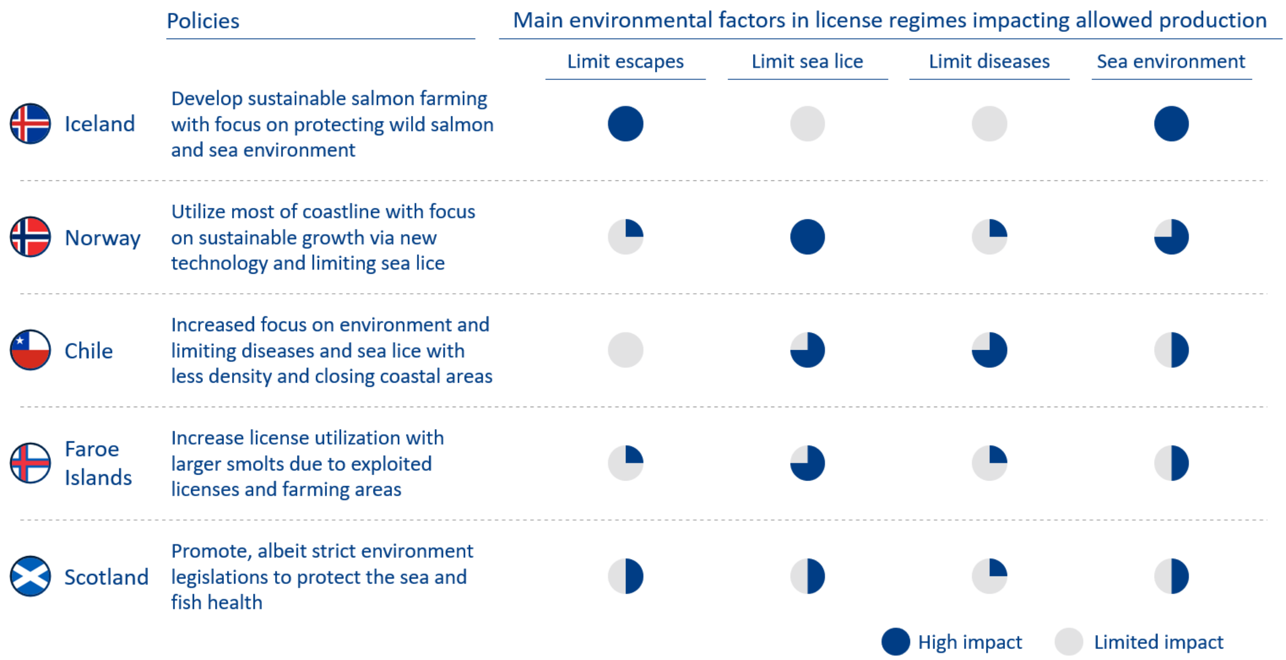
License based on maximum biomass in a geographical area/fjord	✓	✓	✗	✗	✗
License based on maximum biomass in a production area	✗	✓	✗	✓	✗
License based on number of smolts in production area / stocking density	✗	✗	✓	✗	✓
Increased or new biomass offered if production compliant to env. standard	✗	✓	✓	✓	✓
Development licenses or green licenses offered or have been offered	✗	✓	✗	✗	✓
Licenses auctioned or to be auctioned	✓	✓	✗	✗	✓

✓ Yes ✗ No

Policies differ in focus markets and are reflected in license regimes

Policies across focus markets show different ambitions and limitations which are reflected in license regimes. They consider environmental factors which impact maximum allowed biomass or smolt stocking thresholds, determining the possibility of new licenses and increased biomass/smolts. In all markets, however, there are production restrictions which aim to limit impact on the environment and fish welfare.

FIGURE4.15: POLICIES AND ENVIRONMENTAL FACTORS IN LICENSE REGIMES IMPACTING MAXIMUM ALLOWED PRODUCTION[92]



Beyond limits imposed by carrying capacity, Iceland and Scotland set additional restrictions with the objective of limiting the impact of escapes on wildlife and sea environments. In Norway and the Faroe Islands, policies on sea lice are the determining factor over a farmers' maximum allowed production. In addition to sea lice levels, Chile also considers the use of antibiotics, mortality, and other environmental factors to decide whether a farmer can increase or should decrease production volume. Different policy focuses are largely driven by previous challenges experienced in each country. The impact of traditional aquaculture on the environment, and surveillance of operations is further analyzed in section 4.5.

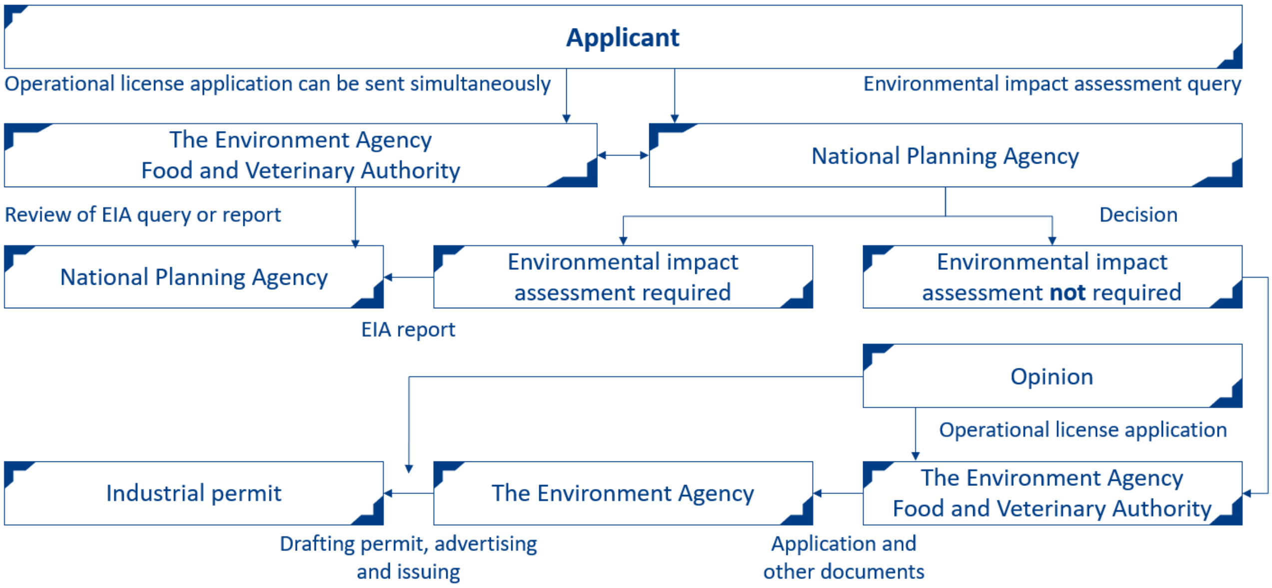
Iceland's farming licenses are based on fjord MAB and fertile salmon limit

License application process in Iceland requires consultation with two authorities

Salmon farming companies operating in Iceland need two types of licenses to obtain a right to farm salmon: an industrial license from the Environment Agency, and a production license from the Food and Veterinary Authority.

[92] Expert interviews, BCG analysis

FIGURE 4.16: THE APPLICATION PROCESS IN ICELAND AND ADMINISTRATIVE BODIES INVOLVED[93]



All active licenses have been granted based on applications submitted before 2019. The processing time from application submission until the point that the license is granted has historically taken up to 8 years. This has been largely due to provisions on the maximum carrying capacity and risk assessments not being implemented before farmers applied for licenses. Today, licenses are to be auctioned in fjords where the carrying capacity and risk assessment have already been conducted, likely reducing application processing times.

New decisions on license allocations in auctions are to be made on the basis for five main criteria: 1) Price; 2) Experience in fish farming; 3) Economic viability; 4) Measures related to previous and expected operations, considering environmental impact; and 5) Pioneers in areas where relevant, e.g., in fjords where companies have been farming fish species for a longer time.[94] That said, no new licenses have been granted based on the amended legislation.[95]

Applicants who submitted adequate information for a planned project to the Planning Agency before the amendments, including a finalized environmental impact assessment or information on how the environmental impact assessment will be conducted, are not subject the new legislation. Some license applications submitted in 2019 are still being reviewed by the Food and Veterinary Agency.

Licenses are granted for 16 years, and scan be renewed thereafter, so far, all renewals have been approved.

[93] Interviews, Environment Agency, National Planning Agency, Icelandic aquaculture legislations and regulations, BCG analysis

[94] Regulation on aquaculture fish farming no 588/2020

[95] Regulation on aquaculture fish farming no 540/2020, the Food and Veterinary Authority

Licenses granted with a maximum allowed biomass within a fjord's carrying capacity and biomass of fertile salmon within limits of risk assessment

Production licenses are granted with a specified maximum allowed biomass (MAB) for production of all species in a specific fjord. Combined biomass in a fjord is within the limits of a fjord's maximum carrying capacity. The Marine and Freshwater Research Institute (MFRI) assesses and determines a fjord's maximum carrying capacity with the objective of limiting impact on the environment, with particular attention to seabed conditions and oxygen levels.

The MFRI conducts a risk assessment considering the likelihood of farmed salmon blending genetically with wild salmon. Therefore, the risk assessment limits the biomass of fertile salmon only, as sterile salmon cannot reproduce with wild salmon. To conduct the analysis, the MFRI monitors salmon rivers to assess how many farmed salmon escape with cameras in selected rivers, sampling, and reports from anglers. It further consolidates data from production areas, where farmers must report any escapes that occur. These are combined to estimate the number of escapees, which is used to calculate the risk of genetic introgression of farmed and wild salmon. The intrusion level indicates the likelihood of genetic introgression (also referred to as genetic mixing), i.e., higher intrusion correlates with higher risk. The MAB cannot be increased if the intrusion level is above 4%.[96] The MAB of fertile salmon is thus often lower than the maximum carrying capacity of the fjord. Farmers are able to produce fertile salmon based on what is determined in the licenses within the limits decided in this risk assessment. In addition to this, the maximum number of smolts in each production area must not be higher than 200k.

TAFLA 4.1: DESCRIPTION OF CARRYING CAPACITY AND RISK ASSESSMENT

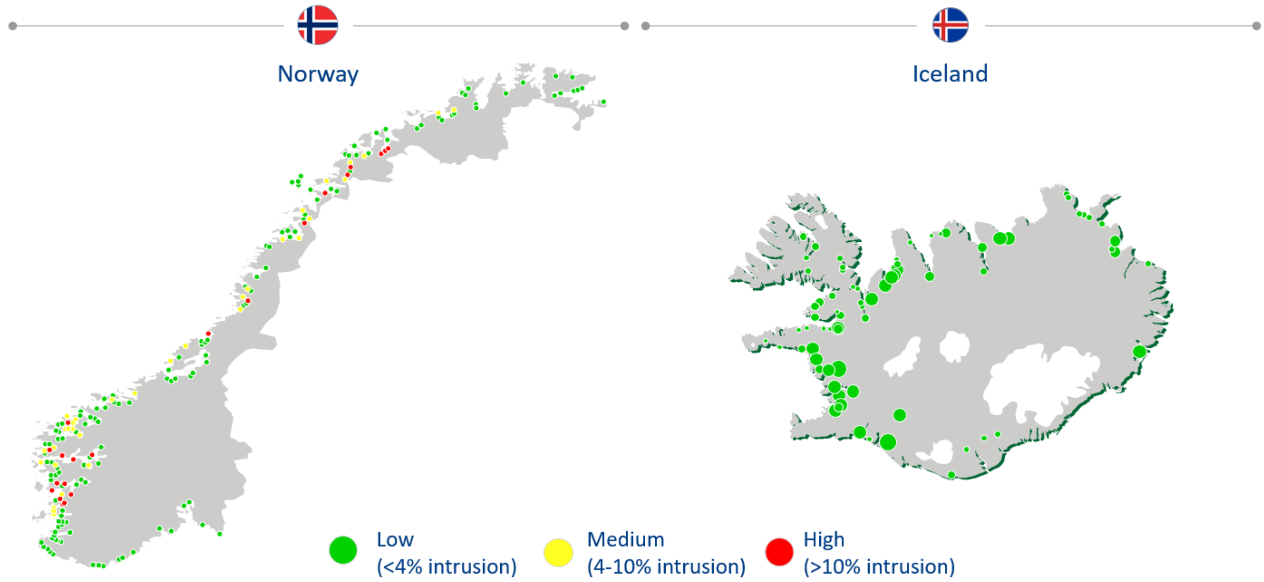
Term	Description
Carrying capacity	The Marine and Freshwater Research Institute (MFRI) assesses the capacity of a body of water to receive additional organic load without causing detrimental impact on its ecosystem and continues to fulfil set environmental standards.
Risk assessment	The MRFI also carries out a risk assessment of genetic mixing, which estimates the amount of fertile farmed salmon that escape and can be expected to enter rivers where wild salmon populations are found and the amount of genetic mixing that is to be expected, accounting for countermeasures, so that it may not endanger the genes of wild salmon stocks.

Iceland with lower intrusion levels than Norway, less risk of genetic introgression

As described above, Norway utilizes most of its coastline and has fewer restrictions on volume in fjords and fewer conservation areas compared to Iceland. Norway also gathers data on farmed salmon escapees and potential genetic mixing with wild salmon. Figure 4.17 shows this data from 2021 in Iceland and Norway. In Norway intrusion levels were above 10% in ~20 rivers, above the Norwegian Martine Institute's recommendation.

[96] The Marine and Freshwater Research Institute (MFRI)

FIGURE 4.17: MEASURED INTRUSION LEVELS IN NORWAY (2019) AND ICELAND (2021)[97]



Today, the intrusion level in all salmon rivers in Iceland is measured below 4%, whereas Norway had levels below 4% in the majority of rivers in 2019. This likely due to Iceland having a lower harvest per coastline km than Norway, resulting from overall lower volumes, Iceland's risk assessment scheme and lower MAB in fjords. When considering intrusion, there has been skepticism around the validity of rates and number of escapees. As rates are difficult to measure, it is possible that intrusion in one or both of these markets is higher than the data suggests. As smolts or young salmon are considered more likely to escape, mitigative actions could include tagging or clipping the smolts to better identify escapees by people or cameras. Escaped smolts or young farmed salmon can closely resemble wild salmon, and without tagging often requires DNA tests to differentiate them.

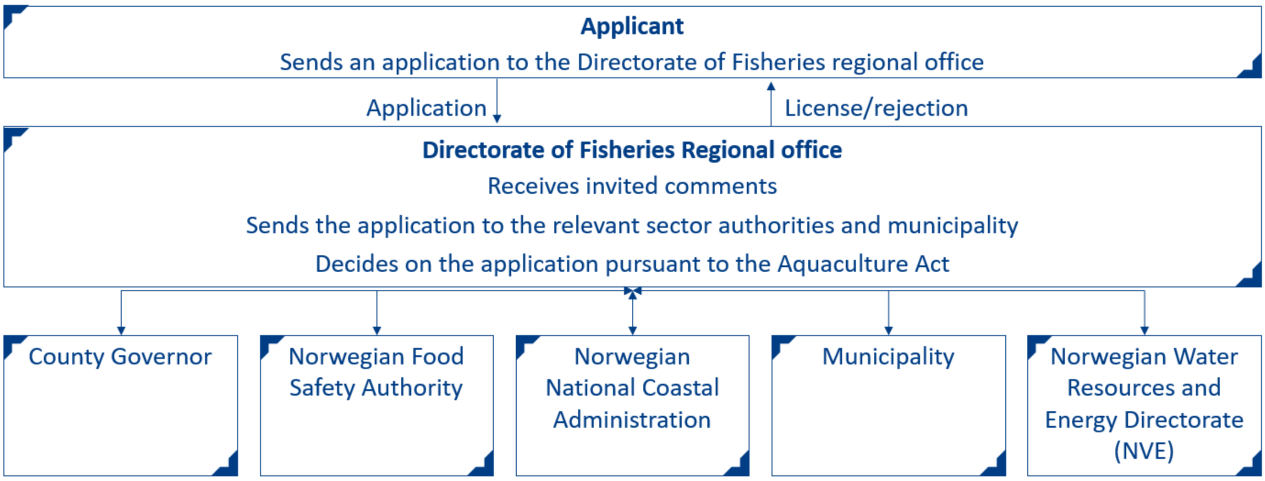
Norway farming licenses are based on MAB

License applications are sent to one administrative body in Norway

In Norway, operating licenses for salmon farming must be obtained through an auction process. In addition, production area approval is needed before commencing operations. License applications are submitted to the Directorate of Fisheries, who sends them to relevant bodies before a decision is made. The Norwegian Ministry of Trade, Industry and Fisheries awards the licenses. The production area must further be approved by the relevant county and municipality.

[97] Rapport fra vitenskapelig råd for lakseforvaltning: Status for norske laksebestander in 2020, The Marine and Freshwater Institute in Iceland, BCG analysis

FIGURE 4.18: THE APPLICATION PROCESS IN NORWAY AND ADMINISTRATIVE BODIES INVOLVED[98]



When licenses are granted, a farmer owns the license indefinitely and has the right to sell it on the open market.

Licensed MAB is granted based on a traffic light system

Norway uses a "traffic light system" to determine the MAB on existing and new licenses. The Norwegian coast is divided into 13 geographical areas of production. Every second year, the government ranks each geographical area based on scientific modelling of currents and temperature by the Norwegian Marine Research Institute. A model for sea lice pressure is consulted based on mandatory weekly reporting by farmers.

A green light allows for an increase in the MAB by 6%, while a yellow light allows for no change, and a red light leads to a requirement to decrease the MAB by 6% within the following two years.[99]

[98] Fiskeridirektoratet, Expert interviews, BCG analysis

[99] Fiskeridirektoratet, Norwegian legislations on aquaculture, BCG analysis

FIGURE 4.19: NON-FINAL TRAFFIC LIGHT EVALUATION AND THE 13 GEOGRAPHICAL AREAS IN NORWAY 2021[100]

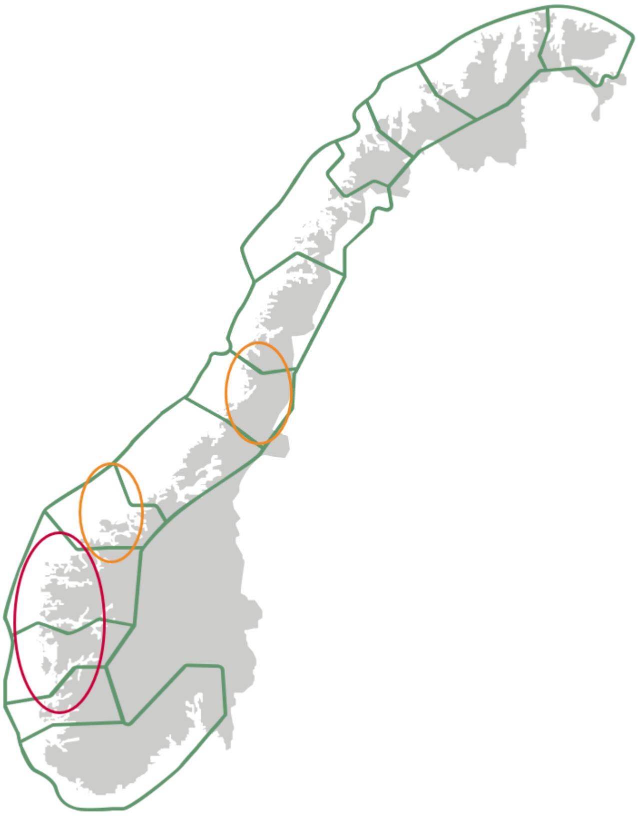


Figure 4.19 illustrates the non-final assessment from 2021, with the 13 assessed geographical areas marked with green boxes. The red- and yellow-scored regions are identified by circular indications over the production areas. In this assessment, there are eight green areas, two yellow areas and three red areas. Farmers in the green areas would be able to increase biomass by 6%, whereas farmers in the red areas would have to decrease production by 6% in the next two years. In 2022, the average license MAB increased from 780 tons to 885 tons. The traffic light system has been used to indicate how many new licenses will be auctioned and the MAB per license.

Additional biomass growth available with compliance to stricter environmental standards

Farmers are also offered additional biomass of 6% if the following conditions are met, regardless of the general situation in the geographical area:

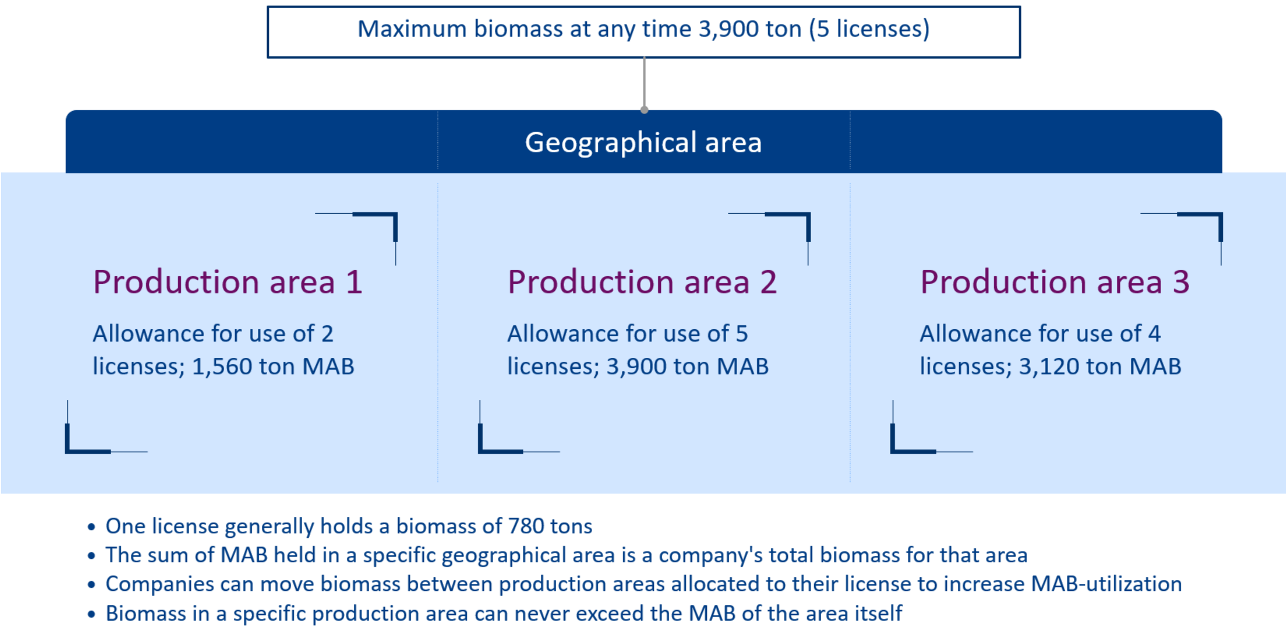
1. Over the past two years, female adult sea lice per fish have been always kept below 0.1 in the period between April 1 to September 30; and
2. There has been a maximum of one sea lice treatment during the last production cycle.

[100] Natural Earth Country boundaries without large lakes and Natural Earth States and Provinces boundaries without large lakes, Kepler Cheuvreux, Fiskeridirektoratet, BCG analysis

Licenses in Norway are based on combined MAB and can be used in different geographical areas

Production licenses are based on a maximum allowed biomass (MAB), defined as the maximum volume of salmon a company can hold at sea at any given time. One license allows a MAB of 780 tons on average. The MAB is higher in the counties Troms and Finnmark at ~945 tons on average, due to colder sea temperature and thus slower growth in sea. If a company has more than one license, they hold the sum of their licensed MABs which can be distributed across different production and geographical areas. However, each production area cannot exceed the site-specific MAB based on the environmental assessment. Generally, the MAB from one license can be split across four production areas within a defined geographical area. This flexibility allows farmers to optimize their use of MAB across production areas, even if located in another geographical area, to account for the fluctuations in volumes during the production cycle. For example, when smolts are first stocked in pens, the total biomass within a production area is at its lowest and far from the maximum carrying capacity of the production area. The flexibility in Norway allows farmers, while smolts are maturing, to increase the biomass in another production area, as long as the combined biomass in all areas is within the licensed MAB and production area MAB.

FIGURE 4.20: EXAMPLE OF LICENSE AWARDED TO A COMPANY IN NORWAY



Green licenses were offered in 2013 to stimulate innovation of greener farming

In 2013, the Norwegian government offered 45 new salmon farming green licenses with ~780 MAB each based on a strict environmental condition for sea lice, escape risk and other environmental factors. This was the first major offering in many years and as such increased motivation for farmers to grow.

The licenses were offered in three different groups. In group A, 20 licenses were sold in Norway's two northern most counties, Troms and Finnmark, at a price of 10m NOK per license. The 15 licenses in group B were awarded in a closed auction, and 10 group C licenses were awarded at 10m NOK per license (1/5 of the market price at the time).

FIGURE 4.21: OVERVIEW OF GREEN LICENSES WITH CONDITIONS AND PRICE[101]

License	Number of licenses offered	Required impact of new farming methods	Price
Group A and B	• **20 licenses** offered to farmers operating in Troms and Finnmark (Group A) and 15 offered in closed auction (Group B) • **MAB of green licenses to be redeemed** simultaneously with previously granted licenses	1 Reduce number of escapees 2 Fewer than **0.25 adult female lice** per salmon in a production area 3 Limit of three sea lice treatments per cycle	• **10m NOK per license** in Group A • **Auctioned** in Group B
Group C	• 10 licenses • An applicant **does not have to redeem** one of its previously granted licenses	1 Fewer **than 0.1 adult female lice** per salmon in a production area 2 Limit of three sea lice treatments per cycle 3 **Knowledge and experience with new solutions shared with industry**	• **10m NOK** per license in Group C equal to 1/5 of market price in 2013

Development licenses granted to incentivize investment in technological development

To further incentivize investment in new technologies, free development licenses were available from 2015 to 2017 for farmers planning on developing new farming practices. This meant that farmers could save 100-200m NOK, which was the price for auctioned licenses at the time. The government's objective was to incentive farmers to find new solutions to overcome the biological and environmental challenges facing the industry. In return, the farmers would take on investment risk for testing out the new innovations or concepts. The licenses were granted for up to 25 years, and if a concept was successful, the license could be changed to a commercial license (the role of the development licenses is discussed further in Chapter 6).[102]

Farming licenses in Chile are based on smolt stocking thresholds

Two licenses are required in Chile to farm salmon

Two licenses are required to farm salmon in Chile:[103]

1) License to operate an aquaculture facility administered by the Undersecretaries of Fisheries and Aquaculture and issued by the Ministry of Economy; and
2) License to use national sea areas for aquaculture production administered by the Undersecretaries for Armed Forces and issued by Ministry of National Defense.

An application must describe the proposed operations, including a plan for compliance with environmental and other applicable regulations. In addition to the above, farmers must acquire the consent of adjacent indigenous communities.

[101] Fiskeridirektoratet

[102] Fiskeridirektoratet

[103] Sernapesca, the Food and Veterinary Authority in Chile

After April 2010, licenses are awarded for 25 years with the option to extend in 25-year increments. Before April 2010, licenses could be obtained indefinitely. Once operations have begun, license holders are not permitted to terminate or suspend operations for a period longer than two consecutive years and are required to commence operations within one year of acquiring a license. License holders must also maintain minimum operational levels of no less than 5% of the annual production stipulated in the RCA (Environmental Qualification Resolution), with some exceptions.

License holders must pay annual license fees to the Chilean government and can sell or rent their licenses. Currently, no new licenses are being granted in three of the 16 administration regions due to high levels of concentration.

Licenses are based on maximum smolts stocked in pens

Licenses are granted based on a maximum smolts stocked in pens within a specific geographic area. From January 2021, all producers have the option to increase smolt stocking based on a combined score including fish health parameters, losses, Caligus treatments (a type of sea lice) and antibiotic use. The individual company's performance on the parameters in the previous period will determine the size of potential increase in the next smolt stocking. A positive assessment will result in an increase of 9%, 6% or 3%, while a negative assessment will result in a decrease of -3%, -6% or -9%.[104]

For example, if antibiotic usage is below 300 g/ton, mortality is less than 10% and the indicator related to treatments against Caligus is below 50%, the model will grant farmers the option to grow by 6% in the next stocking.

Scotland licenses are based on the MAB per production area

Operation license and site approval needed from 4 governing bodies

In Scotland, 4 different site approvals are required: a Planning Permission from the local Planning Authority, a Marine license from Marine Scotland, an environmental license from the Scottish Environment Protection Agency (SEPA) and an Aquaculture Production Business authorization from Marine Scotland. Additionally, as UK territorial waters are Crown Estate property, an operator must apply for a lease from the Crown Estate Commission and pay rent to install and operate a farm on the seabed. Rent payment is per kilo of harvested fish. A Crown Estate lease is generally granted for a 25-year period and is dependent on securing planning permissions. The licenses are not auctioned as in Norway.[105]

The application process is, to an extent, similar to the process in Iceland, where the local Planning Authority consults with other governmental bodies to decides whether a farm can operate the proposed area and whether an environmental impact assessment must be conducted.

Planning permissions for new sites are expected to take around 6 months and applications for environmental licenses around 4 months. An Environmental Impact Assessment (hereafter referred to as EIA) must also be conducted. That said, both processes can take considerably longer. To increase

[104] Sernapesca, the Food and Veterinary Authority in Chile

[105] Scottish Government, Expert interviews

production, the most cost- and time-effective option is to expand already-existing facilities, provided the environment is suitable.[106]

Licenses are based on maximum MAB per production area

Licenses are based on MAB per production area, which is determined based on an assessment of environmental impact, capacity of the seabed and the local marine environment. The MABs are not uniform and vary depending on site characteristics and location. As the MAB is dependent on location, it cannot be moved between production areas as with the total MAB in Norway.

In the event of non-compliance with environmental standards, the MAB can be decreased and potentially revoked in cases of significant and long-term non-compliance.

A new regulatory framework came into effect in 2019. This involved using more precise modeling methods, setting new spatial restrictions on the size of the genetic introgression impact zone around farms, and improving environmental monitoring. The new criteria, a more accurate model, and improved monitoring have made it possible to approve larger farms than would previously have been possible.

Licenses in the Faroe Islands are based on stocking density limitations

Operation license and site approval needed from 4 governing bodies

Fish farming companies must obtain authorizations from Heilsufrøðiliga Starvsstovan (The Faroese Food and Veterinary Authority) to operate an aquaculture site. Once this is received, a license to conduct fish farming activity can be issued by the Ministry of Foreign Affairs and Trade. Licenses are available for a duration of 12 years, and renewable for an additional 12 years. In 2018, a new category of development licenses was introduced to encourage investment in new fish farming technologies.

If a decision is made to award new licenses, beyond the cap of 20 today, licenses are to be granted through an auction.[107]

Licenses are based on maximum smolt stocking with limits on total licenses and foreign ownership

Similar to the license regime in Chile, licenses are granted for a specific geographical area with a threshold of smolts stocked in each production area specified by the license. The number of smolts is further regulated by a maximum density allowed in the pens. Density limitations are calculated based on the pen's size, considering only the first 15 meters below the sea surface. A system referred to as "klippum" determines whether the maximum smolt stocking should be decreased. Each "klipp" represents a repair made or an instance where the number of adult female sea lice is above 1.5 per fish. If a farmers' "klipps" are above 16, the number of smolts used must be decreased.[108]

The number of seawater licenses available in the Faroe Islands is strictly limited to 20. As production is not regulated through limits on MAB, the MAB per salmon farm varies between 1,200 ton and 5,800 ton per year per license, depending on site characteristics and the geographic location. The Food and

[106] Scottish Government, Expert interviews

[107] The Faroese Food and Veterinary Authority

[108] Faroese legislation on aquaculture, the Faroese Food and Veterinary Authority

Veterinary Authority monitors health statuses through all stages of production, based both on monthly health and biomass reports as well as on-site inspections.

In the Faroe Islands, farming companies must abide to a limit of 20% for direct or indirect foreign ownership. Recent amendments to the Aquaculture Act state that a fish farming company cannot hold more than 50% of the total number of licenses in a given period. However, this does not apply to existing licenses held by companies today, even if non-compliant to the new ownership restrictions.[109]

Licenses may be withdrawn in cases of material breach of conditions set out in the individual license agreement or with regards to aquaculture or environmental legislation.

4.3.3 Sub-conclusion

As highlighted in Chapter 2, aquaculture can have both positive and negative effects, and each focus market approaches limitation and growth in a different way. Of the focus markets, Iceland is the country with the highest proportion of coastline conserved, and licensing limitations focus on the potential negative impact to wild salmon populations through escapes and changed sea environments. Scotland similarly conserves large swathes of coastline, but licensing regulation also takes into account sea lice and diseases. Some other markets, such as Norway, Chile, and the Faroe Islands, allow more of their coastlines to be utilized for aquaculture. These markets also center their legislation around fish health, such as sea lice and diseases, with a relatively smaller focus on escapes. The varying approach and focus of each company will have an impact on both the growth of the industry and its impact on the environment; thus, a balance must be sought between the two.

4.4 Taxes, fees, and distribution regimes

Tax and fee regimes, including financial resource allocation between central government and municipalities, differ between focus markets, reflecting each market's policies and objectives. These regimes impact farmers' competitive advantage, government surveillance and administrational efficiency, municipalities' financial resources to invest in infrastructure, and society.

This section describes levies applicable to salmon farmers in focus markets as well as general taxes applicable to corporate entities i.e., corporate income tax. The key analyses conducted include a comparison of the different regimes, their respective impacts on farmers' competitive positions, and how payments are allocated between the central government and municipalities.

4.4.1 Taxes and fees applicable in focus markets

Corporate income tax

Farmers are subject to general corporate income taxes across all focus markets, ranging from 18% (Faroe Islands) to 27% (Chile), which usually accounts for the largest share of taxes or levies paid. The effective tax rate after deductions also differs in markets based on national tax legislations.

[109] Faroese legislation on aquaculture, the Faroese Food and Veterinary Authority

FIGURE 4.22: OVERVIEW OF CORPORATE INCOME TAX RATES 2022[110]

	Chile	Scotland	Norway	Iceland	Faroe Islands
Corporate income tax	27%	19% (25% in 2023)	22%	20%	18%

Chile has the highest corporate income tax rate at 27% when comparing the focus markets. Small- and medium sized farmers with an average gross revenue below 2.5m EUR over the last three years may opt for a scheme referred to as the Pro Pyme regime,[111] which decreases the corporate tax rate to 25%. Scotland's corporate income tax rate is at 18% and is expected to increase to 25% from April 1, 2023, resulting in Chile and Scotland having the highest corporate income tax rates of all markets.

Other corporate taxes and fees are excluded from this analysis

Farmers in all markets are also subject to other taxes, including pension tax and other labor market related fees. Whether certain taxes apply and how much they impact a farmer's competitive position depends on each operation e.g., customs based on import levels, oil and carbon fees depending on usage, and other fees such as real estate tax provided that a farmer owns the property. To enable a like-for-like comparison, these taxes are not considered in the analyses in this section unless specifically stated.

Special taxes and fees are applicable to traditional aquaculture operations and farmers

Iceland, the Faroe Islands and Norway have implemented similar special taxes and fees applicable to traditional farmers, whereby a fee is charges based on a farmer's harvest volume, see Figure 4.23.[112] The fee is referred to as the production fee in Norway and Faroe Islands, and as resource fee in Iceland (hereafter referred to as production fee in this report for simplicity). Iceland has, moreover, implemented a fixed fee based on the license's MAB and a harbor fee based on harvest volume. Norway has a different structure in which farmers are subject to research and export fees in addition to a municipal real estate tax on sea operation.

[110] Sernapesca, Icelandic Act on corporate income tax, Norwegian act on corporate income tax, Faroese Act on taxes (skattalógin)

[111] Few other conditions must be fulfilled, e.g., that direct owners must be resident individuals or foreign resident entities and hence subject to final taxation

[112] In Chile, all companies including farmers must pay an annual tax based on each hectare where operations are granted, incl. concessions. In 2022, the fee was 2 Chilean Monthly Tax Unit (MTU), or approximately 143 USD for each hectare where concession is granted. Farmers must further pay municipal tax ranging between 0.25% and 0.5% calculated over the entity's tax equity with a minimum annual tax of ~72 USD (1 MTU). In Scotland, the Crown Estate Scotland manages public property in Scotland and companies with permission to produce salmon in public locations must pay a fee/rental cost reflecting the level and value of the production. The size of the fee is normally revised every five years and was set at 2.25 pence per kilo of fish slaughtered January 1, 2017. The fee is not distributed to local authorities but used for marketing and research projects related to aquaculture.

FIGURE 4.23: TYPE OF LEVIES APPLICABLE IN ICELAND, NORWAY, AND FAROE ISLANDS[113]

Type of levies implemented	Iceland	Norway	Faroe Islands	Scotland	Chile
Environmental fee	✓	÷	÷	✓	÷
Production / Resource fee	✓	✓	✓	÷	÷
Harbor fee	✓	÷	÷	÷	÷
Research and export fee	÷	✓	÷	✓	÷
Resource rent tax	÷	*Planned 2023*	÷	÷	✓
Municipal real estate tax for production installation	÷	✓	÷	÷	✓

÷ Levies not implemented ✓ Levies implemented

Different fee structures apply in Chile and Scotland. In Chile, no special for traditional aquaculture farmers has been implemented. However, farmers as well as land-based companies must pay an annual tax based on hectare usage for concessions. In 2022, the fee was 2 Chilean Monthly Tax Units (MTU), or approximately 143 USD for each hectare where concession is granted. Additionally, farmers must pay municipal taxes with a minimum annual tax of ~72 USD (1 MTU).[114]

Scotland has implemented a fee specifically applied to farmers, often referred to as a rental fee. The Crown Estate Scotland manages public property in Scotland, and companies with permission to produce salmon in public locations must pay a fee/rental cost reflecting the level and value of the production. The size of the fee is normally revised every five years and was set to 2.25 pence/kg (~0.03 EUR/kg) on January 1, 2017 for all harvested fish. The Crown Estate is currently reviewing proposals to align rental payments to company turnovers, and rental costs are therefore forecasted to increase. The fee is not distributed to local authorities but used for marketing and research purposes related to aquaculture. Farmers must also pay an annual fee for an environmental license, which can cost more than 15k GBP (~17k EUR). If a production area is not used for 4 consecutive years, farmers must pay an additional 1k GBP (1.1k EUR) and a further 2k GBP (2.3k EUR) if an area is dormant for 2 more years.[115]

The following sections compare the different tax and fee regimes in Iceland, Norway, and the Faroe Islands.

[113] National legislations

[114] Sernapesca

[115] Scottish Government

4.4.2 Iceland's production/resource fee is based on the Faroe Island fee

Traditional farmers are subject to production/resource, environmental, and harbor fees

In addition to income tax and other taxes applicable to companies in Iceland, traditional farmers are subject to three levies, see Figure 4.24.

FIGURE 4.24: LEVIES APPLICABLE TO FARMERS IN ICELAND AND FEE PAID/KG IN 2021[116]

Special levies	Objective	Calculation basis	Fee/kg in 2021[1]
Production fee/ Resource fee	Combination of a resource fee i.e., a payment for the use of limited available sea area in fjords available for farming, and a cost recovery fee to cover administrative cost	Harvest volume (HOG) multiplied with a variable fee rate[2] and average market price[3]	0.058 EUR
Environmental fee	Fixed fee to fund projects which limit environmental impact e.g., carrying capacity and risk assessments and monitoring	20 Special Drawing Right (SDR)[4] per ton based on license MAB	0.029 EUR
Harbor fee	Fee paid to the relevant municipality to cover cost of e.g., building, operating, maintaining and renovating mooring structures and port	Harvest volume (HOG) multiplied with 0,7% and average market price[3]	0.041 EUR
Total payment per kg			**0.128 EUR**

1. Fee rate based on production of fertile salmon; 2. The fee is implemented incrementally with 3/7 of the total fee rate of 3.5% to be paid in 2021 until reaching 7/7 in 2026. The fee rate (%) was previously based on average salmon price in August – October (from 0.5 %– 3.5%), changed in 2023 to be based on full year average price; 3. Average salmon price August – October at 5.8 EUR/kg according to Fish Pool Index; 4. 1.23 EUR per Special Drawing Right (SDR) (which are monetary reserve currencies created by the International Monetary Fund)
Note: 0.84 kg/HOG per harvested kg salmon

Production/resource fee incrementally implemented until '26, increasing from 0.058 to 0.203 EUR/kg

The production/resource fee (hereafter referred to as "production fee") is a combination of a resource fee and cost recovery fee. Farming companies must pay for the use of the sea area in fjords and to cover administrative costs. Two thirds of the fee is allocated to the government and one third to the Aquaculture Fund (Fiskeldissjóður). This fund is further distributed to municipalities to subsidize local investment in relevant infrastructure. Municipalities submit a grant application to the fund describing a project for which they are requesting funding. The Aquaculture Fund assesses the application and thereafter distributes subsidies.[117] It has distributed subsidies in 2021 and 2022. In 2022, nine projects

[116] Act no. 61/2003 on harbors, Act no. 89/2019 on production fee in fish farming at sea and the fish farming fund, Act no. 71/2008 on fish farming

[117] Act no. 89/2019 on production fee in fish farming at sea and the fish farming fund, Regulation no. 874/2019 on the Environment Fund for traditional farming, Act no. 71/2008 on Aquaculture, Stjórnarráð Íslands

were funded in six municipalities, totaling 185m ISK (~1.3m EUR),[118] up from 105m ISK (~745k EUR) in 2021.[119]

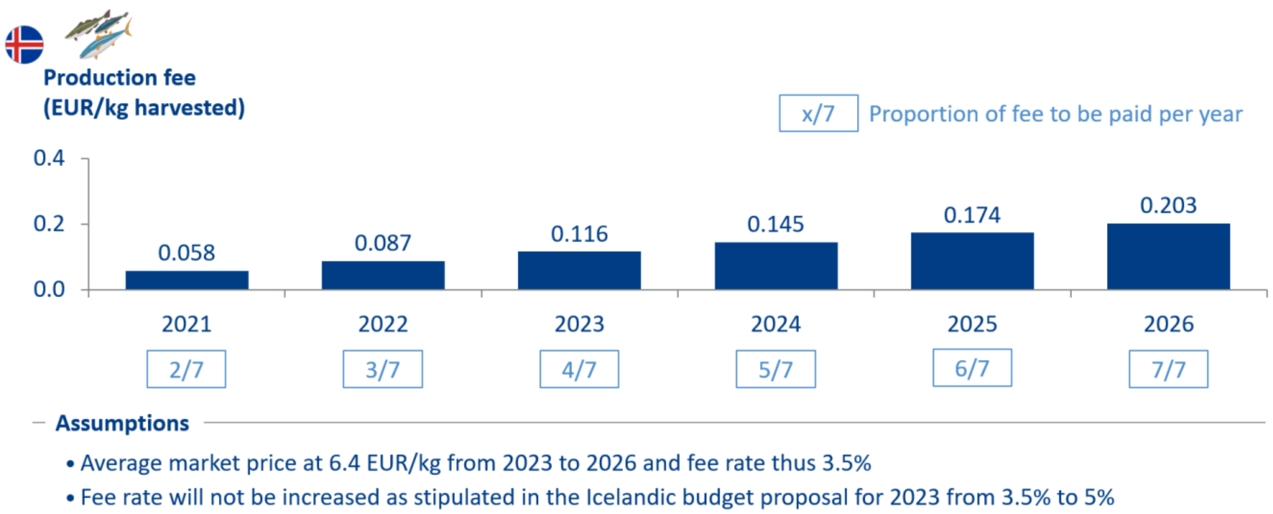
The fee is based on the total weight of salmon harvested (HOG) multiplied by the fee rate. The fee varies and depends on the average international market price, where a higher price results in a higher fee % and vice versa. The price used to be based on average prices according to Fish Pool Index from August to October, but was recently changed to reflect full-year average prices.

TABLE 4.2: AVERAGE MARKET PRICE FROM AUGUST TO OCTOBER AND THE ASSOCIATED FEE RATE IN ICELAND

Average market price	Fee rate
Above 4.8 EUR/kg	3.5%
Between 4.3 – 4.8 EUR/kg	2%
4.3 EUR/kg or below	0.5%

The production fee has been in effective since January 1, 2020, and will be implemented incrementally. In 2020, 1/7 of the proportion of the base should be paid, 2/7 in 2021, 3/7 in 2022, and so on until 2026, when a full fee will be charged. The production fee would amount to 0.203 EUR/kg harvested if prices remain above 4.8 EUR/kg as they are currently.

FIGURE 4.25: IMPLEMENTATION OF PRODUCTION/RESOURCE FEE FROM 2021 TO 2026 IN ICELAND[120]



[118] Projects that received fund in 2022: Construction of water transfer tank in Bolungarvíkurkaupstaður, Renewal of water pipes in Ísafjarðarbær, Student dorms for a University, Ísafjarðarbær, Sewage works in Djúpavogur, Infection control in Súðavíkurhöfn, Development of harbor area, Tálknafjörður, Fire stations at Bíldudal, Water safety in Vesturbyggð, Construction of sidewalks, Patreksfjörður, Stjórnarráð Íslands

[119] Stjórnarráð Íslands

[120] Act no. 89/2019 on production fee in fish farming at sea and the fish farming fund

The fee is charged twice a year, each time based on a report submitted by the farmer on harvest volume. Reports are submitted before the February 15 (for the period between July 1 to December 31) and before August 15 (January 1, and June 30) each year.

Environmental fee to fund assessment of fjords' carrying capacities and the risk assessment

A company with license to farm salmon must also pay a yearly fee to the Environmental Fund amounting to 20 Special Drawing Rate (SDR)[121] for each licensed ton.[122] The fee is 50% lower per ton of infertile salmon or Rainbow trout, and 5 SDR per ton of salmon produced in closed pens. The environmental fund is independently run under the Ministry of Food. The fund's key purpose is to limit traditional farming's environmental impact and it finances projects with that aim. This includes the Marine and Freshwater Research Institute's assessment of fjord carrying capacities and the risk assessment of genetic introgression.

Harbor fee up to a rate of 0.7%, allocated directly to municipalities based on harvest volume

The farmers are subject to a harbor fee that is used to develop harbor infrastructure. It is calculated by the total harvest volume multiplied by a rate of up to 0.7% and by the average international market price according to the Fish Pool Index. The harbor fee varies between municipalities and is paid directly to the municipality where the salmon was harvested.[123] Farmers can be further subject to an excise duty for each ton of feed transported to harbor.

Icelandic budget proposal to increase the production fee was not passed

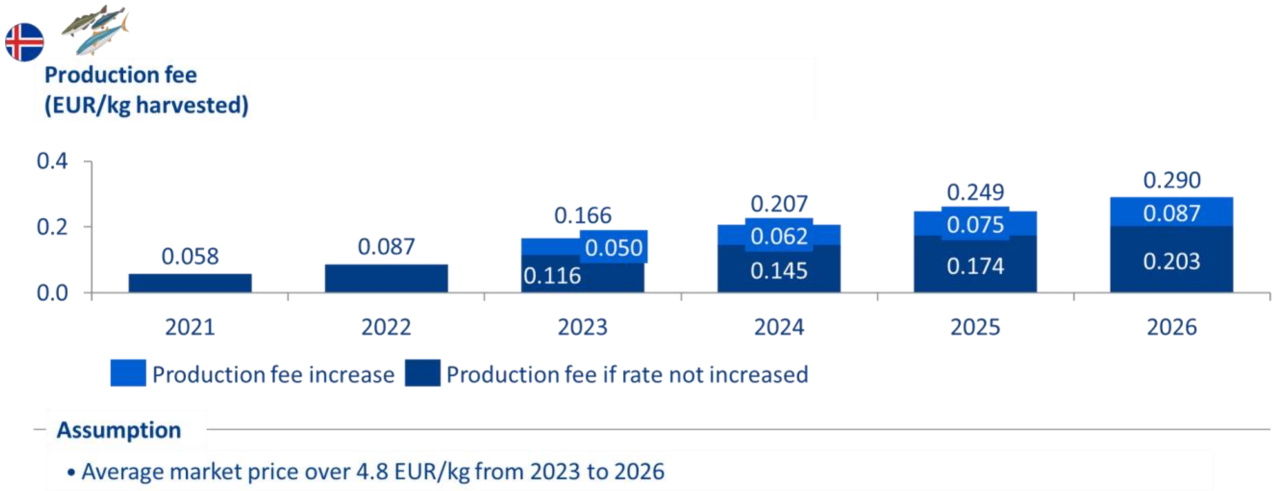
The Icelandic budget proposal for 2023 proposed an increase in the production fee from 3.5% to 5% when the average market price exceeds 4.8 EUR/kg. This change was not passed in parliament. It was also proposed that the average market price would be based on the full year average market price, instead of the average price from August–October. This change was passed. The production fee rate therefore remains unchanged for now. If, however, the rate changes would have been approved, the fee would be ~0.90 EUR higher per kg harvested, assuming the same average market price as in August–October 2021 based on the Fish Pool Index, see. Figure 4.26.

[121] Monetary reserve currencies created by the International Monetary Fund

[122] Does not apply to fish farming in freshwater or closed natural water and lower fee of 10 SDR for sterile salmon and Arctic char, Statistics Iceland, Icelandic Food and Veterinary Authority, Regulation no. 874/2019, BCG analysis

[123] The harbor fee varies between municipalities and can be found in Stjórnartíðindi, e.g., the fee for Vesturbyggð is outlined in Gjaldskrá Hafnasjóðs Vesturbyggðar no. 1287/2019

FIGURE 4.26: PRODUCTION FEE IF RATE INCREASED BASED ON THE ICELANDIC BUDGET PROPOSAL FOR 2023[124]



4.4.3 Fixed yearly production fee in Norway and resource rent tax proposed

Farmers are subject to production fee, research and export fee, and municipal real estate tax

In Norway, in addition to corporate income tax (22%), traditional farmers are subject to three levies, see Figure 4.27. In 2022 the Norwegian government proposed a new resource rent tax, as of now it is not clear if the tax will be implemented nor what the details of its structure will be.

[124] Frumvarp til fjárlaga 2023, Act no. 89/2019 on production fee in fish farming at sea and the fish farming fund

FIGURE 4.27: OVERVIEW OF SPECIAL FEES APPLICABLE TO FARMERS IN NORWAY 2021[125]

Special levies	Description	Calculation basis	Fee rate 2021[1]
Production fee	Fee allocated directly to farming municipalities and counties	Harvest volume (HOG)	0.405 NOK/kg (~0.039 EUR/kg)
Municipal real estate tax	Fee paid to municipalities for floating production installations and pens; applies in 50% of municipalities	Property value	0.2% - 0.7%
Research and export fee	Export fee (0.3%) allocated to the Seafood Council and research fee (0.3%) to the Research Organization	Export value	0.6%
Resource rent tax	*The government has proposed to implement a new resource tax subject to Parliamentary approval*		

1. Fee rate based on production of fertile salmon

Production fee lower in Norway compared to Iceland at 0.039 EUR/kg in 2022

In 2021, the government introduced a production fee of 0.405 NOK/kg (~0.039 EUR/kg) of salmon harvested (HOG). The tax will increase to 0.45NOK/kg (~0.045 EUR/kg) from January 1, 2023 and can be amended annually.[126] The production fee is collected on an annual basis by the government, and the payment is entirely allocated to municipalities and counties where the farming operations are located. The reason Norway has a low base compared to the Faroe Islands and Iceland is to limit its burden on farmers in times of low profitability.[127]

Municipal real estate tax for floating installations is 0.2%-0.7% of tax base value

Farmers may also be subject to municipal real estate tax (property tax) for floating production installations, which can vary between 0.2% and 0.7% of their value. The payment is relatively low compared to other fees.[128] Approximately half of municipalities have implemented the tax, and each municipality decides on a rate every ten years.[129]

Research (0.3%) and export fee (0.3%) to fund seafood research and marketing

Farmers are further subject to a research fee (0.3%) and an export fee (0.3%) collected by customs.[130] The research fee is directly allocated to the Norwegian Seafood Research Fund (FHF), which is a limited

[125] Norwegian Act no. 9 of April 27, 1990 with amendments, Foskrift om samordnet innkreving av avgift på fiskeeksport, Fiskedirektoratet, Interviews

[126] Fiskedirektoratet, Skatteetaten, Forskrift om særavgiften (FOR-2001-12-11-1451), Stortingets vedtak om avgift pð produksjon av fisk, Stortingsvedtak om særavgifter for 2022

[127] Fiskedirektoratet, Årsrundskriv for avgift på produksjon av fisk (Skatteetaten)

[128] Expert interview, BCG analysis

[129] Skatteetaten

[130] Norwegian Act no. 9 of April 27, 1990 with amendments, Foskrift om samordnet innkreving av avgift på fiskeeksport

company of the Norwegian Ministry of Trade, Industries and Fisheries. FHF aims to create added value for the seafood industry through industry-based research and development. The export fee is allocated to the Norwegian Seafood Council (NSC). The NSC is a public company owned by the same Ministry. It aims to increase the value of Norwegian seafood through marketing and research on market insights, development, risk management, and reputational risk management in select markets around the world. The farmers must pay an annual registration fee to the NSC of 15k NOK (~1.5k EUR).

The research and export fees are calculated based on the export value according to the average market price value in the Fish Pool Index (FOB). The fee varies according to the type of species and product category.

The government has proposed to implement a new resource ren tax (40%) effective in 2023

The Norwegian government has proposed the implementation of a new resource rent tax subject to Parliamentary approval. Initial plans were for the resource rent tax to be 40% and begin in January 2023. The resource rent tax is designed as a tax cash flow tax where profits after accounting for corporate tax and deducting certain investments, are taxed on an ongoing basis in the year in which they are earned or incurred.[131] Due to the resources tax being applied after corporate tax, the total tax payment is 51.3% of profits (rather than the marginal rate of 22%+40%, or 62%).[132] To safeguard smaller farmers from the impact of the resource rent tax, a tax-free allowance of between 4-5 kT is planned. This means that smaller farmers are not or to a lower degree impacted. Considering farmers' licensed biomass in 2021, it is estimated that 35-40% of farmers would be subject to the new resource rent tax.[133]

The tax payment is to be split evenly between the municipalities and the government and is expected to yield between 3.65 and 3.8bn NOK (~365-380m EUR) in annual revenue.[134]

The resource rent tax met strong opposition from farmers and other stakeholders including some states and municipalities. Strong reaction was also seen in the Norwegian stock exchange after the government proposed the new tax on 28 September 2022. The largest farmer's share price dropped by more than 40% after the announcement. Farmers have also announced their intentions to revoke planned purchases of new licenses and reconsider planned investments. SalMar has, for example, announced pullbacks from planned infrastructure and the acquisition of a 1,223ton MAB, valued at ~224m NOK (~23m EUR).[135] Meanwhile Mowi, Lerøy and Grieg Seafood have also released statements announcing that the proposed tax could affect their operations and future investments. It is still unclear if the

[131] Revenues are to be calculated based on market prices for salmon as determined by Nasdaq (and not the actual sales price). Fixed assets acquired before the introduction of the resource rent tax can further be deducted through the depreciation of its remaining tax values; see: Høringsnotat Grunnrenteskatt på havbruk

[132] If implemented, the corporate tax (22%) will be calculated before the resource rent tax (40%) and therefore deducted from the basis for resource rent tax. With such sequential calculation of the taxes, the basis for the resource rent tax will be lower than if taxes were calculated in parallel; see: Høringsnotat Grunnrenteskatt på havbruk.

[133] Kyst.no, BCG analysis

[134] Høringsnotat Grunnrenteskatt på havbruk

[135] Company announcements

resource rent tax will be implemented and if so, what form it will take. Since October, share prices have rebounded to some degree but remain volatile as the debate continues.

4.4.4 The Faroe Islands might change their production fee from 2023

Overview of special taxes and fees applicable to farmers in the Faroe Islands

Faroese farmers are subject to a corporate tax (18%), of which 70% is allocated to the government and 30% to municipalities where salmon farming companies operates their production facilities.[136]

Production fee in Faroe Islands is 1.5% higher than in Iceland if the market price is above 4.8 EUR/kg

Salmon farmers pay a production fee to the government based on the total weight of salmon (HOG) harvested in a month, multiplied by a fee rate (%) that varies depending on the average international market price, according to the Fish Pool Index:[137]

TABLE 4.3: AVERAGE MARKET PRICE AND ASSOCIATED FEE RATE IN THE FAROE ISLANDS

Average market price in harvest month	Fee rate
Above 36 DKK/kg (4.8 EUR)	5%
Between 32 and 36 DKK/kg (4.3–4.8 EUR)	2.5%
32 DKK/kg or below (4.3 EUR)	0.5%

The structure of the production fee as described above was implemented in 2016, but the thresholds have increased as well as the fee rate (the highest rate of 5% was previously 4.5%). According to Faroese legislation, a farmer is not subject to the production fee in cases where the authorities decide that all salmon must be harvested e.g., due to a disease outbreak which prevents sales at market prices. It is not stated in the legislation what share of the fees should be allocated to a specific Aquaculture Fund, leading to the interpretation of the provision being disputed.[138]

Information on the monthly harvest volume of salmon must be reported to the tax authorities no later than on the 15th day in the month following the harvest. If information on harvesting is submitted too late, a fine of 1,000 DKK (~135 EUR) will be added to the fee for that month. The harvesting is collected in four instalments (first day of February, May, August, and October), and this must be paid no later than on the 20th day in the relevant month.

Proposal to amend the production fee considering increased salmon prices and cost

The record high salmon prices observed in 2022, accompanied by increasing production costs, has incentivized the government to consider revising the current tax system.[139] The amendments propose

[136] The Faroe Islands' Tax Authority (TAKS), Faroese Act on aquaculture, Fish Pool Index, BCG analysis

[137] The Faroe Islands' Tax Authority (TAKS), Faroese Act on aquaculture, BCG analysis

[138] The Faroe Islands' Tax Authority (TAKS), Faroese Act on aquaculture, Løgtvingslóg nr. 64/2014 sum broytt 2015 og 2018, Skatta- og avgjaldskærunevndin – avgerðir mál nr. 21/11073, November 2, 2021

[139] iLaks.no, received 3 October 2022

increasing the number of differentiated fee rates from three to five. Furthermore, it suggests reflecting inflationary pressures in current rates. Lastly, it suggests linking the average market price threshold to reflect the average production cost for farmers to be assessed on a yearly basis. The purpose of these changes is to increase fees when profitability is high, and decrease fees when profitability is low, and costs are high. Re-evaluating the brackets on an ongoing basis serves to account for the fact that costs might increase with the outlook of more inflationary pressure in the coming years.

As a part of these amendments, the lowest threshold would be based on the average production cost for farmers in Faroe Islands. For 2023, it is proposed that 39.15 DKK/kg should be used as the lowest threshold instead of 32 DKK/kg, driven by increased cost[140].

TABLE 4.41: PROPOSED PRODUCTION FEE AMENDMENTS IN THE FAROE ISLANDS

Average market price in harvest month	Fee rate	Amendments
Above 69.15 DKK/kg (9.3 EUR)	10%	New threshold and higher rate
Between 54.15 and 69.15 DKK/kg (7.3-9.3 EUR)	7.5%	New threshold and higher rate
Between 44.15 and 54.15 DKK/kg (5.9-7.3 EUR)	5%	Lower threshold increased from 36 DKK/kg
Between 39.15 and 44.15 DKK/kg (5.2-5.9 EUR)	2.5%	Threshold increased from 32 DKK/kg and 36 DKK/kg
39.15 DKK/kg or below (5.2 EUR)	0.5%	Threshold increased from 32 DKK/kg

The proposal has been submitted to the Parliament in the Faroe Islands but has not yet been implemented.

4.4.5 Comparison of key differences in tax and fee regimes

This section compares the different tax and fee regimes in the focus markets and provides examples of different profitability levels in markets associated with different salmon prices.

In the analyses below, the average cost of 4.37 EUR/kg of produced salmon has been assumed across all countries.[141] This is because, although cost differs between companies and markets, feed is generally the largest cost component accounting for up to 50% of total operational costs.[142] Differing deductibles in countries' tax regimes have not been considered. The actual sales price accrued differs between markets and companies and will also not be considered to enable a like-for-like comparison of the taxes and fees across markets.

[140] It is unclear how the production cost is assessed, but experts assume it is an average production cost for Faroese farmers before taxes and interest

[141] MOWI 2021

[142] Kontali

Structure and basis for production fee in Iceland, Norway, and Faroe Islands

Figure 4.28 outlines the main differences between production fee structures, including proposed amendments in Iceland and the Faroe Islands.

FIGURE 4.28: COMPARISON OF PRODUCTION FEE STRUCTURES AND BASIS FOR FEE RATE IN ICELAND, NORWAY, AND THE FAROE ISLANDS[143]

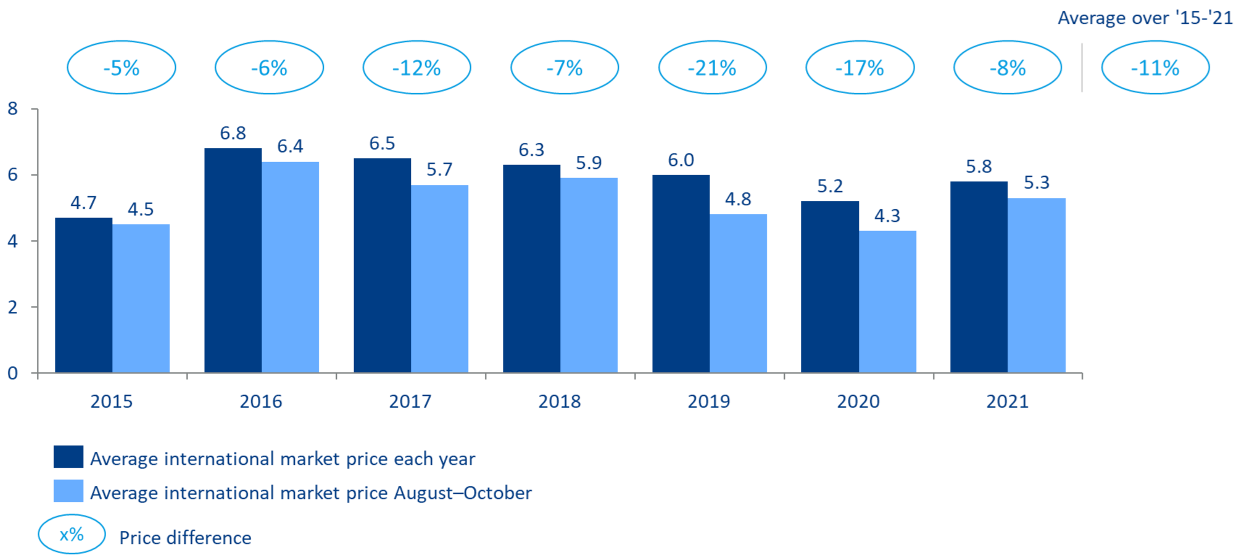
	Iceland	Norway	Faroe Islands
Fee based on volume (HOG)	Yes	Yes	Yes
Basis for price per kg	Average market price August to October	Fixed fee per kg	Avg. price in month salmon is harvested
Basis for price per kg Change since 1 February 2023	Average price in the year salmon is harvested	N/A	N/A
Fee rate if price > 5.8 EUR/kg	3.5%	N/A	5%
Proposed changes of fee rate	Price (EUR/kg) – Fee rate >4.8 – 5% *(Not approved in parliament)*	N/A	Price (EUR/kg) – Fee rate <5.2 – 0.5% 5.2-5.9 – 2.5% 5.9-7.3 – 5% 7.3-9.3 – 7.5% >9.3 – 10%
Fee payable	Two times a year	Once a year	Four times a year

Actual ■ Proposed or newly implemented amendments

The proposed financial budget in Iceland for 2023 included a proposed change to the basis for price per kg to be the market price for the full year in which the salmon was harvested, instead of only from August to October. This change was approved and was implemented in 2023. Historically, the full year average market price has been higher than between August to October see Figure 4.29. The budget also proposed increasing the fee rate from 3.5% to 5% when market price is higher than 4.8 EUR/kg. This change was not approved by the Icelandic parliament.

143 Applicable legislation in markets and proposed or newly implemented legislative amendments

FIGURE 4.29: AVERAGE PRICES AUGUST–OCTOBER COMPARED TO AVERAGE YEARLY PRICES (EUR)[144]



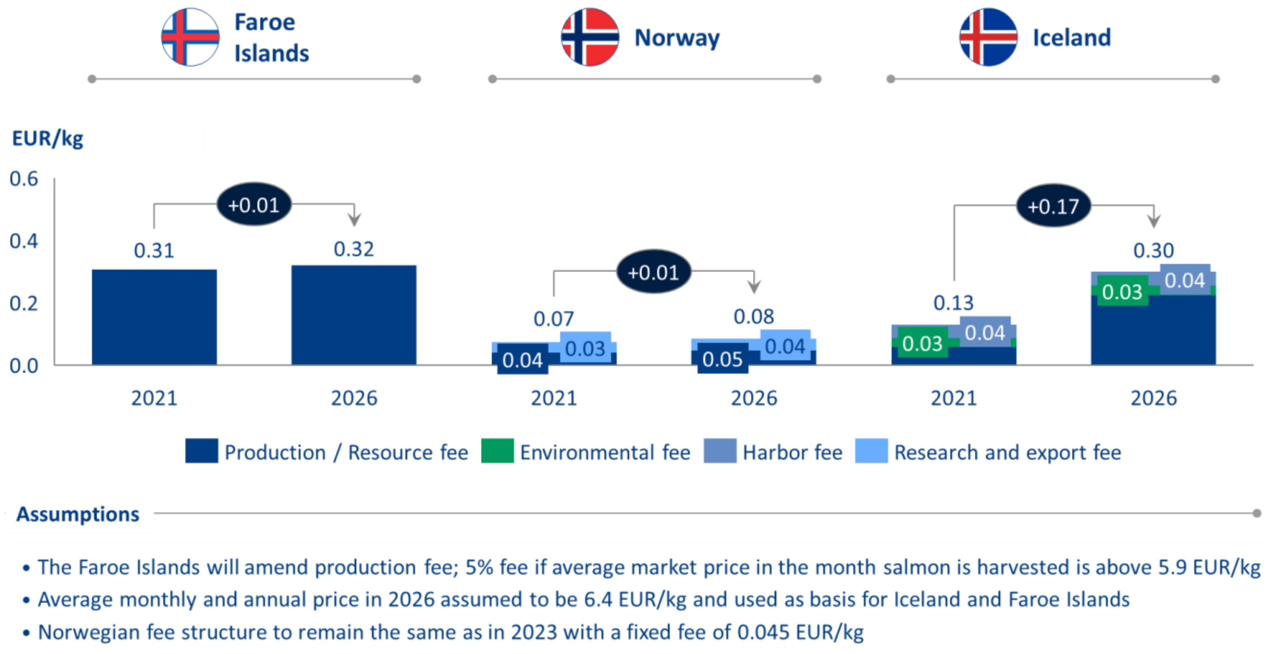
Fee per kg harvested highest in the Faroe Islands, Iceland will overtake 2026 if prices stay flat

In 2021, the fee per kilogram of harvested salmon was highest in the Faroe Islands and lowest in Norway. Although 2021 fees in Iceland were less than half of those in the Faroe Islands, Iceland's fees are expected to increase when the production fee is fully implemented and reaches 3.5% in 2026 (from 1% in 2021). Total fees in Iceland when market price is 6.4 EUR/kg[145] will still be lower than in the Faroe Islands in 2026 assuming the proposed amendments in production fee are implemented there, see Figure 4.30. If the Icelandic parliament had approved the proposed changes to the production fee (highest bracket from 3.5% to 5%) total fees in Iceland would have been highest in 2026 at a market price of 6.4 EUR/kg. Total fees would become highest in the Faroe Islands once market price went beyond 7.3 EUR/kg.

[144] Fish Pool Index

[145] Assuming salmon price of 6.4 EUR/kg based on average price from 2017 to 2022 (from January to September) according to Fish Pool Index

FIGURE 4.30: FEE PER KILOGRAM HARVESTED IN MARKETS IF PRICE IS 6.4 EUR/KG IN 2026 (EUR/KG)[146]



Currently, Norway has lowest total taxes and fees among the three markets assuming salmon price of 5.2 EUR/kg and 10 EUR/kg and Iceland has fully implemented production fee in 2026

The fees described above are based on a company's harvest volume (production/resource, environmental and harbor fee) and export value (research and export fee), whereas weight of the different corporate tax rates and the proposed resource rent tax in Norway depend on a company's profit. In Norway, the operational margins have the last 5 years (2017-2021) been between 20% and 35%.[147] As the industry in Iceland is less mature, combined aquaculture companies have only generated profit in one year since 2014 based on official financial statements.[148] However, to compare levies of taxes across countries this sub-section assumes equal costs (operational cost of 4.37 EUR/kg)[149] and prices, resulting in equal gross margins across countries.

Under these assumptions and considering two scenarios with a relatively low salmon price of 5.2 EUR/kg (lowest average yearly price in 2017-2021)[150] and a relatively high salmon price of 10 EUR/kg,[151] the total taxes and fees to be paid by farming companies is highest in Iceland assuming the production fee is fully implemented (i.e., as it will be in 2026), see Figure 4.31. The higher total fees and taxes as compared to Faroe Islands stem from a smaller corporate tax rate in Faroe Islands (18% vs.

[146] Fish Pool, MOWI industry report, BCG analysis

[147] Kepler Cheuvreux

[148] Statistics Iceland (Hagstofa Íslands)

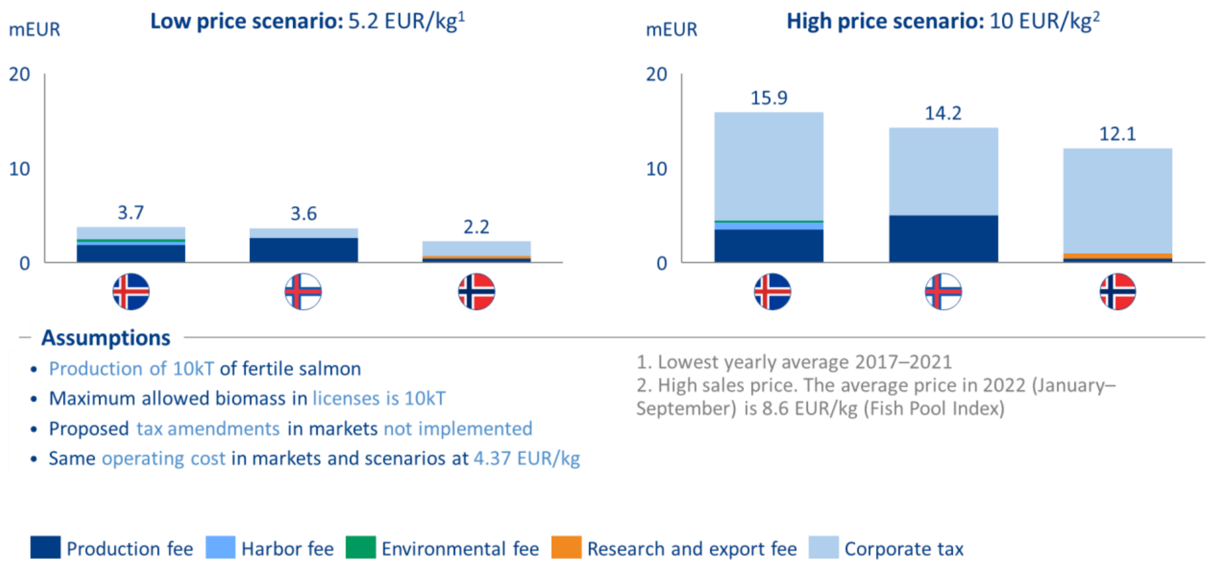
[149] MOWI industry handbook

[150] Fish Pool Index

[151] Prices of Salmon have increased to record levels in 2022 and average price from January to September 2022 is 8.6 EUR according to Fish Pool Index

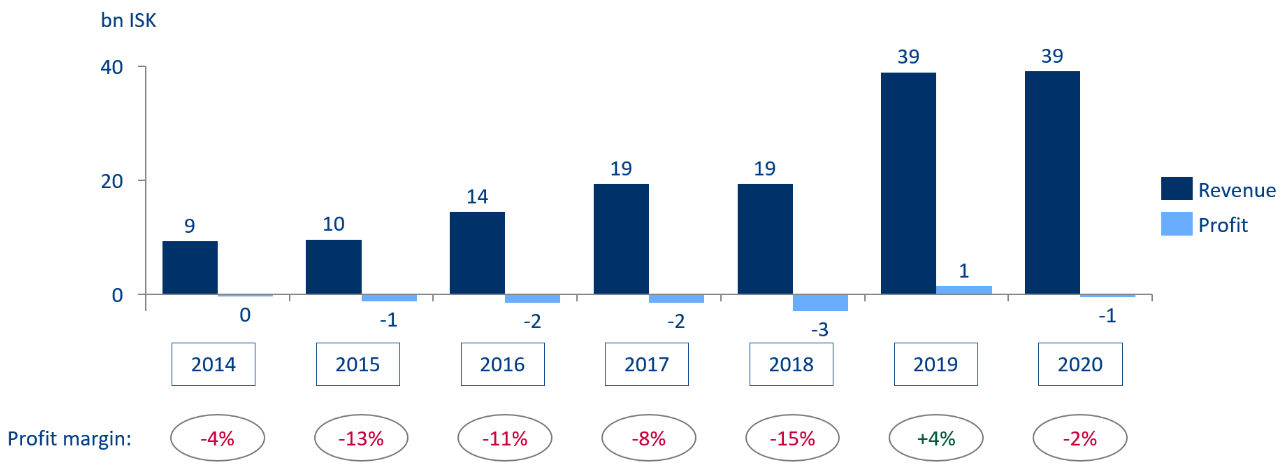
20%) while Norway in both scenarios accrues the lowest fees and taxes among the three markets mainly due to a substantially lower production fee.

FIGURE 4.31: TOTAL TAXES AND FEES IN 2026 PROVIDED NO AMENDMENTS ARE IMPLEMENTED IN MARKETS[152]



Although the total taxes and fees in the example above are highest in Iceland, it should be considered that the example illustrates the total levies in 2026 assuming companies in Iceland will generate the same profits as in Norway and the Faroe Islands. Historically, fish farming companies have not generated profits in Iceland except for in 2019, see Figure 4.32.

FIGURE 4.32: REVENUE AND PROFIT FOR FISH FARMING COMPANIES '14–20 IN ICELAND (BN ISK)[153]



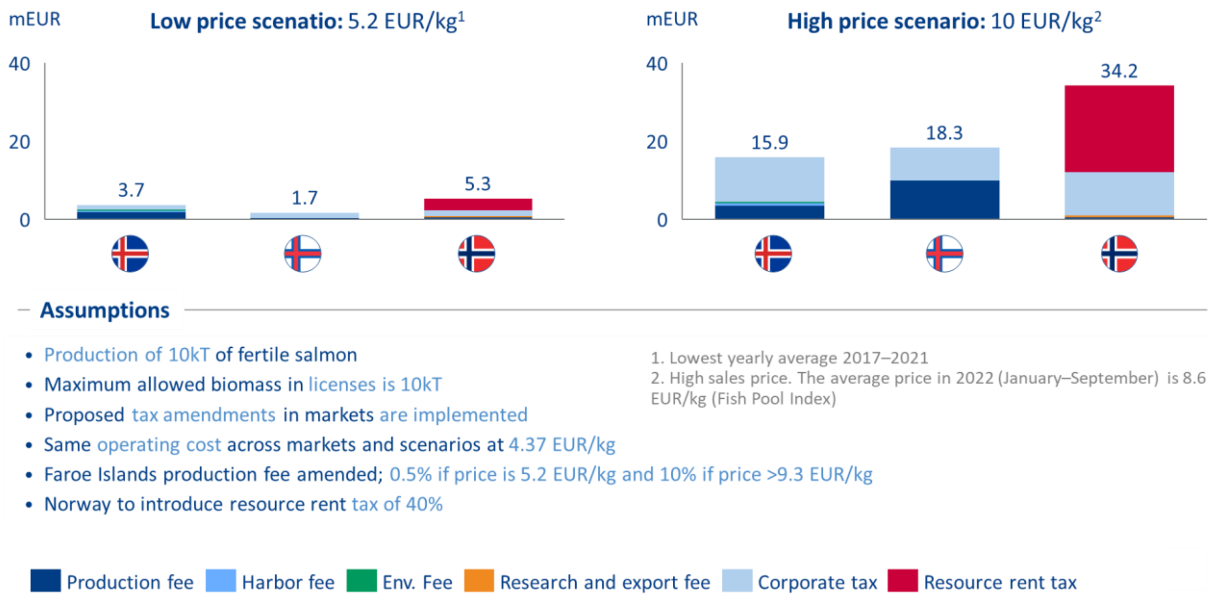
152 Assumed the Norwegian production fee is the same as in 2023, Fish Pool, BCG analysis

153 Statistics Iceland (Hagstofa Íslands)

Norway with highest levies in 2026 if proposed tax and fee amendments are implemented in all markets

The tax burden in markets changes significantly if proposed amendments are implemented i.e., if Norway introduces the resource rent tax and the Faroe Islands amend its production fees as described in sections 4.4.2 and 4.4.4. What form the resources rent tax will take is not clear at this stage but to explore a potential scenario it is assumed that the original proposal of 40% tax is implemented. Again, we consider two scenarios, one with low market price and the other with high market price.

FIGURE 4.33: TOTAL TAXES AND FEES IN 2026 PROVIDED PROPOSED AMENDMENTS ARE IMPLEMENTED IN MARKETS[154]



Norwegian farming companies would be subject to the highest levies in both the low price and the high price scenario due to the proposed resource rent tax. In the low-price scenario, the Faroe Islands would have the lowest total taxes and fees driven by a relatively low production fee rate at 0.5% when the market price is 5.2 EUR/kg.[155]

In the high price scenario, taxes and fees would be more than 2x higher in Norway than in Iceland, compared to ~43% higher in the low-price scenario. In the high price scenario, farmers in Iceland would also be subject to lower total taxes and fees compared to the Faroe Islands due to the suggested 10% production fee charged in the Faroe Islands if market prices exceed 9.3 EUR/kg.

Comparing Figure 4.31 illustrating the total taxes and fees with no amendments and Figure 4.33 above with amendments, it is apparent that total levies would generally increase. An exception to this is the low-price scenario in the Faroe Islands as the production fee rate would be lower (0.5%) when salmon price is 5.2 EUR/kg.

[154] Assumed the Norwegian production fee is the same as in 2023, Fish Pool, MOWI, Høringsnotat Grunnrenteskatt på havbruk, BCG analysis

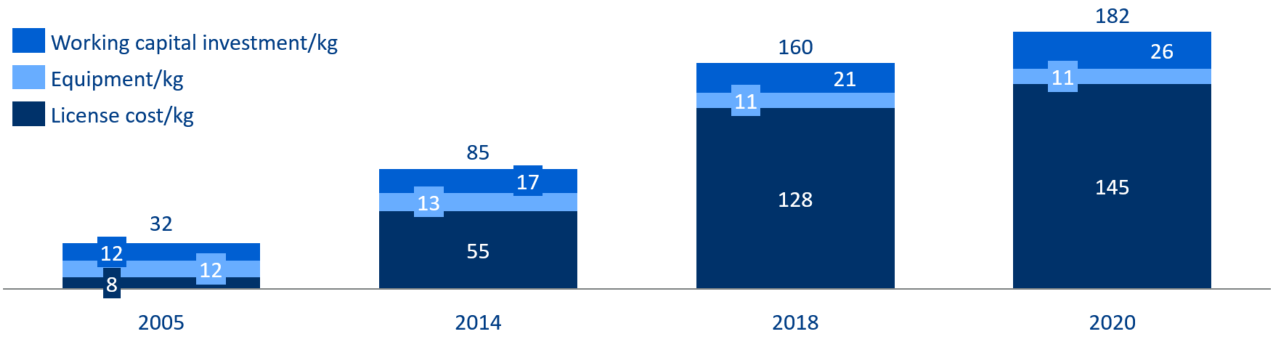
[155] Assuming the lowest threshold in the Faroe Islands will be as described in the proposed legislative amendments, although might be decreased or increased according to Faroese farmer's production cost (see further above in Section 4.4.4)

License cost is currently highest in Norway, no auctions planned for Iceland or the Faroe Islands

In Norway, licenses are granted for an indefinite period and are generally considered to be a farmer's most valuable asset. In Iceland and the Faroe Islands, licenses are granted for a limited period (16 and 12 years respectively) and can thereafter be renewed. In the Faroe Islands farmers can trade licenses between local companies, in Iceland production licenses can be and transferred, rented, and used as collateral with written approval from the Food and Veterinary Authority.

In Norway, farmers bid for licenses in an auction, creating a source of revenue for the government. Since 2014, license costs have accounted for the highest share of Norwegian farmers' invested capital per kg harvested, see Figure 4.34.

FIGURE 4.34: TRADITIONAL FARMERS INVESTED CAPITAL PER KG HARVESTED IN NORWAY IN SELECTED YEARS (NOK/KG)[156]



Going forward, licenses are to be auctioned in Iceland and the Faroe Islands, but no licenses have yet been auctioned. Until now, there has been no direct payment for licenses in Iceland and the Faroe Islands, but farmers have paid fees to cover administration related cost such as an application fee to the government.[157]

To compare total license costs between Norway, the Faroe Islands and Iceland, Figure 4.35 looks at a hypothetical example and calculates the total payments made to the government and municipalities in Iceland, Faroe Islands and Norway. First total payments at the granting of license are considered, then accrued payments over 10 years, including all applicable taxes and fees. In the example, it is assumed that proposed tax and fee amendments are not implemented. Average market price for salmon is assumed to be 6.4 EUR/kg (average price 2017 – 2022) and operational costs are assumed to remain constant at 4.37 EUR/kg.[158] License price in Norway is based on the average payment for licenses in 2020 at 145 NOK/kg (~14.5 EUR/kg)[159]

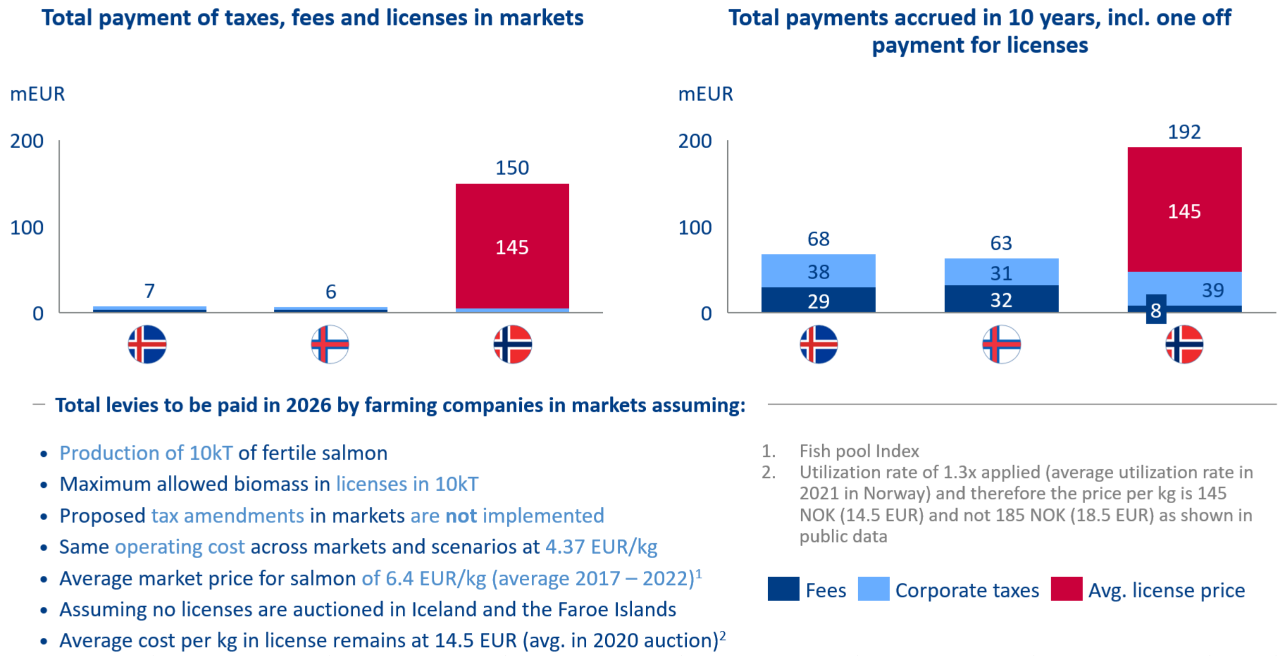
[156] Arctic Securities Research, Fiskeridirektoratet

[157] A fee for receiving licenses applies but is minimal, e.g., ~10kISK (the Food and Veterinary Authority)

[158] Fish Pool Index, MOWI industry report, BCG analysis

[159] Fiskeridirektoratet, Note: It is assumed that each license has a utilization rate of 1.3x (average utilization in 2020) and hence the price per kg in Norway is 145 NOK/kg

FIGURE 4.35: TOTAL LEVIES, INCL. LICENSE COST IN NORWAY AND TOTAL PAYMENTS IN 10 YEARS WITHIN CURRENT REGIMES[160]



As illustrated in Figure 4.35, the license cost in Norway accounts for the largest share of farmer's payments to the Norwegian government and municipalities. For Iceland and the Faroe Islands, it takes ~20 years to obtain the same revenue as one year in Norway.

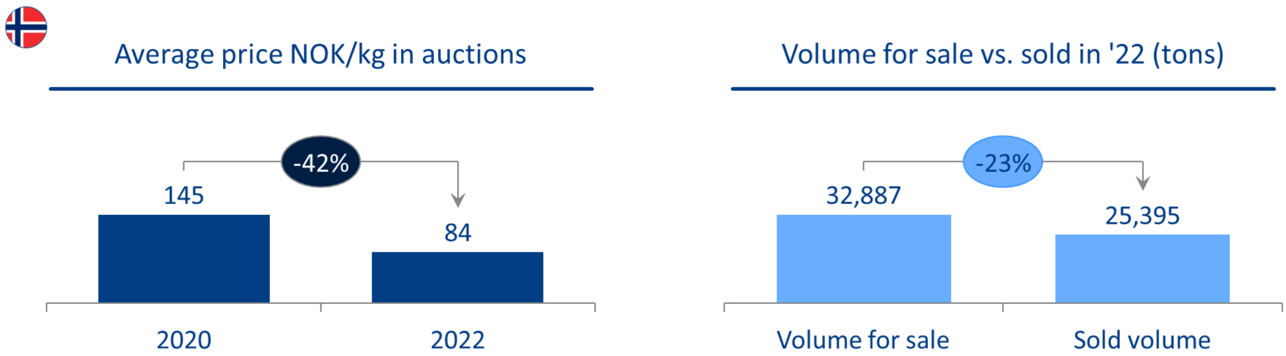
The Norwegian sector is the most mature and farmers operate at the greatest scale. This is likely to influence Norwegian farmers' ability to invest in licenses. Regardless, if a new farmer were to join the market in Norway now under this premise, it would likely take them much longer to achieve profitability in comparison with new farmers in Iceland or Faroe Islands. It should be noted that licenses in Norway were granted without payment until 1998 and that their value has increased significantly from 2005 to 2020 (0.8 EUR/kg to 14.5 EUR/kg, or ~18x). It is likely that the free licenses granted until 1998, have helped Norwegian farmers build the financial capability to buy licenses at current price levels.

Proposed resource rent tax in Norway assumed as main driver for lower auction prices in '22

New licenses were auctioned in Norway in October 2022, only a few weeks after the Norwegian government proposed to introduce a new resource rent tax at 40%. Auction prices were significantly lower compared to those in 2020, see Figure 4.36. In addition, no licenses were sold in two geographical areas. This implies that Norwegian farmers are less inclined to invest in licenses under the new resource rent tax regime.

[160] Fish Pool Index, Applicable legislations, MOWI industry report, BCG analysis

FIGURE 4.36: ESTIMATED PRICES AND # OF LICENSES SOLD IN 2022 AUCTION IN NORWAY, INCL. TAX REVENUE IMPACT[161]



It remains to be observed whether and under what conditions the resource rent tax will be implemented and what impact it will have on Norway's competitive position and attractiveness to salmon farmers.

Future auction prices in Iceland will largely depend on local industry profitability

Auction prices generally reflect the value farmers place on increased production capacity, essentially how much profit they expect to derive from additional biomass they are licensed to farm. Many factors determine expected profitability, such as the expected conversation rate of MAB to harvested fish, regional biology conditions and overall costs of production, including taxes and levies.

In October 2022, MOWI acquired a 51.28% stake in Arctic Fish for 1.88bn NOK. At the time, Arctic Fish held MAB of 27.1kT (includes Rainbow trout). Arctic Fish's enterprise value at the time was around 4bn NOK, implying a purchasing price of EV/kg licensed capacity of 147 NOK[162]. This transaction illustrates that market players see significant value in licensed MAB in Iceland. It however remains to be seen what value market players will place on directly acquiring biomass through auction in Iceland when and if they take place. These will, to a large extent, as described before, depend on the expected profitability.

Furthermore, future auction prices can also be impacted by the government's auction structure and criteria to determine the outcome, e.g., whether farmers with plans for more environmentally friendly farming will be favored.

Iceland distributes ~20% of total taxes and fees collected directly to municipalities

Municipalities in the focus markets either receive a share of the total levies paid by farming companies or collect a fee directly. Figure 4.37 provides an overview of the distribution of levies in Iceland, Norway, and the Faroe Islands:

[161] Intra Fish, BCG analysis

[162] Kepler Cheuvreux

FIGURE 4.37: DISTRIBUTION OF FEES AND TAXES TO MUNICIPALITIES

% allocation of fees and taxes to municipalities

	Iceland	Norway	Faroe Islands
Production fee	33%[1]	100%	0%
Environmental fee	0%	⊗	⊗
Harbor fee	100%	⊗	⊗
Research and export fee	⊗	0%	⊗
Municipality real estate tax	⊗	100%	⊗
Corporate tax	0%	0%	30%
Resource tax[2]	⊗	50%	⊗

⊗ Not applicable

1) Funds are not automatically allocated to municipalities. They are placed in the Aquaculture Fund that receive competing applications from municipalities and distributes grants based on the board's decision
2) Yet to be passed by the Norwegian government at the writing of this report

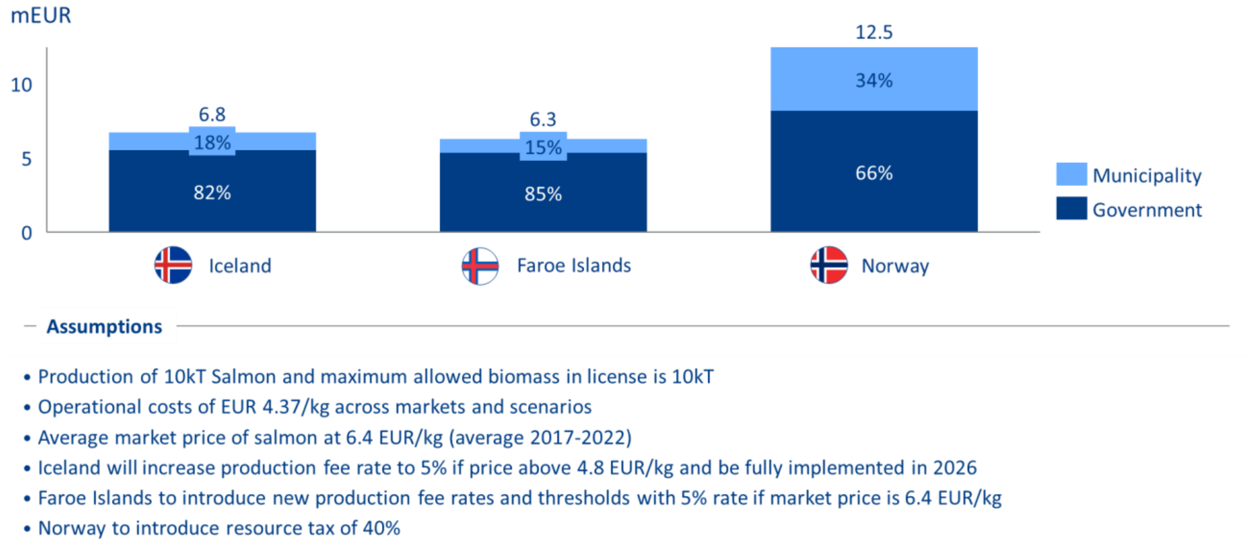
Under the current regime, Iceland will distribute around 18% of total fee and tax revenues to municipalities in 2026.[163] The Faroe Islands generally distributes tax and fee revenues to municipalities through a 30% share of corporate taxes paid and nothing directly through the production fee. Norway is expected to distribute the highest share provided the new resource rent tax is implemented, where a 50/50 split of revenue between government and municipalities/counties is proposed.[164] Beyond taxes and fees, Norway also distributes up to 70% of license cost to municipalities and counties.[165]

[163] Assuming a salmon price of 6.4 EUR/kg (yearly avg. fish pool price from 2017-2022)

[164] Høringsnotat Grunnrenteskatt på havbruk

[165] Fiskerirektoratet, Fishfarmermargazine from October 19, 2021, Share based on distribution to municipalities in the Norwegian auction in 2020

FIGURE 4.38: SHARE OF TOTAL FEE AND TAXES ALLOCATED TO GOVERNMENT AND MUNICIPALITIES IN MARKETS (EUR/KG)



4.4.6 Sub-conclusion

Salmon farmers are subject to taxes in all focus markets. Iceland, Norway, and the Faroe Islands have implemented relatively comparable levies applicable to traditional farming. A production/resource fee has been implemented in Iceland, Norway, and the Faroe Islands and is based on harvested volume. Farming companies in Iceland must further pay an annual environmental fee based on their MAB and a harbor fee to municipalities where they dock their harvests. In Norway, farmers are subject to a research and export fee based on export value. The fees are used for market research and marketing Norwegian salmon in key supply markets. In Norway, farmers are also subject to a municipal real estate tax based on the value of their production installations at sea.

The analysis of different fee regimes and rates in focus markets has identified the following key takeaways:

- In 2021, the total fee per kg harvested was highest in the Faroe Islands (0.31 EUR) followed by Iceland (0.13 EUR) and Norway (0.07 EUR). The main driver for a lower fee in Iceland, compared to the Faroe Islands, is that the total production fee rate will not be fully implemented until 2026, i.e., currently only 1% to be increased to 3.5% in even steps until 2026.
- If changes were to be made to the highest production fee bracket in Iceland (5%) and the proposed production fee changes in the Faroe Islands are implemented and market prices stay at 6.4 EUR/kg, Iceland would have the highest total fees per kg harvested in 2026, at 0.39 EUR/kg followed by the Faroe Islands (0.32 EUR/kg) assuming the proposed amendments in the Faroe Islands are implemented.
- Assuming as in previous bullet that changes in both markets take place but that prices increase to above 9.3 EUR/kg in 2026, farmers in the Faroe Islands will be subject to the highest fees due to the proposed amendments of a 10% fee rate (for prices >9.3 EUR/kg).

When adding corporate taxes to the overall levies, the total cost for operators is dependent on profitability:

- The total taxes and fees are highest in Iceland driven by higher corporate tax rate at 20% compared to the Faroe Islands (18%). Norway's low fees per harvest volume results in lower costs, despite a higher tax rate at 22%.
- The above applies in both scenarios where companies have a profit margin of 16% and +50%. That said, Iceland and the Faroe Islands are relatively comparable when profit margins are around 16%.
- Although Iceland has higher levies compared to the other markets, farming companies in Iceland have in most years not paid corporate tax due to lack of profits between 2014–2020, apart from in 2019 when the combined profit rate was estimated to be ~4%.

In the Faroe Islands and Iceland, governments have proposed to amend the production fee, and in Norway, the government has proposed to introduce a new resource rent tax:

- In the Faroe Islands, a proposed amendment to the production fee structure has included a higher threshold for the lowest fee rate to be based on farmers' average production cost in a year. This done to account for increased cost in the industry and balanced by a higher fee rate (10% vs. 5%) if prices continue to increase.
- In Iceland, a proposal was made to increase the production fee rate from 3.5% to 5% in 2026. This was not approved by parliament.
- In Norway, a proposal has been made to introduce a resource rent tax at a 40% rate, calculated after the corporate taxes rate of 22%.
- Provided that the above amendments are implemented in Norway and the Faroe Islands, Norway will have the highest total levies followed by Iceland and the Faroe Islands if prices are low (at 5.2 EUR/kg). If prices are high (10 EUR/kg) Iceland will have the lowest total levies.

License costs differ across markets and further impact competitive position:

- In Norway, licenses are granted for an indefinite period of time and are generally considered to be a farmer's most valuable asset, whereas licenses in Iceland and Faroe Islands are granted for a limited number of years. In Norway and the Faroe Islands licenses can be sold between companies, in Iceland production licenses can be and transferred, rented, and used as collateral with written approval from the Food and Veterinary Authority. The license cost has been the largest revenue driver for the government and municipalities/counties in Norway since 2004, with an average price per kg in 2020 of 14.5 EUR.
- Due to high license costs in Norway, barriers to entry in Iceland and the Faroe Islands have been lower. Lower barriers are often expected for industries growing in scale. Going forward, new licenses in Iceland and the Faroese Islands are to be auctioned. Despite an absence of price information for these licenses, it can still be inferred that auctions cost will create higher barriers to entry for new players.
- Due to the license fees in Norway, farmers have generated the highest revenues for government and municipalities. It would take farmers in Iceland and the Faroe Islands ~20 years to provide the same revenue as paid by Norwegian farmers through the license cost alone, assuming a 2020 price level.

- In Norway, auction prices in October 2022 decreased by 42% vs. 2020 levels, likely due to the proposed new resource rent tax. This has resulted in total government and municipality/county revenue to be 43% lower than expected if the same volume had been sold in 2020.
- Distribution of tax and levies between the central government and municipalities varies between markets. If all the proposed tax and fee amendments are implemented, municipalities and counties in Norway will receive 34% of total tax revenue, compared to lower shares in Iceland (18%) and the Faroe Islands (15%). This is excluding distribution of revenue accrued from licenses in Norway that partly are allocated to municipalities/counties.

Overall, Norwegian farmers currently have a competitive advantage in terms of total fees and taxes. They do however invest significantly in licenses, and if the proposed resource rent tax is implemented in 2023, Norwegian farmers will be at a disadvantage compared to farmers in Iceland and the Faroese Islands.

4.4.7 Next steps for consideration based on practices in other markets

Taxes, fees, and license costs impact farming companies' competitive position. In the absence of other constraints such as available production capacity, these inherently play a large role in decisions on where to locate operations. Although the salmon market is global, Iceland's competitive market has been defined as the EEA area.[166] Due to this, it is important to consider the impact of the tax and fee regime in Iceland both from the perspective of Icelandic farmers' competitive position and the generation of revenue for the government and municipalities to fund governance and surveillance and receive payment for the use of common resources.

Based on best practices in markets and the importance of a well-structured and transparent tax and fee regimes, the Icelandic government should consider the following:

1. Allocating revenue from taxes or fees directly to municipalities as is done in Norway, i.e., not by way of an intermediary body such as the Aquaculture Fund. This is likely to increase long term predictability and support local investments in infrastructure to support farmers and their workers.
2. Allocating a higher proportion of revenue to municipalities, potentially only for a few years whilst long term infrastructure is being developed.
3. Establishing funds that receive revenue from the industry and are governed by municipalities (e.g., all municipalities in Westfjords and Eastfjords) to determine how the revenue is best allocated to support the industry and its workers. Counties in Norway play a similar role.
4. Assess whether the production fee should apply to all harvest volume or for example exclude salmon culled due to a decision made by the authorities as is done in the Faroe Islands. Currently,

[166] Decision in case no. COMP/M.6850 Marine Harvest / Morpol regarding a merger of two salmon farming companies in Norway and Scotland

Note: In the merger case no. 28/2021 between Måsøval Eiendom AS and Ice Fish Farm (mother companies of the farming companies in the Eastfjord), the Icelandic Competition Authority did not conclude on the geographical market but stated, among others, the following: The Competition Authority is of that opinion that there are indications that the market for salmon farming and primary processing covers a larger territory than Iceland.

farmers not only suffer operational losses due to culled salmon, but they are also challenged by the fees that apply irrespective of salmon being sold to market or not. As the current construct naturally incentives farmers to limit biological challenges, this needs to be balanced with increased surveillance and may only be applicable where operations have been fully compliant with regulation.

5. Lowering entry barriers for new farmers with temporary tax or fee rebates, or lower license cost in auctions. This will allow them the investment capacity to establish profitable operations, after which the rebates can be revoked.

6. Offer temporary tax or fee rebates, or lower license cost in auctions, if companies use more sustainable farming methods such as semi-closed or closed pens to incentivize greener methods

7. Revisit conditions around the trading of licenses bought in future auction. This might increase their market value and as a result government revenue.

8. Analyze the impact of introducing a resource rent tax as has been proposed in Norway, including when the sector is able to withstand such new taxation.

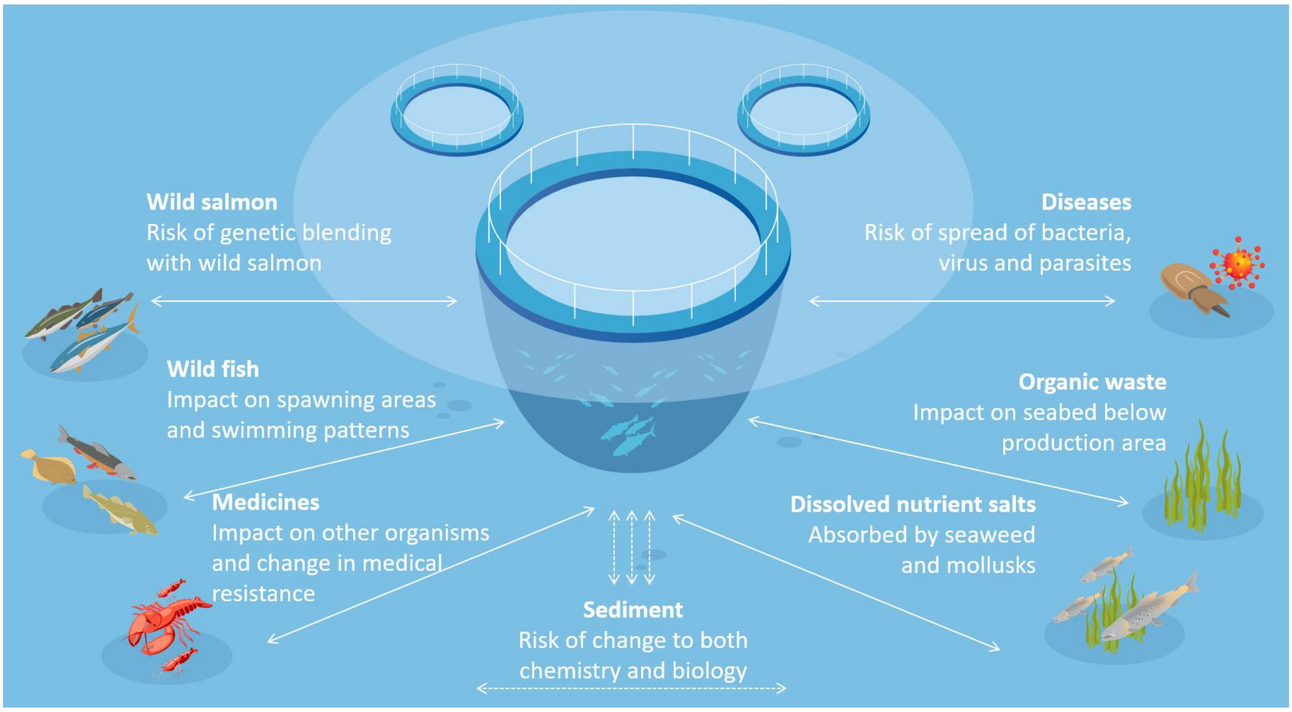
4.5 Environmental impact and fish welfare

Salmon farming, like other farming practices on an industrial scale, impacts the environment, both directly and indirectly. The main impact is driven by the production itself, with repercussions on the environment, including wildlife, ocean conditions and the seabed. Escaped fish can cause genetic introgression between farmed and wild fish, which can impact their ability to survive in the wild. Sea-based fish farms can elevate the rate of sea lice up to 40 miles from the production area, as the high fish concentration causes the sea lice to breed rampantly. Additionally, the organic load (feces and spillover feed) from the sea pens enters the fjords directly and can damage the ocean environment and seabed. This may lead to explosive algae growth, the decay of which takes large quantities of oxygen from the seawater ("eutrophication") and is detrimental to other sea life.[167] Copper and plastic, often used in farming and sea pen netting, can also be toxic to marine life, with particular risk to the early life stages of infauna and sedentary benthic organisms.[168] Thus, the health of ecosystem in areas where traditional aquaculture is conducted is closely tied to farming operations.

[167] BNP Paribas Exane (2021)

[168] ICES: Aquaculture overviews - Norwegian Sea ecoregion (2022)

FIGURE 4.39: POTENTIAL IMPACT ON ENVIRONMENT FROM SALMON FARMING[169]



Salmon farmers are subject to legislation with the objective to safeguard environmental interests and animal welfare. These generally include impact assessments of production plans and production areas, internal control policies, and action plans to mitigate the impacts of sea lice, disease outbreaks and escapes. Sanctions in cases of negative impact are also applied, such as an obligation to decrease biomass in Norway in the case of a high level of adult female sea lice (traffic light system) and similar sanctions in Scotland if production has a damaging impact on seabed and water conditions.

This section's focus is on the environmental requirements farmers must adhere to and the environmental challenges traditional aquaculture faces. These are analyzed across the focus markets, beginning with an overview of the main environmental legislation and governance bodies. The section then looks at viral diseases and vaccines, with focus on Infectious Salmon Anemia (ISA) due to the recent outbreak in Iceland, followed by an overview of bacterial diseases and the use of antibiotics. Salmon mortality is also discussed before finally considering internal monitoring and surveillance.

[169] Miljødirektoratet (2020)

4.5.1 Overview of main environmental legislations for governance bodies

Surveillance and impact assessments monitor production effects on the environment in Iceland

Surveillance is mainly governed by the Icelandic Food and Veterinary Authority

There are multiple legislations and regulations applicable in Iceland with the objective of limiting environmental impact and protect fish health.[170]

Surveillance of production areas and fish welfare is governed by the Icelandic Food and Veterinary Authority. The Directorate of Fisheries consults the Authority as required, and salmon samples are analyzed by the Research Department of Fish Diseases at the Experimental Center at the University of Iceland (The Institute for Experimental Pathology at Keldur). The Consultative Committee on aquaculture,[171] with members appointed for four years, has the role to consult governance bodies on all matters related to aquaculture. This includes evaluating the assumptions and data processing on which the risk assessment is based, assessing the risk of fish diseases and parasites, and monitoring farmers operations.

The Environmental Agency assesses the impact of aquaculture operations on the ocean around and under the production area, whereas the Marine and Freshwater Institute assesses the overall impact on fjords. Impact on seabed and ocean is further assessed by farmers and results shared with the Environment Agency, who then publishes the reports.

Farmers in Iceland must assess a production plan's impact on the environment[172]

Salmon farmers must assess the environmental impact of a production plan to be approved by the Environment Agency, provided the biomass applied for is more than one ton. An environmental impact assessment is defined as the analysis and evaluation of possible environmental impacts of proposed activities likely to influence the environment. For a license to be granted, the environmental impact assessment must determine that a proposed production adheres to several legislations and regulations related to the environment and fish welfare, including standards referred to in regulations such as ISO[173] and a Norwegian standard on requirements for production area assessment, risk analyses, design, execution, assembly, and operation.[174]

An applicant for an industrial license must assess and ensure the production plan fulfills requirements outlined in legislations by conducting a comprehensive environmental impact assessment, considering

[170] Examples: Act on Aquaculture, Act no. 60/2006 on the Research Department of Fish Diseases, Act no. 33/2003 on protection of water and coast, Regulation no. 300/2018 on farmed fish welfare, disease prevention and health control of farms, Regulation no. 540/2020 on fish farming, Regulation no. 60/2006 on protection against fish diseases, Regulation no. 890/2019 on the Consultative Committee on aquaculture, Regulation no. 220/2013 on measurements to limit impact on selected diseases in farmed and wild species, Regulation on. 462/2021 implementing EEA Regulation no. 2016/429 on animal welfare, Regulation no. 691/2020 supplementing the EEA Regulation on animal welfare

[171] Samráðsnefnd um fiskeldi

[172] Regulation (EU) 2016/429 on transmissible animal diseases

[173] Example: ÍST EN ISO 17065:2012, Requirements for farmers that certify products, processes and services, ÍST EN ISO/IEC 17020, General criteria for the operation of various types of organization that handle inspections

[174] Example: 9415:2009 (NS Flytende oppdrettsanlegg - Krav til lokalitetsundersøkelse, risikoanalyse, utforming, dimensjonering, utførelse, montering og drift)

e.g., water conditions, currents, expected number of escapees, mitigating actions to limit escapes, sea lice and diseases, internal surveillance of fish health and action plans in case of an outbreak, impact on the society, tourism, farming equipment and farming sectors.

Iceland is further obligated to implement and comply with applicable EEA regulations such as the regulation on fish health and transmissible animal diseases.[175]

Farmers in Norway subject to similar regulation as farmers in Iceland

Surveillance is governed by six administrative bodies in Norway

The relationship between the Norwegian aquaculture and the environment is mainly regulated by the Aquaculture Act (2005), which emphasizes that aquaculture must be established, operated, and discontinued in an environmentally responsible way.

The Directorate of Fisheries, the Norwegian Food Safety Authority, the Norwegian Coastal Administration, the County Governor, the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Veterinary Institute are all responsible for different parts of the administration and monitoring of fisheries and aquaculture activities.[176]

Farmers in Norway must adhere to same EEA regulations as farmers in Iceland

Farmers must conduct an environmental impact assessment of proposed farming plan in a similar manner as in Iceland. Farmers must further comply with EEA regulations, with the newest amendments in the EEA fish welfare regulation implemented in April 2022. The regulation emphasizes prevention of the spread of diseases.[177]

Chilean operators must obtain approval to use production area as well as site assessment

Surveillance is mainly governed by the National Fisheries and Aquaculture Service

The main legislation governing aquaculture consists of the General Act on the Environment, Environmental Regulation on Aquaculture (2001) and the Act on General Fisheries and Aquaculture. These outline the requirements that farmers must adhere to related to the environment, including disease control and water quality. The National Fisheries and Aquaculture Service, the Environmental Agency and Undersecretaries for Armed Forces are responsible for monitoring fisheries and aquaculture activities in Chile.[178]

Assessment of production area required in addition to a site environmental impact assessment

Farmers need to obtain an authorization to operate in a specific area and use national sea areas for salmon farming, issued by the Undersecretaries for Armed Forces (Ministry of Defense). The Environmental Regulation on Aquaculture requires the preparation of the CPS (Preliminary

[175] Example: EEA Regulation no. 2016/429 on animal welfare and EEA Regulation on water and marine environment

[176] Fiskeridirektoratet

[177] Mattilsynet, Mattilsynets faglige beredskapsplan for kontroll med utbrudd av Infeksiøs lakseanemi (ILA) saksnr. 2020/180582

[178] Sernapesca

Characterization of Site) for the determination of the physical, biological, and chemical parameters of a production area, including a plan for complying with other applicable regulations.[179]

Farms in Scotland must obtain an environmental license that can be revoked for non-compliance

Surveillance is governed by the Marine Scotland Fish Health Inspectorate

There are multiple legislative acts applicable in Scotland with the aim to limit environmental impact, including the Aquaculture and Fisheries Act (2007) and associated secondary legislation, the Aquatic Animal Health Regulations (2009), and orders on Fish Farming Businesses regulating what farmers should record and report.[180] The Scottish Government has further funded a computer model (DEPOMOD) developed by the Scottish Association for Marine Science. The objective is to limit environmental impact by predicting the impact of farming on the seabed, considering e.g., feeding rate, configuration, and water currents.[181] Certain EU regulations have further been implemented such as a regulation on animal health and welfare.[182]

The Marine Scotland Directorate is responsible for governing farming operations in cooperation with the Scottish Environment Protection Agency (SEPA) and Scottish Natural Heritage (SNH). Surveillance is administered by the Marine Scotland Fish Health Inspectorate. The Fish Health Inspectorate carries out assessments for disease control, sea lice management and containment measures and the Scottish Environment Protection Agency (SEPA) oversees impact from organic load on seabed, including other pollutants from production areas.[183]

A separate environmental license is required to operate a salmon farm

Farmers must obtain an environmental license from the Scottish Environment Protection Agency (SEPA) to produce salmon and assess the production plan impact on the environment. The maximum allowed biomass for sites in Scotland was changed in 2019 and is dictated by the environmental and fish-health performance of each site instead of a standard unit per production area overseen by the DEPOMOD computer model. The environmental license can be reviewed, and MAB reduced in the event of non-compliance with environmental standards and revoked in cases of significant and long-term non-compliance.

[179] Sernapesca

[180] The Fish Farming Businesses (Record keeping) order 2008 and the Fish Farming Businesses (Reporting) order 2020

[181] SAMS Enterprise - DEPOMOD

[182] EU Regulation 2017/625 on animal health and welfare

[183] Scottish Government, Scottish Environment Protection Agency (SEPA)

The Faroe Islands have similar regulation to Iceland but a separate environmental license

Surveillance is mainly governed by Food and Veterinary Authority

The main environmental legislation in Scotland is comprised of the Environmental Act, the Food Safety Act, the Aquaculture Act, and the regulation on fish welfare and disease prevention.[184] Surveillance of production area and fish welfare is governed by the Faroese Food and Veterinary Authority.

A separate environmental license is required to operate a salmon farm

Farmers must apply for licenses issued by the Faroese Environment Agency. The application must contain a description of the proposed operations and plan to for complying with environmental regulations, similarly to the requirements in the other focus markets.

International sustainability standards

In addition to regional legislations to limit environmental impact, there are global standards that apply to sustainability. The Aquaculture Stewardship Council (ASC) and Global Aquaculture Alliance (GAA) manage the international salmon aquaculture sustainability standards. The ASC was initiated and funded by salmon farmers. The GAA further certifies the Best Aquaculture Practices (BAP), which is a certification program that encompasses compliance with the Global Food Safety Initiative and the Global Sustainable Seafood Initiative.[185]

It is not obligatory to comply with standards, as the initiative is industry driven. However, the standards generally outline stricter environmental requirements to comply with compared to regulations applicable in markets. In Norway, the state is collaborating with companies to increase the number of ASC-certified salmon farms.

4.5.2 Main salmon health risks in focus markets

Disease is an unwelcome biproduct to all industrial scale farming practices, including salmonoid farming. Diseases in salmon farming were first detected and reported in the early 1960s and have followed the industry since its emergence. At times, disease has posed a significant threat to the industry, with many farmers nearing or reaching insolvency due to operational losses.

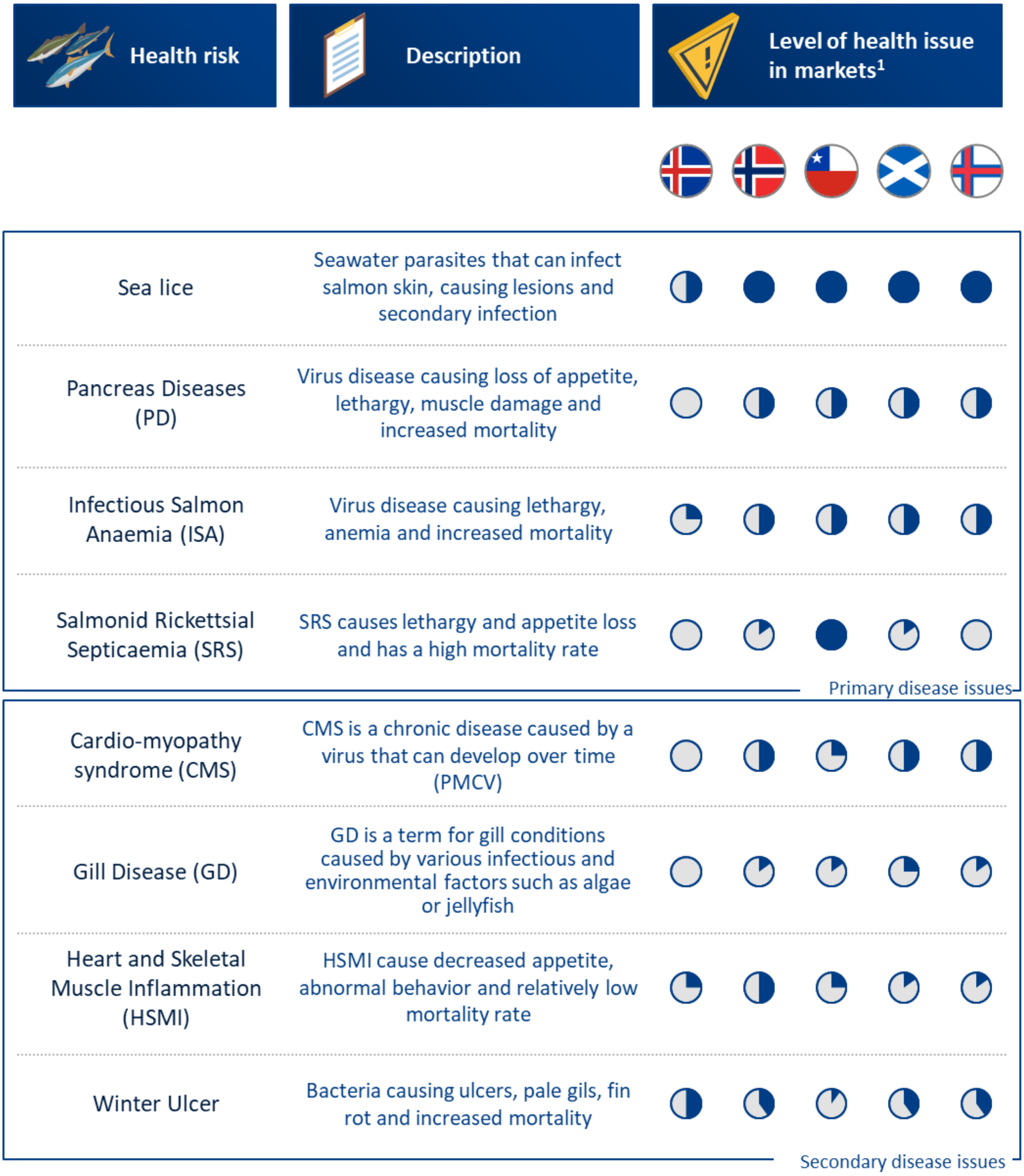
The industry and governance bodies are increasingly focusing on measures to increase fish welfare. Apart from compromising fish health, disease can limit growth and cause financial losses. Experience has shown that fish health is first and foremost achieved through farmers' management practices and operating policies, with focus on limiting exposure to health risks. Biosecurity plans, risk mitigation plans, disinfection procedures, surveillance schemes, and synchronized area management approaches (e.g., an area with only one generation farmed at the same time and fallowed afterwards) are all examples of decreasing the risk of health challenges.

[184] Environmental Act No 134 from October 29, 2009, with latest amendments from 2021, Food Safety Act No. 58 from May 26, 2010 with latest amendments from 2017, Kunngerð um stovnan og sjúkufyrirbyrgjandi rakstur av alibrúkum, Djóravælferðarlógin

[185] The Aquaculture Stewardship Council (ASC), Global Aquaculture Alliance (GAA)

Health challenges differ across markets. Sea lice and ISA are the largest biological challenge in Norway, Scotland, and the Faroes Islands, followed by Pancreas Disease (PD) and Cardio-myopathy syndrome (CMS). In Chile, Salmonid Rickettsia Septicemia (SRS), ISA, and Caligus (sea lice) are the main challenges, followed by PD. Iceland has not experience disease challenges on the same scale as in the other markets, but sea lice have increased, Heart and Skeletal Muscle Inflammation (HSMI) has been confirmed, and winter ulcers have led to higher mortality. Infectious Salmon Anaemia (ISA) is also an issue across markets, with recent outbreaks in Iceland.

FIGURE 4.40: MAIN FISH HEALTH RISKS AND INSTANCES IN FOCUS SUPPLY MARKETS[186]



1. Risk level based on main historical challenges

[186] Expert interviews, BCG analyses

4.5.3 Sea lice historically the largest challenge in markets

Sea lice are parasites that feed on salmon mucus, skin, and blood, impacting fish health, and increasing the likelihood of other infections and mortality. Sea lice are monitored by farmers and administrative bodies in all focus markets. The number of adult female sea lice per fish is the main measurement used to assess risk levels, as the adult female sea lice reproduce and hence increase the number of sea lice.[187] There are several methods used to treat sea lice, both medical and non-medical, such as bath treatments in freshwater without medicine, cleaner fish (lump fish), feed treatments and medical treatments. Efficient vaccines produced to date are limited.[188]

The threshold for the number of adult female sea lice allowed in production area before contingency plans should be activated differ across markets. Chile has the highest threshold of 3.0 adult female sea lice per fish. However, it should be noted that the sea lice in Chile is a different species than the sea lice in the other focus markets and thus sea lice thresholds not as comparable. The frequency of reporting also differs. In this regard, Norway, Scotland, and Chile have stricter internal monitoring compared to the other focus markets.

FIGURE 4.41: COMPARISON OF AVG. NUMBER OF ADULT FEMALE SEA LICE LEVELS AND MONITORING[189]

	Adult female sea lice threshold	Average female sea lice per fish 2021 and 2022		Report frequency
		2021	2022	
Iceland	0.5 Activates contingency plan	0.21	0.47	Monthly if sea temperature is 4°C or higher Bi-weekly 1 Jun – 1 Oct
Norway	0.2 – 0.5 Seasonally adjusted	0.15	0.16	Weekly in areas with sea temperature >4, else bi-weekly
Chile	3.0	1.7	Not available	Weekly
Faroe Islands	0.5 - 1.0 Seasonally adjusted	0.45	0.32	Bi-weekly
Scotland	2.0 Activates contingency plan and stricter gov. monitoring	0.73	0.50	Weekly

In Iceland, adult female sea lice level above 0.5 activates farmer contingency plan

Female sea lice have only been present in the Westfjords of Iceland in recent years. Since 2014, measures have been implemented to mitigate sea lice risk. Farmers must count the number of sea lice per fish and

[187] Expert interviews, BCG analysis

[188] Expert interviews, BCG analysis

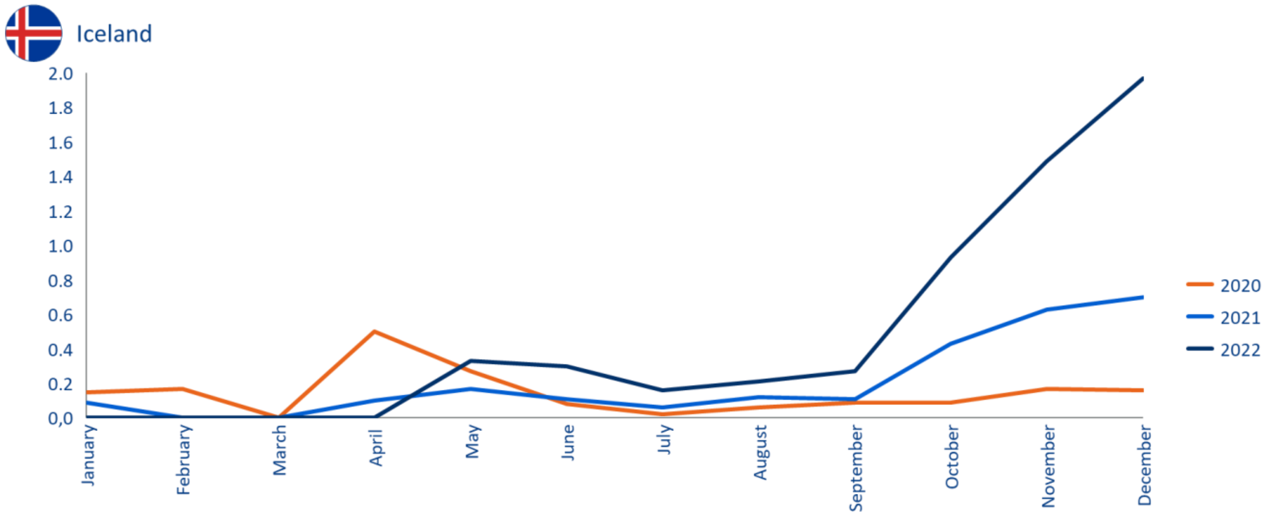
[189] The Icelandic Food and Veterinary Authority, Mattilsynet, Scotland Government, Lusedata.no, The Faroe Islands' Food and Veterinary Authority, Sernapesca, BCG analysis

report figures on a bi-weekly basis from June 1 to October 1. Outside this period, they must report figures monthly if sea temperature is 4°C or higher. When sea temperature is lower than 4°C or air temperature below -5°C, farmers are not obligated to count sea lice.

The farmers in the Eastfjords have been granted an exception from counting, as no sea lice have been present in the area. The exception is granted based on fish welfare and to limit any unnecessary handling related to counting sea lice. Farmers are also required to implement internal monitoring- and contingency plan. In 2021, a threshold of 0.5 adult sea lice per fish was implemented to mitigate potential sea lice outbreaks.

On average, adult female sea lice per fish in Iceland were 0.16 in 2020, 0.21 in 2021 and 0.47 in 2022.

FIGURE 4.42: AVERAGE ADULT FEMALE SEA LICE IN ICELAND (JANUARY 2020 TO AUGUST 2022)[190]



The number of adult female sea lice is generally higher during warmer months due to faster reproduction, while cold temperatures weaken lice. However, sea lice can still survive colder temperatures as can be seen in Figure 4.42. Noticeable is the large increase during October to December in 2022. This is explained by one operator deciding not to treat the fish due to it reaching harvest size. The fish has now been harvested and the area will not be used until summer 2023. The sea-lice will not survive until then and it is therefore expected that numbers will go down in 2023.

The sea lice level in 2021 (0.21) was higher compared to Norway (0.13), which may partly be explained by more treatments used in Norway compared to Iceland. The sea lice level in Iceland was lower in 2021 compared to Scotland (0.73), Faroe Islands (0.45) and Chile (1.7). This is partly explained by higher sea temperatures in the markets compared to Iceland and high density in Chile increasing likelihood of sea lice outbreaks.[191]

[190] The Icelandic Food and Veterinary Authority

[191] Mattilsynet, the Icelandic Food and Veterinary Authority, Sernapesca

With the expected growth in Iceland, the number of sea lice is likely to follow, increasing the importance of effective internal monitoring and surveillance to limit outbreaks.

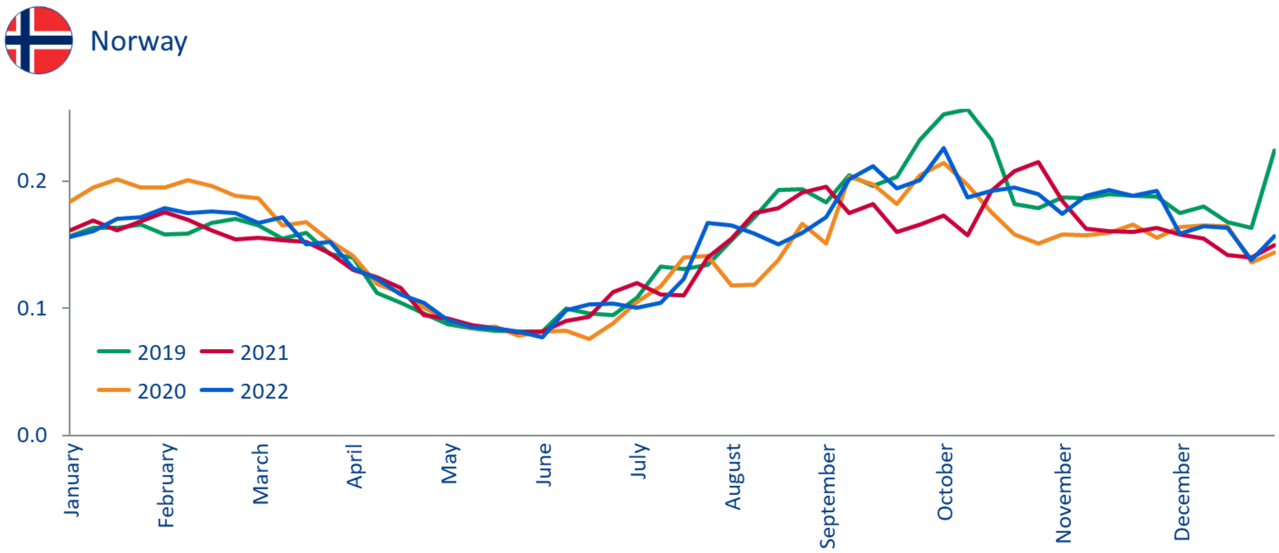
In Norway, sea lice levels must be lower than 0.5 and below 0.2 during salmon migration period

The sea lice level in Norway must be always lower than 0.5. Furthermore, the maximum level is seasonally adjusted and cannot exceed 0.2 during the main migration period of wild salmonoids. The migration period is from week 16 to 21 in all areas except for Northern Norway (from week 21 to 27) due to colder sea temperatures. This scheme is designed to restrict the spread of sea lice from farms to wild salmon and trout.

Farmers in Norway must count the number of sea lice per fish and report weekly to the Norwegian Food and Safety Authority. Reporting also includes sea temperatures, treatments against sea lice, amount of active substance used in treatment, and any suspicion of medicine resistance. Farmers are also required to develop a plan for the prevention, monitoring, and treatment of sea lice to be approved by the Authority.[192]

Although the threshold for the number of adult female sea lice per fish is 0.5 during colder months, the average sea lice levels rarely go above 0.2. The average levels were 0.15 per fish in 2021 and 0.16 in 2022. Farmers are incentivized to maintain good fish welfare, not only to limit mortality, but also due to the Norwegian traffic light system that allows farmers to increase MAB if sea lice levels are low.

FIGURE 4.43: NUMBER OF ADULT FEMALE SEA LICE IN NORWAY (2019–2022)[193]



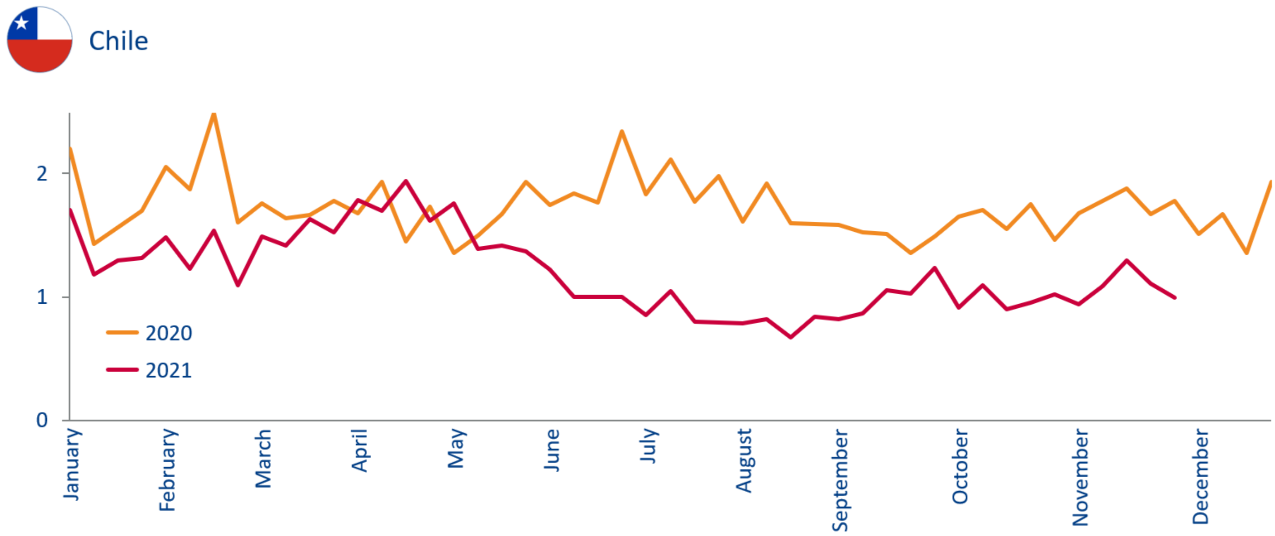
[192] Mattilsynet, Matloven, Forskrift om bekjempelse av lakselus i akvakulturanlegg (FOR-2012-12-06-1140). The surveillance programme for resistance in salmon lice (Lepeophtheirus salmonis) in Norway (2021) report no. 8/2022

[193] Lusedata.no, BCG analysis

High threshold of 3.0 Caligus (type of sea lice) applied in Chile – avg. 1.7 in 2021

Caligus infestation is one of the largest challenges in Chile, with a higher threshold at 3.0 Caligus per fish compared to other markets. In 2021, the average Caligus per fish was 1.7. Out of the three main areas in Chile, sea lice risk is largest in Aysén, with sea lice levels regularly above 3.0 on average per fish in 2020, and lowest in Magallanes, or below 0.4 on average in 2020 and 2021. The main reason for high number of Caligus is due to high density in pens. Farmers in Magallanes have in the recent years increased surveillance and the government has closed off coast areas for farming to limit environmental impact.

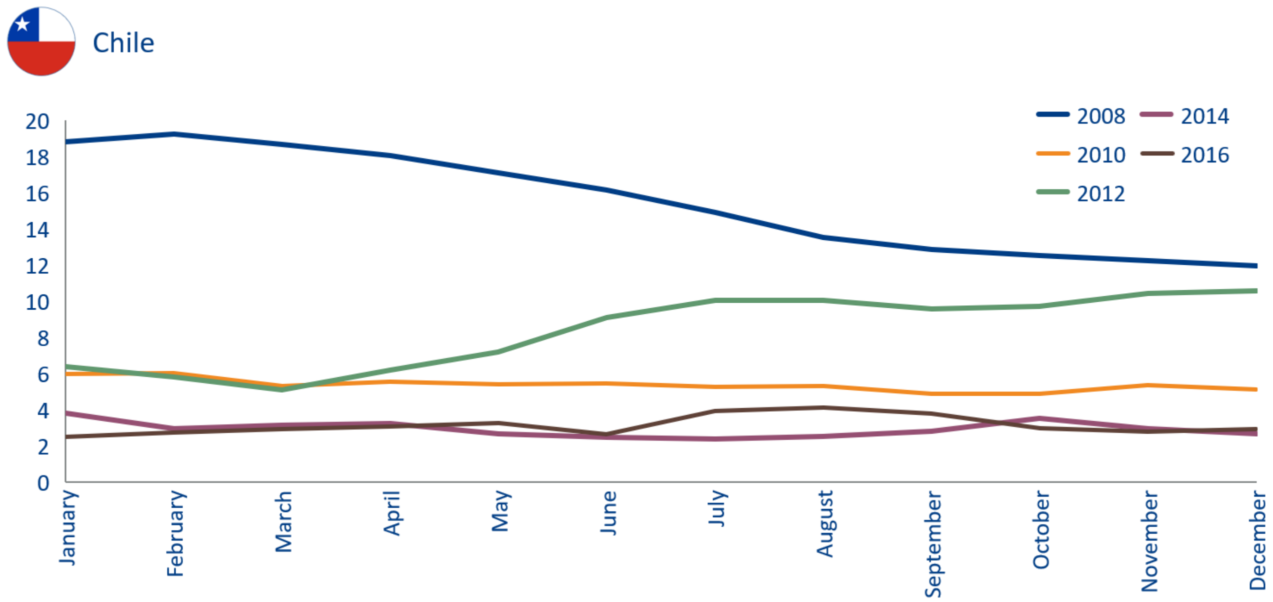
FIGURE 4.44: AVERAGE ADULT FEMALE SEA LICE PER FISH IN CHILE (JANUARY 2020-NOVEMBER 2021)[194]



Although sea lice levels are high in Chile, the levels have decreases significantly since 2008, where number of Caligus per fish was between 13 and 19. The improvement is due to stricter monitoring, surveillance, and legislations.

[194] Sernapesca, BCG analysis

FIGURE 4.45: HISTORICAL NUMBER OF ADULT FEMALE SEA LICE PER FISH IN CHILE (EVERY SECOND YEAR 2008-2016)[195]



Sea lice levels in the Faroe Islands 0.26 in 2021

The average adult female sea lice per fish in the Faroe Islands was 0.26 in 2021, a significant decrease since 2017, where the average adult female sea lice per fish was 0.66. Due to historically high levels of adult female sea lice, the government decreased the threshold for maximum adult sea lice from 1.5 to 0.5 per fish in 2021. The threshold is decreased to 0.2 when sea temperatures are warmer, or from June through July 2021 and from May 2022 and going forward. If the sea lice levels are above the threshold three times in a row (counted at minimum every two weeks), or four times total during the production cycle, the salmon must be harvested within 11 weeks.[196]

Adult female sea lice level beyond 2.0 per fish in Scotland activates government monitoring

In Scotland, farmers must demonstrate satisfactory measures are in place to prevent, control and reduce sea lice on farm sites. Farmers are required to report the weekly average adult female sea lice numbers per fish on farm sites to the Marine Fish Health Inspectorate (FHI).[197] The FHI can carry out inspections and assess measures in place to control and reduce parasites on farms. Before March 2021, farmers were only required to report if specific levels were met or exceeded (weekly average of 2 adult female sea lice per fish). The amendment was initiated to reduce sea lice instances with stricter surveillance.

[195] Sernapesca, BCG analysis

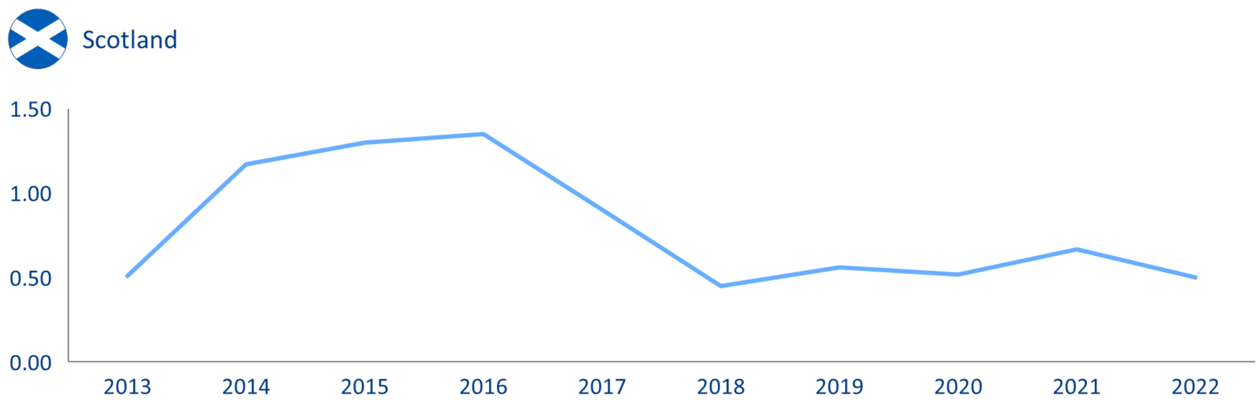
[196] Kunngerð nr. 75 frá 28. juni 2016 (lúsakunngerðin), Kunngerð um broyting í kunngerð um yvirvøku og tálming av lúsum á alifiski (Lúsakunngerðin) frá 3. juni 2021

[197] Scottish Government

Today, if sea lice count reach or exceed an average of 2.0 adult female sea lice per fish, the FHI will increase monitoring of site until levels are below 2.0. If levels reach or exceed 6.0, the farmer must intervene with treatments or harvesting until levels are below 2.0 again.

Scotland had a sea lice outbreak in 2014-2016, where average number of adult female sea lice per fish went above 1.0. between 2018 and 2022, the adult female sea lice levels were around 0.5, which is low in comparison to the 10 years shown in Figure 4.46.

FIGURE 4.46: YEARLY AVERAGE ADULT FEMALE SEA LICE PER FISH IN SCOTLAND FROM 2013 UNTIL 2022[198]



Internal monitoring and surveillance

In all focus markets, farmers are obligated to count sea lice. Internal monitoring obligations are stricter in Norway compared to Iceland, where the authority must approve the farmers monitoring plan. The plan must outline when and what routines the farmer will conduct to decrease risk of sea lice, including what treatments are expected to be used. The farmers must further have an internal animal welfare specialist to assess impact from treatments, including medicine resistance.

[198] 2013-2020 Scottish Salmon Producers Organisation (SSPO), 2021-2022 Scottish Government, Marine Scotland's Fish Health Inspectorate

FIGURE 4.47: INTERNAL MONITORING OF SEA LICE AND CONSEQUENCES ICELAND, FAROE ISLANDS AND NORWAY[199]

	Internal sea lice monitoring	Sea lice treatments	Consequences if above threshold
Iceland	• Monitoring plan for prevention to be approved and is overseen by the competent authority	• Approval from the Authority to initiate medicine treatments	• None stipulated in regulation
Norway	• Monitoring plan for prevention and treatments to be approved and is overseen by the competent authority • Internal animal welfare specialist to assess impact of treatments, incl. medicine resistance • New sea lice regulation for discussion to increase surveillance, incl. obligation of using closed wellboats	• Treatments allowed • Approval for treatments granted in the internal monitoring plan before production is started	• If authority does not agree with internal monitoring plan, it can lower threshold for sea lice in area, reduce biomass, require harvesting. etc. • If sea lie levels too high, authority can order mitigating actions • Farmers to pay a daily fine for every 10k salmon in the area if they do not comply with decision
Faroe Islands	• Monitoring plan for prevention and treatments of sea lice	• Treatments allowed	• If sea lice levels are above 1.0 three times in a row (count minimum every two weeks), or four times during the production cycle, the salmon must be harvested within 11 weeks • The national disease authority can further decide that maximum number of smolt in licenses is decreased

Pre- and post-treatments can be used to decrease number of sea lice. There are several methods used to prevent sea lice such as feeder fish (lump fish eats sea lice off salmon), bath in freshwater without medicine and with medicine.

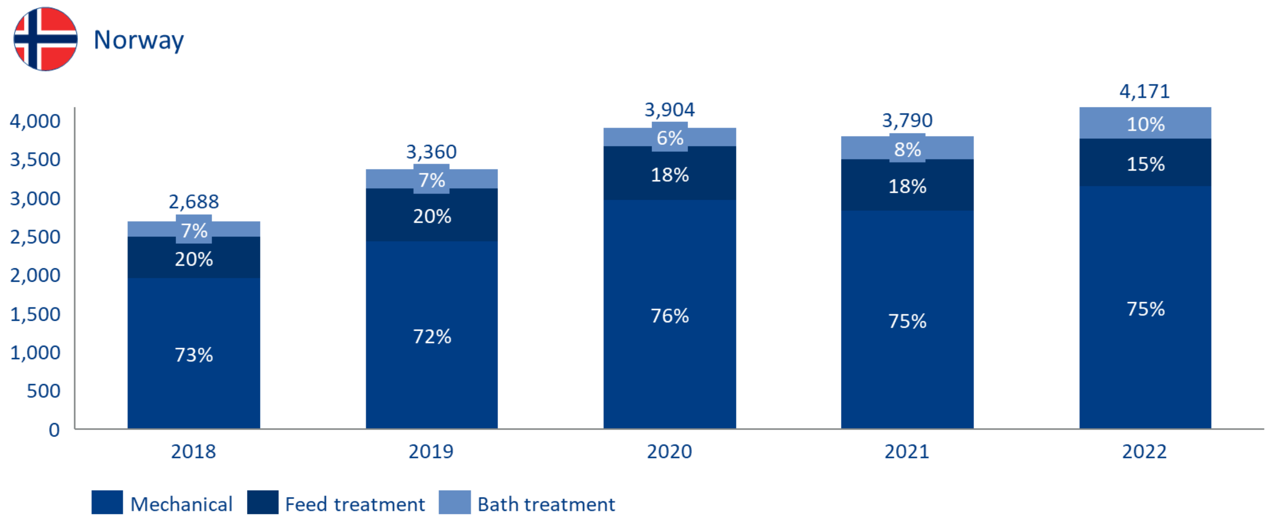
Medicine treatments for sea lice

Sea lice treatments are common Norway and increasingly used in Iceland. In Norway, treatments do not have to be pre-approved by authorities, but farmers must describe which treatments they expect to use ensure sea lice levels are below 0.2 or 0.5. A fish health employee is responsible for the fish when it is treated, both with medicine and non-medicine, and may only be treated by a veterinarian or fish health biologist. Farmers in Norway mainly use mechanical treatments, including medicine bath treatments.

[199] Dyrevelferdslove, Dyrehelsepersonelloven, Akvakulturdrifsforskriften, Matloven

Note: Non-exhaustive

FIGURE 4.48: NUMBER OF SEA LICE TREATMENTS IN NORWAY 2021 AND METHOD USED[200]



In Iceland, sea lice outbreaks rarely warranted medical treatment before the past six years. In 2017, the authorities approved medical treatment of salmon against sea lice for the first time in nearly 30 years, with a second treatment following later that year. Since then, several sea lice outbreaks have been deemed necessary to treat medically each year, with 5-7 production areas across 1-3 fjords treated each year in 2018-2022. In these instances, treatments in the form of feed (Slice, Emamectin benzoate 0.2%) and a bath medicine (Alpha Max, Deltamethrin 10%) have been approved to mitigate the spread of sea lice. Initially, Alpha Max played a larger role in treatments, with a total of 5.1kg used in 2018. However, the use of Alpha Max has been reduced, with 0.6kg used in total in 2021. Slice feed treatments, on the other hand, have remained at 2.5-3.1kg total each year since outbreaks became more common (2018-2021).[201]

High use of medicine treatments can increase the resistance of the lice and as such lead to higher doses. Farmers are thus focused on decreasing their use of medicine and developing other methods and technologies to reduce number of sea lice. In Iceland, no evidence of resistance to medicine has yet been found, based on analysis of 412 samples.[202] However, the Fish Disease Committee and other stakeholders have noted that more research is needed in accordance with the growth of outbreaks and treatments.[203]

4.5.4 Viral diseases are widespread across markets

Pancreas Diseases (PD), Cardio myopathy syndrome (CMS) and Infectious Salmon Anaemia (ISA) have generally been the main virus challenges in the industry. However, focus is here placed on ISA due to the recent outbreak in Iceland.

[200] Mattilsynet luse data, Barentwatch, Havforsikningsinstituttet

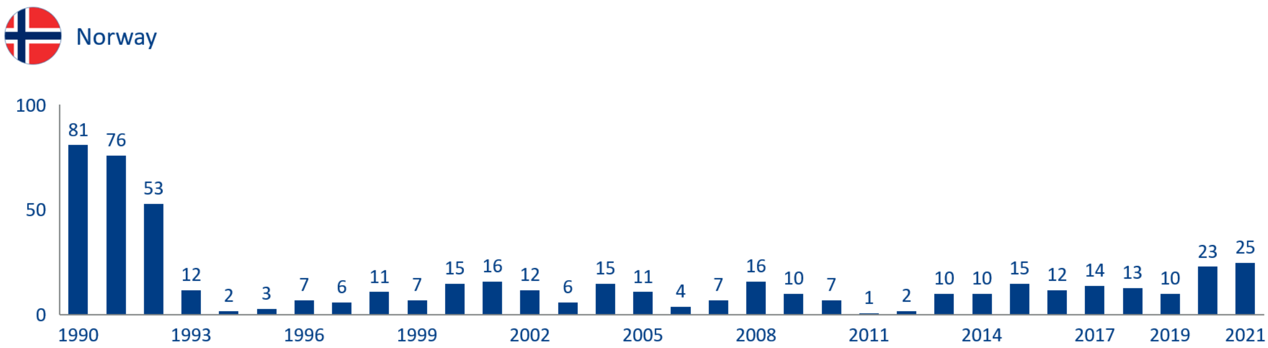
[201] The Veterinarian of Fish Disease Annual Reports (2017-2021); Until September 2022, 7 production areas across 3 fjords had been treated

[202] The Veterinarian of Fish Disease Annual Reports (2017-2021)

[203] The Veterinarian of Fish Disease news; Expert interviews

ISA has historically and continues to be a large biological challenge in Chile, Norway, Scotland, and more recently in the Faroe Islands. In Norway, annual cases of ISA infection in production areas have decreased since 1990 but still remain a large challenge, with 25 production areas infected in 2021. The ISA virus was registered for the first time in the Faroe Islands in 2000 and in Scotland in 1998. In Scotland, the ISA virus was confirmed in 11 production areas (out of ~160 sites).[204] In 2007, Chile experienced the worst ISA outbreak ever recorded, where 97% of all production areas got infected. This led to enormous economic loss of ~2bn USD and societal loss, where thousands of workers lost their jobs as farmers.

FIGURE 4.49: ANNUAL CASES OF ISA OUTBREAKS IN NORWAY (NUMBER OF INFECTED PRODUCTION AREAS)[205]



Vaccines for ISA and testing for HPR0 ISAV strain to limit outbreaks

Vaccines are available to limit risk of ISA virus and are commonly used in Norway, although not an obligation. There is higher demand than supplies for the ISA vaccines, and it does not guarantee that salmon cannot be infected, though it can limit the risk.

The relevant authorities in the focus market are increasingly investigating the effect of the non-pathogenic virus HPR0 ISAV strain. The strain can mutate into HPR-deleted strains of ISA and thus lead to ISA virus outbreaks. The World Organization for Animal Health has determined that the HPR0 should be internationally reported.[206] Currently in Chile, Norway, The Faroe Islands and Scotland there is no disease control strategy to monitor HPR0 and the EU regulation on animal welfare does not obligate farmers to report a confirmed presence of HPR0.[207] However in reaction to these developments, a project group has been formed in Norway to develop a method to model the risk of an area developing ISA based on the presence of HPR0 and for local spread of the HPR related ISA virus. The objective of the model is to make monitoring more efficient and risk-based and to support the implementation of a more effective disease prevention scheme. Similar research is underway in Chile, Canada, the Faroe Islands and Scotland.

[204] The Faroese Food and Veterinary Authority

[205] Veterinærinsinstituttet (Norwegian Veterinary Instititue)

[206] Norwegian Veterinary Institute - ILAV

[207] Regulation (EU) 2016/429

Methods to decrease risk of ISA outbreaks and other viral diseases

Farmers must generally harvest the fish immediately in the case of an ISA outbreak.[208] In order to prevent this occurrence, each focus market has implemented several measures to limit ISA outbreaks. In all markets, an identification of ISA and other listed diseases must be reported to authorities. In Scotland and Norway, there are also regulations on disease prevention during transport, including:[209]

- A transport unit used must be approved by the competent authority.
- The duration of the transport, including wellboats, must be as short as reasonably possible, the means of transport must be cleaned and disinfected before dispatch.
- If the animal is transported in water over land, it must be transported in such a way that water cannot escape from the means of transport.
- Any water exchange must be carried out at a water station which the competent authority has approved.

A farmer must further record information on the number of salmon that die in the course of transport, all water exchange, the source of any water introduced into wellboat, and the location at which any water is discharged.

In Norway, farmers must further report the following:[210]

- Number and/or weight of salmon in transportation.
- Disease and mortality in transportation, including probable cause.
- Facilities visited.
- Use of oxygen in water.
- Sea temperature and other water quality parameters that are monitored.
- Time, quantity of cleaning and disinfection remedy and method used to clean and disinfect the transport unit.

These types of requirements are not applicable in Iceland.

Recent ISA outbreaks in Iceland promote strengthening regulation to mitigate outbreaks

The volume growth in Iceland since 2015 and expected growth, increases the importance of clear regulation and guidance on how to reduce the risk of ISA outbreaks. Iceland experienced its first ISA outbreak in November 2021 in Reyðarfjörður in the Eastfjords, leading to all salmon in infected sites to be harvested. The operator had experienced increased mortality in one production area in 2021 without identifying the cause. From April 2022 through May 2022, the disease spread out and infection was

[208] Expert interviews, Master Thesis on Quantifying the economic impacts of viral disease in Norwegian aquaculture, Rasmus Rasmussen

Note: Although the harvesting of affected fish is not automatically required under Icelandic legislation, the authorities can obligate farmers to do so, and this was done in response to the 2021 ISA outbreak.

[209] The Aquatic Animal Helath Regulations 2009 (Scotland) No 85/2009

[210] Forskrift om transport av akvakulturdyr (FOR 2008-06-17-820)

confirmed in two production areas in Reyðarfjörður and in two other production areas in another fjord in the East, Djúpivogur resulting in all infected sites in both Djúpavogur and Reyðarfjörður to be harvested. In the meeting notes from the Fish Diseases Committee, it is concluded that the ISA virus most likely was transmitted to Djúpavogur due to shared use of equipment. Sequencing of the virus revealed that the first outbreak in Reyðarfjörður was a so-called primary outbreak due to mutation of a local non-pathogen ISAV HPR0 variant. Infection tracing showed that the virus isolated from the second outbreak was identical to the first outbreak.[211] In other words, the virus can spread between production areas and fjords if an undiagnosed salmon is transported in an open wellboat used by sites in different fjords or if the same equipment is used.

The process to identify the disease was relatively lengthy, where samples were e.g., sent abroad for testing. However, the farmers and the Food and Veterinary Authority acted as if a disease was confirmed. The potential infectious area was locked down, any transportation of products from the production area was prohibited, and all exposed salmon was slaughtered. After the diagnosis of the virus, a surveillance plan was activated with increased sampling in all pens once a month for a period of six months.

In reaction to this, a working group has been established to work on new guidelines on disease prevention and surveillance with reforms expected to be implemented early 2023.

4.5.5 Risk of bacterial diseases higher in warmer sea temperatures

Winter Ulcer bacteria are mainly reported in cold sea water temperatures. The bacteria can increase mortality and is mainly found in Norway, the Faroe Islands and Iceland, although to a much lesser extent than other biological challenges. The disease Salmonid Rickettsia Septicaemia (SRS) is one of the main fish health challenges in Chile, with only a few instances been recorded in Norway and Scotland.

Bacteria can be treated by antibiotics and have been used in salmon farming since the 1980s. Over time, increased focus has been placed on limiting use due to negative impact on the environment and increasing medical resistance.[212] Consumers' demands for antibiotic-free meats is also increasing,[213] indicating a potential to attract price premiums where production is antibiotic-free.

Chile uses most antibiotics relative to production in focus markets

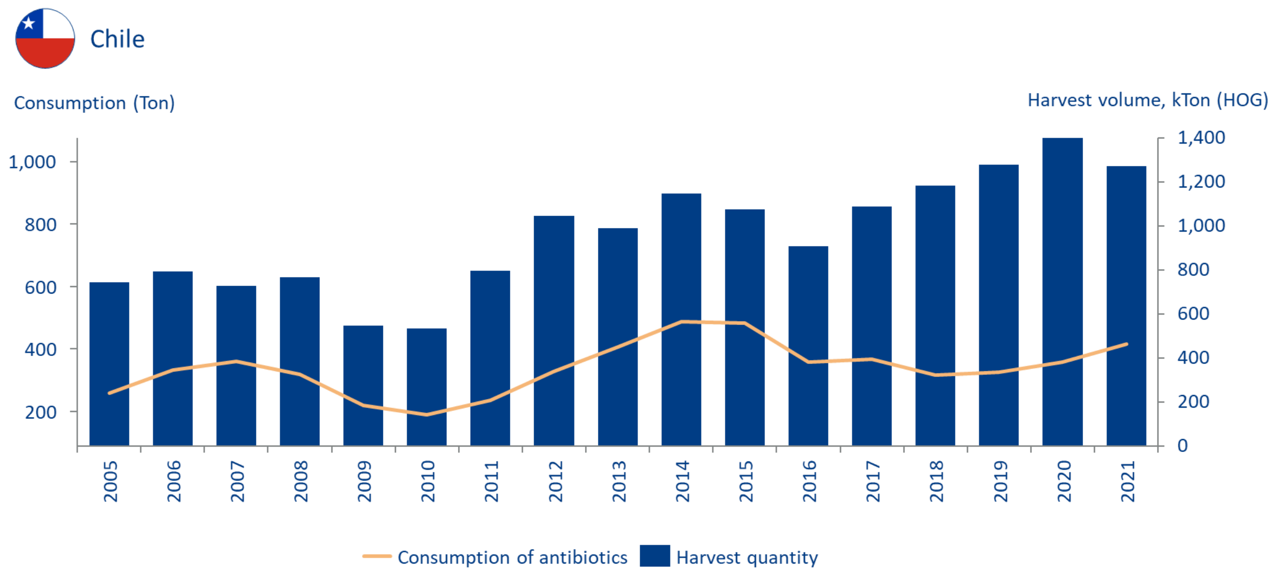
Chile, due to higher water temperatures, is more exposed to diseases and uses most antibiotics relative to production. As an example, in 2021, a total of ~460 ton was used to produce ~1mT of salmonoids (Atlantic salmon, trout and Coho salmon).

[211] Meeting minutes from the Fish Disease Committee meeting June 13, 2022

[212] Sernapesca, BCG analysis

[213] Consumer Reports – Natural and Anitbiotics Labels Survey 2018

FIGURE 4.50: USE OF ANTIBIOTICS PER HARVEST VOLUME IN CHILE (2005-2021)[214]



The use of antibiotics reached its high point in Chile in 2014 with almost 600 ton of antibiotics consumed to produce ~900kT salmonoids. The industry in Chile is focused on decreasing the use of antibiotics with the objective to decrease consumption to 200 ton per million ton of harvested volume.[215] However, Salmonid Rickettsia Septicemia (SRS) is widespread in some regions in Chile and the largest share of antibiotics consumed is to fight SRS. SRS occurs mainly in Chile, but has also been observed, albeit to a much lesser extent, in Norway, Scotland and the UK.

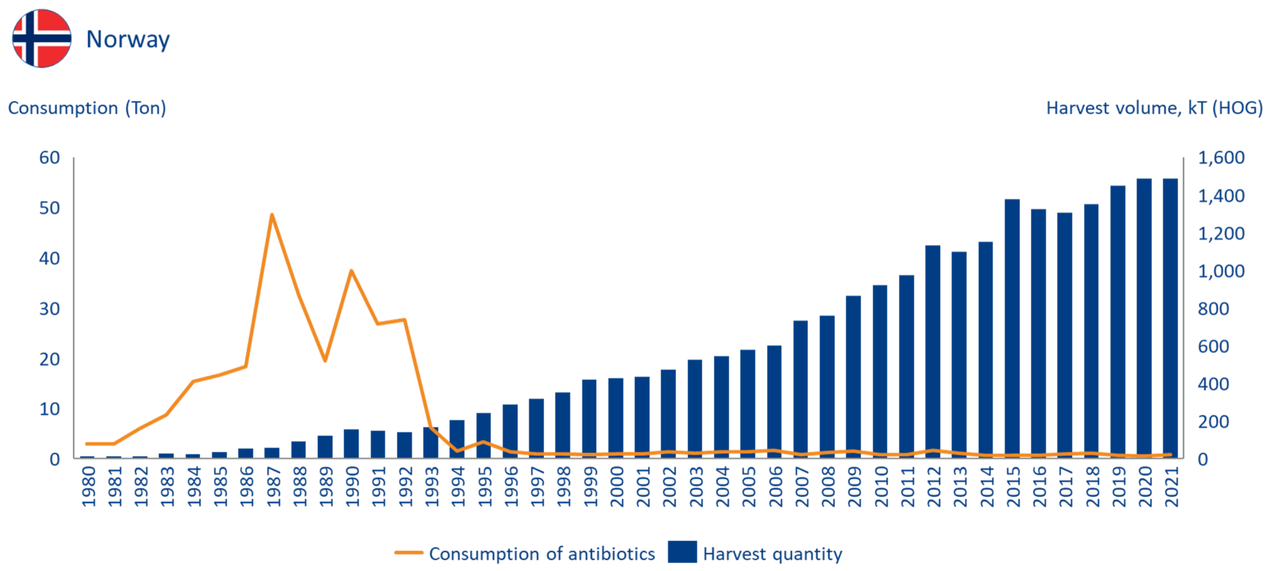
Limited use of antibiotics in Norway and less than 1.4 ton per year since '94

In Norway the use of antibiotics reached its maximum of 50 ton in 1987 and has been less than 1.4 ton since 1994.

[214] Sernapesca, BCG analysis

[215] Monterey Bay Aquarium, the Chilean Salmon Antibiotic Reduction Program (CSARP)

FIGURE 4.51: USE OF ANTIBIOTICS PER HARVEST VOLUME IN NORWAY (1980-2021)[216]



In the 1980s, the occurrence of bacterial disease increased in Norway and no effective vaccine was available explaining the relatively high quantity of antibiotics used in the period. The use of antibiotics dropped significantly in 1993 and has since been low due to increased use of vaccines against the main bacterial challenges.

Antibiotics rarely used in Iceland in the past ten years

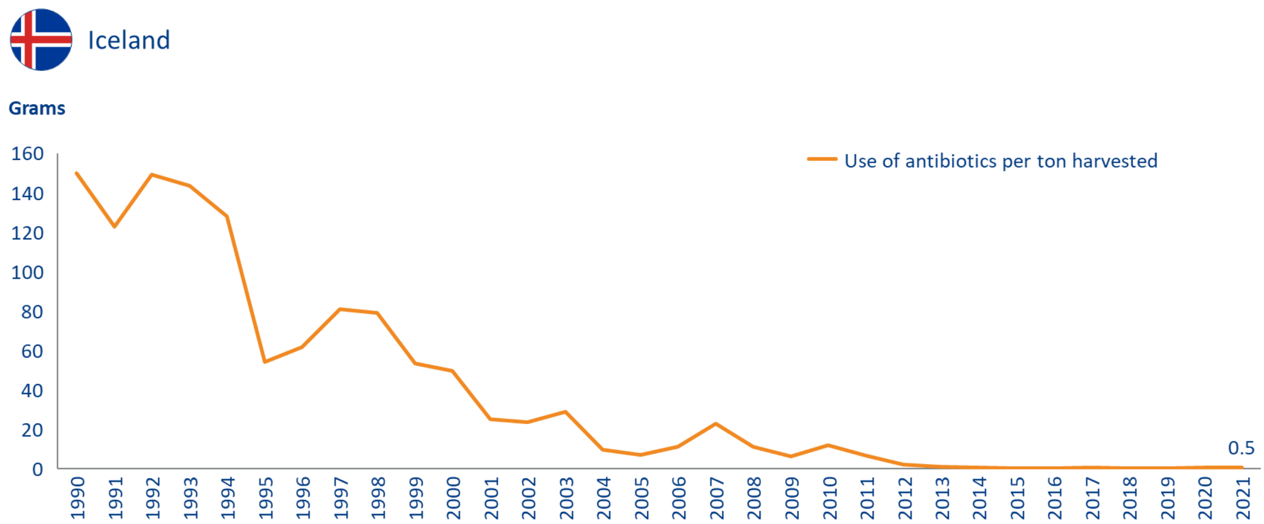
In Iceland, the use antibiotics and other medicines is prohibited unless approved by the Food and Veterinary Authority.[217] For a decade until 2021, no antibiotics had been used in farming in Iceland, where antibiotics were used in land-based farming of char, a total of 26 kg. Antibiotics used in traditional farming was used in two instances to against a disease found in a fry from a wild salmon to be used in salmon farming. The total antibiotics per ton of fish harvested was 0.5 gr in 2021, which is a large decrease since 1990 where 150 gr. was used per harvest ton.[218]

[216] FAO, Fiskeridirektoratet, BCG analysis

[217] The Veterinarian of Fish Disease Annual Report 2021

[218] The Veterinarian of Fish Disease Annual Report 2021

FIGURE 4.52: USE OF ANTIBIOTICS IN ICELAND INCLUDING ALL FISH AND LAND-BASED (1990-2020)

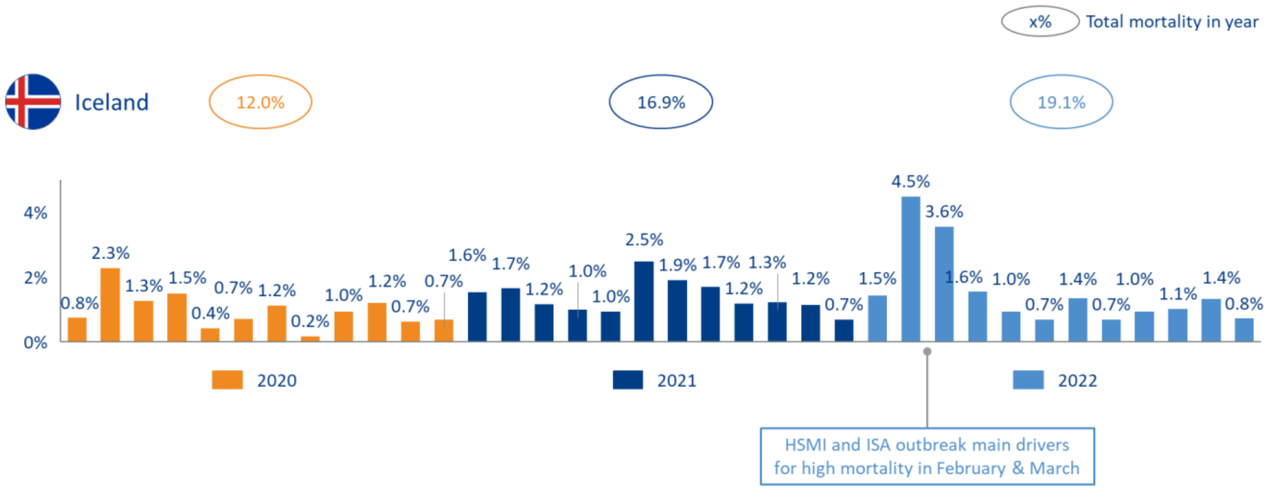


4.5.6 Iceland's mortality has increased from 12% in 2020 to ~19% in 2022

Mortality in Iceland is mainly due to low quality smolts stocked in pens (i.e., not yet smoltified and thus not equipped for sea water) and handling of smolts when transferred and stocked in pens.[219] Diseases and sea lice treatment have also led to mortality.

The level of mortality is indicative of fish welfare, resource utilization, efficiency of monitoring, and surveillance. The mortality rate in Iceland has increased from 12% in 2020 to 19.1% in 2022. The percentages shown in Figure 4.53 are the share of mortality per month of total number of salmon in all pens in Iceland.

FIGURE 4.53: MONTHLY AND YEARLY AVERAGE MORTALITY RATES FROM 2020 UNTIL AUGUST 2022 IN ICELAND[220]



[219] Icelandic Food and Veterinary Authority, Expert interviews, BCG analysis

[220] Icelandic Food and Veterinary Authority

In the first months of 2022, the HSMI virus in Dýrafjörður led to mass mortality.[221] In January 2022, an increase mortality in the fjord was reported to the Food and Veterinary Authority. Samples were assessed and concluded that the HSMI virus had spread in the area. The mass mortality in the fjord was further driven by high volume of large salmon (and thus high density) in the production area, a recent sea lice bathing treatment in November 2021, and low sea temperatures.[222] This led to large volume of salmon harvested to mitigate outbreak.

Average mortality in Norway at 18% from 2019 – 2021

In Norway, mortality rates have been relatively stable from 2005 until 2018, ranging between 12 and 17%. However, Norway has experienced higher mortality rates since 2020, reaching a high point of 21% in 2022 (Average for January-September) due to several factors such as increase of bacterial decreases, sea lice and sea lice treatments leading to wounds. The mortality rate is also considerably higher than in Chile in 2020 and 2021(from January until June).

FIGURE 4.54: AVERAGE MORTALITY RATE PER YEAR FROM 2016 UNTIL 2022 TO DATE IN NORWAY [223]

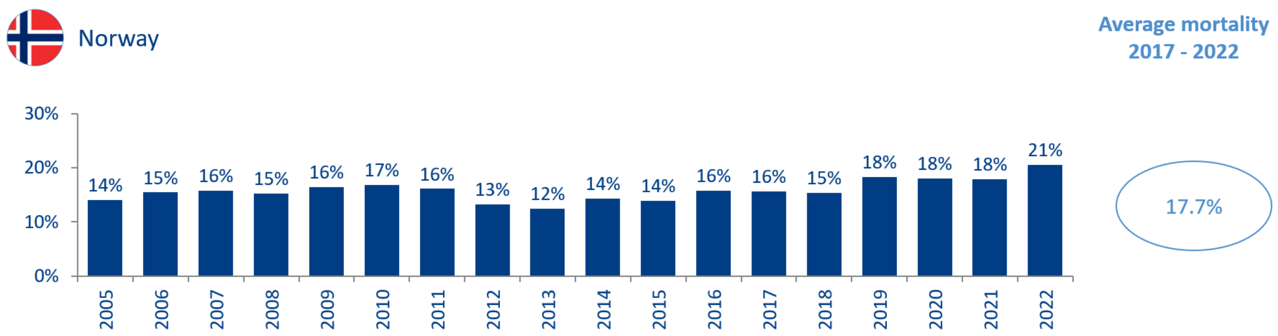
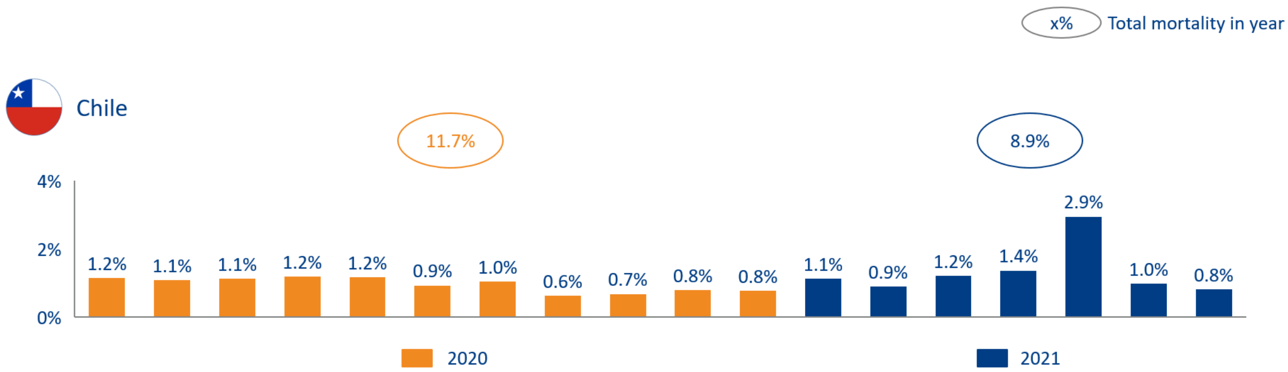


FIGURE 4.55: AVERAGE MORTALITY RATE IN 2020 AND FROM JANUARY–JUNE IN 2021[224]



[221] Icelandic Food and Veterinary Authority

[222] Icelandic Food and Veterinary Authority

[223] Mattilsynet, Veterinærinstituttet, Fisk.no, BCG analysis

[224] Sernapesca, BCG analysis

4.5.7 Sub-conclusion

In all focus markets, farmers must conduct an environmental impact assessment of its planned production. Farmers must further develop an internal monitoring plan to limit impact on environment and to prevent diseases overseen by administrative bodies.

Biological challenges differ across markets. Sea lice have historically been the largest biological challenge in Norway, Scotland, and the Faroe Islands, whereas Salmonid Rickettsia Septicemia (SRS) and other bacterial outbreaks represent challenges for farms in Chile due to the warmer temperatures. Iceland has not experience disease challenges on the same scale as in the other markets, but number of adult female sea lice has increased, and Iceland reported its first ISA outbreak in 2021 and 2022. Thus, while Norway and the Faroe Islands have stricter regulations than Iceland and other markets especially around sea lice, including consequences in case levels are above a defined threshold, recent increases in sea lice in Iceland have prompted more industry and regulatory attention. Moreover, the process to identify the recent ISA outbreak was relatively lengthy and allowed the virus to spread widely, highlighting the need to strengthen the regulatory framework in Iceland both to limit the risk of, and to mitigate, future outbreaks.

While Iceland has historically not had as many or as severe outbreaks as other focus markets, the recent growth of the industry has brought with it an increase in biological challenges. In developing Iceland's aquaculture strategy, special focus needs to be placed on the potential impact of continued growth to fish health and the environment.

4.5.8 Next steps for consideration based on practices in other markets

Tighten regulation and monitoring of sea lice and streamline treatment

Number of adult female sea lice per fish have increased in Iceland in the recent years. To limit the risk of sea lice outbreaks, the following actions, inspired by regulation in other markets, can be considered:

1. Adjusting the sea lice threshold from 0.5 to 0.2 during migration period.
2. Increasing farmers' internal monitoring, e.g., with weekly reporting all year and a detailed description of preventive and planned treatment to be approved and overseen by the Food and Veterinary Authority.
3. Implementing in regulation consequences (e.g., penalties) if the number of adult female sea lice is higher than the threshold over a specific period, similar to the Faroese Islands and Norway.
4. Streamlining the medicine treatment application process to ensure fast reaction to limit the risk of sea lice outbreaks.
5. Considering pre-approving one treatment per production cycle or in a fjord as a contingency plan if sea lice threshold is breached. However, this requires assessment on impact on environment and potential medicine resistance.
6. Requiring a fish health specialist or the use of one if sea lice treatments are pre-approved.

Assess the risk of ISA outbreaks derived from the HRP0 strain

The industry is focused on assessing the potential risk of ISA outbreaks derived from the HRP0 strain due to a recent announcement from the World Health Organization for Animal Health that the HRP0 strain should be reported. In that relation, the following can be considered:

1. Forming a research group to analyze the presence of the ISAV HRP0 strain in farming areas.
2. Implementing regular screening for the ISAV HRP0 strain.

Increase internal monitoring to limit risk of diseases, including requirements for transportation

The first ISA outbreak was reported in Iceland in 2021 and the diseases was spread to two different fjords. To limit the risk of future ISA outbreaks, the following can be considered:

1. Implementing clear guidance on internal measures and reaction if there is a suspicion of ISA and other diseases, e.g., based on the EU regulation on fish welfare with reference to the EEA agreement.
2. Enforcing stricter internal biosecurity procedures related to transportation, e.g., an obligation to disinfect effluents and equipment before transportation, reduce seawater-to-seawater fish transfers, reduce the number of long transportations between fjords.
3. Surveying transportation, e.g., based on farmers' reports on death and diseases during transportation, measuring oxygen levels and sea temperatures.

Consider vaccination against ISA virus

To limit risk of ISA outbreaks, vaccinations can further be considered:

1. Assessing the impact of ISA vaccination on fish welfare and environment.
2. Considering assessing areas with higher risk of ISA and consequently based on scientific research whether a) vaccination should be mandatory for all areas, b) vaccination should be mandatory in higher-risk areas, c) mandatory in case an area or farmer has experienced infections, d) vaccination to be optional.

Clarify minimum distance between production areas to limit risk of outbreaks

There must be a 5 km distance between production areas if they are not operated by the same farmer. However, an exception can be granted (e.g., in Ísafjarðardjúp), and it is unclear how the distance should be measured and what conditions farmers must adhere to when exceptions are granted. The following can thus be considered:

1. Implementing requirements or guidance on how operations should be conducted if production areas are within 5 km distance from each other, e.g., regarding equipment used in fjord, fallow out period, number of generations in fjords, measures to take to limit the risk of disease spreading between production areas.
2. Clarifying how to measure distance between production areas, e.g., whether it is from the middle of a production area or boundaries of the cages around.

Clearly state in regulation the measures to be taken in case of outbreak

Despite prevention efforts, some parasitic and viral outbreaks are likely to occur, and it is important that the procedure that follows is clear. For example, following an ISA outbreak, it should be clear exactly which pens farmers are expected to harvest, and whether there is a wider zone of potential infection to be monitored more closely. Having these regulations established beforehand, rather than deciding them on a case-by-case basis, will accelerate the reaction time and consequently reduce the risk of the outbreak spreading further.

Implement surveillance and regulation to increase welfare and monitor environmental impact

Focus on mitigating challenges related to fish welfare have increased in the industry with governments implementing stricter internal surveillance and incentivize development of new technology to increase welfare. To increase fish welfare in Iceland, the following can be considered:

1. Allowing surveillance of smolt facilities or receive data on smolts stocked in pens to ensure weight is optimal and smolts are smoltified (i.e., feasible to survive in sea waters).
2. Reviewing how maximum density is calculated to decrease health risk, e.g., from 25 kg/m^3 to 20 kg/m^3, or by only measuring the volume in the first 15 meters below the ocean's surface.
3. Implementing incentives to develop farming in closed- and semi-closed pens to limit risk of disease and sea lice.
4. Implementing surveillance without deployment, e.g., with the use of drones to inspect production areas without the use of farmers own vessels.
5. Simplifying governmental surveillance by improving internal surveillance requirements monitored by authorities.
6. Increasing surveillance resourcing and considering structural changes, e.g., by combining different specialists in one entity (e.g., marine biologists, fish disease specialists, etc. purely focusing on aquaculture).
7. Allowing only one generation in fjords with fallow out period at the same time to limit spread of diseases.
8. Tagging or clipping smolts to enable identification of escapees by people or cameras, allowing tracking of intrusion without the expenses of DNA tests.
9. Monitoring copper accumulation in sediments as a part of surveillance around organic load impact on the seabed.

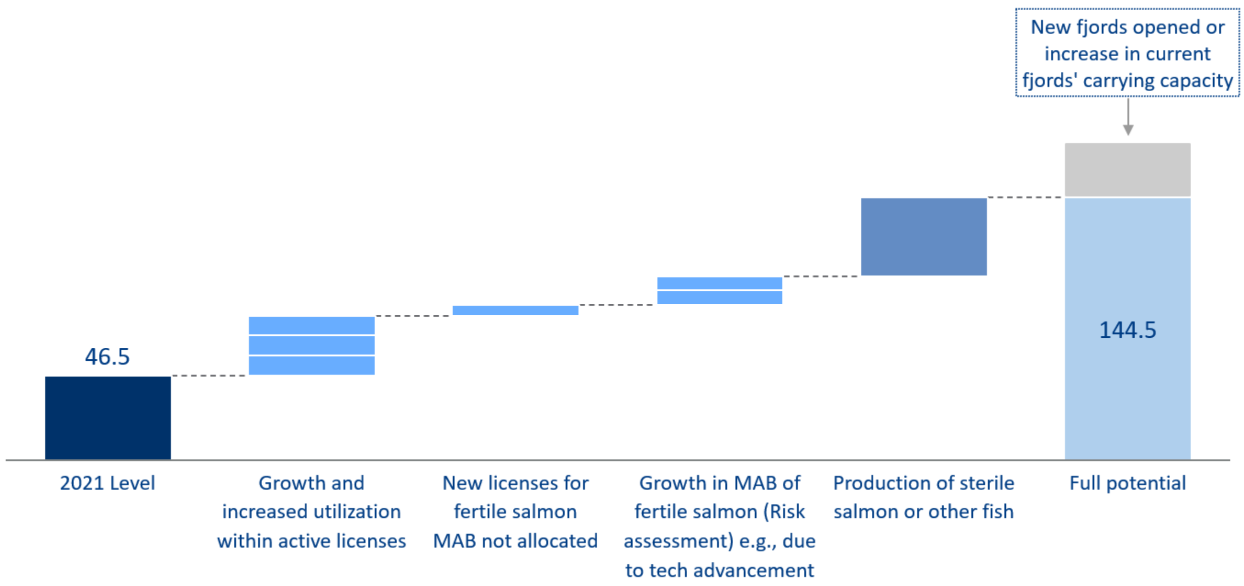
Provide guidelines on best practices in farming

Considering all the above mentioned, it is considered useful for both the government and companies to have one guidance consolidating both internal measures related to biosecurity, prevention, efficient reaction plan, etc.

4.6 Production volume

Iceland's traditional aquaculture sector has been growing faster than the global salmon farming industry. The following section explores how the sector can continue this growth trajectory. The analysis focuses on levers to grow fertile salmon, drawing on the preceding sections to understand how regulatory and environmental factors come into play as progress made in decreasing the environmental impact of traditional aquaculture are likely to support future growth.

FIGURE 4.56: POTENTIAL FOR VOLUME GROWTH OF SALMON IN ICELAND (KT)



Several levers exist to increase the production of fertile salmon in Iceland. The first involves growth within current active licenses through higher MAB utilization. The second lever is to allocate the rest of the available licenses within the current maximum carrying capacity and MAB of fertile salmon according to the risk assessment. The third lever pertains to potential changes in the risk assessment if advances in environmental impact can be illustrated (a new risk assessment could also lead to a decrease in MAB). Lever four reflects the ability to produce sterile salmon or other fish species up to the current carrying capacity. Finally, changes in carrying capacity of current fjords or assessing new fjords will open for new license allocations. These levers are described in more detail in this section.

4.6.1 Potential for harvests to increase within active licenses

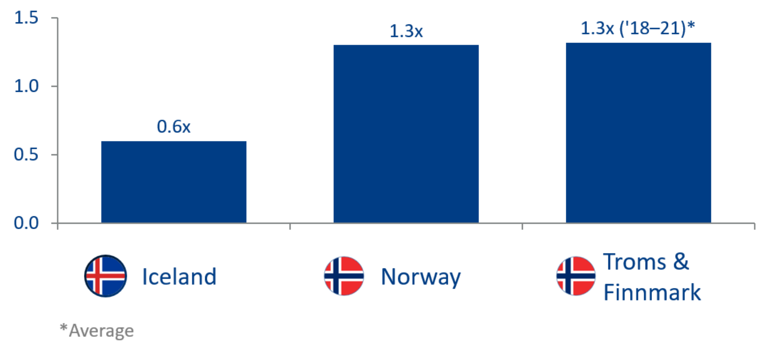
Some future growth is expected as the industry in Iceland matures, and new farms reach their full production capacity. Improvements could also stem from targeted efforts towards efficiency, both by farmers and the government. Increased utilization can be achieved with larger smolt, thereby decreasing their time at sea. Using larger smolt is also likely to lead to a decrease in mortality. In addition any effective measures taken to improve fish biology will lead to higher utilization.

Recently licensed farms are expected to increase production as full capacity is reached

In January 2021, the combined MAB of active licenses was 75.7kT, on the basis of those licenses, ~46.5kT of salmon was harvested,[225] resulting in an average MAB harvest of 0.6x in 2021 (an increase from 0.5x in 2019). Given the large share of new licenses granted in the past three years (~25kT MAB), the average harvest per license is expected to increase when salmon generations from the past three years reach a harvestable size.

Indicative of Iceland's MAB utilization potential is that in Norway, the average MAB harvest in 2021 was 1.3x, see. Figure 4.57. When examining areas with sea temperatures most similar to Iceland (Troms and Finnmark), the average MAB harvest in 2021 was 1.46x. That said, the average harvest per license in Troms and Finnmark has been on average 1.32x from 2018 to 2021. The peak of 1.46x in 2021 demonstrates the possibilities available for improvement.

FIGURE 4.57: AVERAGE HARVEST PER LICENSE IN NORWAY AND ICELAND IN 2021 AND NORTHERN NORWAY ('18-21)[226]



- Low average harvest per license in Iceland mainly driven by new licenses granted in the past three years (~30kT MAB), with salmon not harvested until end of production cycle (after 2-3 years)
- Average harvest per license expected to increase in Iceland with potential to reach +1.3x per license if only considering similar sea temperatures in Iceland and Northern Norway (Troms and Finnmark)

Higher biomass utilization can increase harvests per license

Even when a farm has completed a full cycle and is harvesting at capacity, overall harvest volume per allowed biomass is impacted by several salmon health factors, include growth, disease, and mortality.

Improved mortality and disease experience

Mortality and diseases directly impact harvest volume and biomass utilization. Robust internal monitoring and effective surveillance key drivers to limit the risk of diseases and decrease mortality rates. Not only does this positively affect fish welfare, but it increases the productivity of the salmon farm. The future potential of these improvements is considered in Chapter 8.

[225] January 2021 license figure used as it takes up to three years to harvest salmon (1-2 years in sea), cf. further in Section 4.1.2

Note: January 2021 figure includes both fertile and sterile salmon

Note: MAB in standard licenses in Troms and Finnmark are 956 ton and are recalculated to 780 to enable holistic comparison

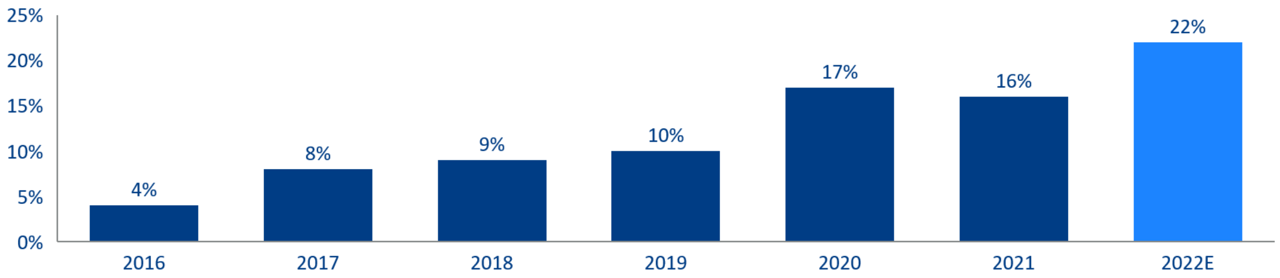
[226] Mowi, Pareto Securities, Fiskeridirektoratet, BCG analysis

Increased smolt weights

Within the current license regime in Iceland, it is likely feasible to increase the utilization rate and subsequently the harvest volume by releasing higher weight smolts. This will decrease time required at sea and reduce the risk of mortality.[227] The process requires smolts to grow longer in freshwater post smolt facilities before being transferred to sea. It is therefore a prerequisite that post smolt facilities in Iceland scale to cater for higher volumes of post smolt.

Today, the average smolt size is around 100 grams in Norway and Iceland. Norway has focused on increasing its smolt size since 2016, with 16% of smolts stocked above 250 grams in 2021 and expected to account for 22% of smolts stocked in 2022.[228] The largest farmers in Iceland are also investing in smolt facilities with the objective to increase smolt weight to 250-400 grams and hence reduce production time at sea by 2-6 months.[229] Similar trends can be observed in the Faroe Islands with smolt sizes expected to reach up to 1,000 grams.[230]

FIGURE 4.58: SHARE OF SMOLTS STOCKED ABOVE 250 GRAMS IN NORWAY



If these developments continue in Iceland and post smolt facilities scale, it is expected to contribute positively to MAB-utilization and harvest volume in the coming years.

Optimizing MAB-utilization has the potential to increase harvest volume

MAB-utilization is analyzed by calculating the total biomass in a period divided by total MAB in the same period. In 2021, Iceland had an average MAB utilization rate of 38%, compared to Norway with 86% MAB-utilization rate in the same period.

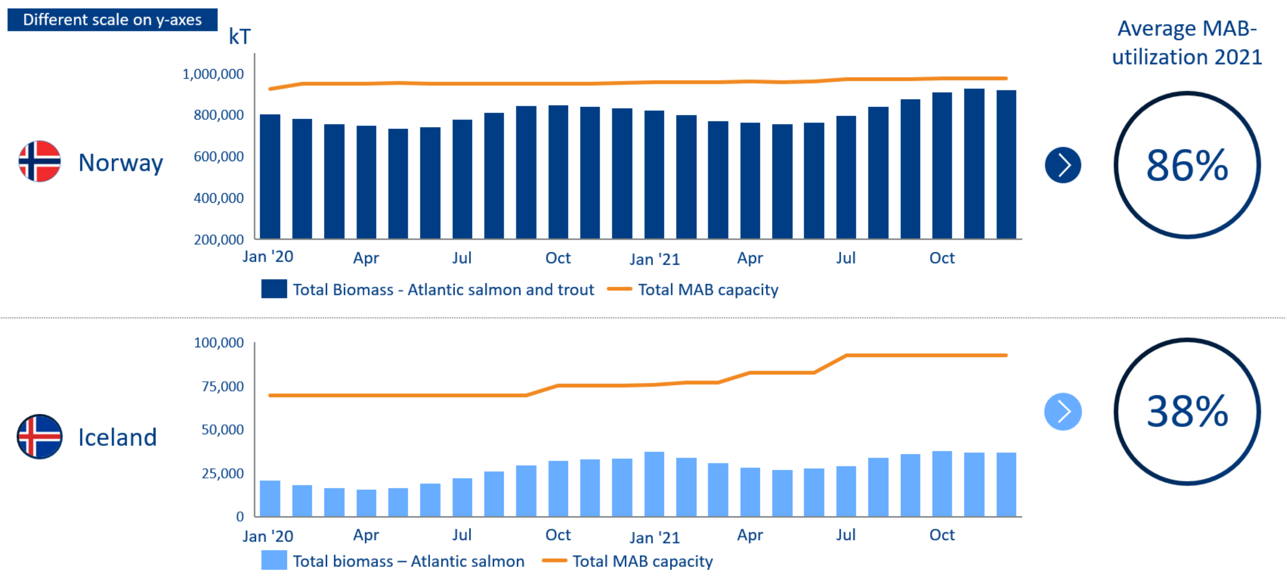
[227] Mortality and diseases estimated to be lower in post smolt compared to pens and less likelihood of diseases if smolts weight higher

[228] Kepler Cheuvreux

[229] Farmers annual and quarterly reports (Ice Fish Farm, Laxar and Icelandic Salmon/Arnarlax)

[230] Expert interview

FIGURE 4.59: MAB UTILIZATION IN ICELAND AND NORWAY[231]



Norway's high MAB-utilization is mainly driven by its license regime as described earlier, which allows farmers to optimize their use of MAB across production areas to account for the changes in volume during the production cycle. In Iceland, on the other hand, a license is linked to MAB in fjords and the biomass cannot be moved between production areas or fjords to increase utilization Thus, while there are more nuances to the difference between Norway and Iceland, this suggests that there is potential to enable higher MAB-utilization by allowing salmon farmers more flexibility to allocate their licensed MAB between various production areas. The high potential shown in the previous section of reaching 1.3x or higher MAB-utilization, as in Norway, might thus be enabled with more flexibility in the licensing system. Figure 4.60 illustrates the differences between the two regimes.

[231] Fiskeridirektoratet, The Food and Veterinary Authority in Iceland, BCG analysis

FIGURE 4.60: COMPARISON OF LICENSE REGIMES IN ICELAND AND NORWAY[232]

	Iceland	Norway	Description
Maximum carrying capacity	÷	✓	• MAB assessed in 13 geographical areas in Norway; Iceland carrying capacity is fjord based
Maximum carrying capacity of a fjord	✓	÷	• Licenses allocated as a share of fjords carrying capacity in Iceland
Risk assessment	✓	÷	• A risk assessment that aims to limit genetic introgression with wild salmon dictates MAB of fertile salmon in fjords
Production area MAB	÷	✓	• MAB per production area defined in Norway, not in Iceland
MAB can be moved between production areas	÷	✓	• In Norway, each license normally has a biomass of 780ton and can be used in 4-6 production areas in a geographic area • Operators can use combined licensed MAB in a geographic areas within the area's MAB limits, allowing movement of MAB between production areas

✓ Included when licenses allocated ÷ Not included when licenses allocated

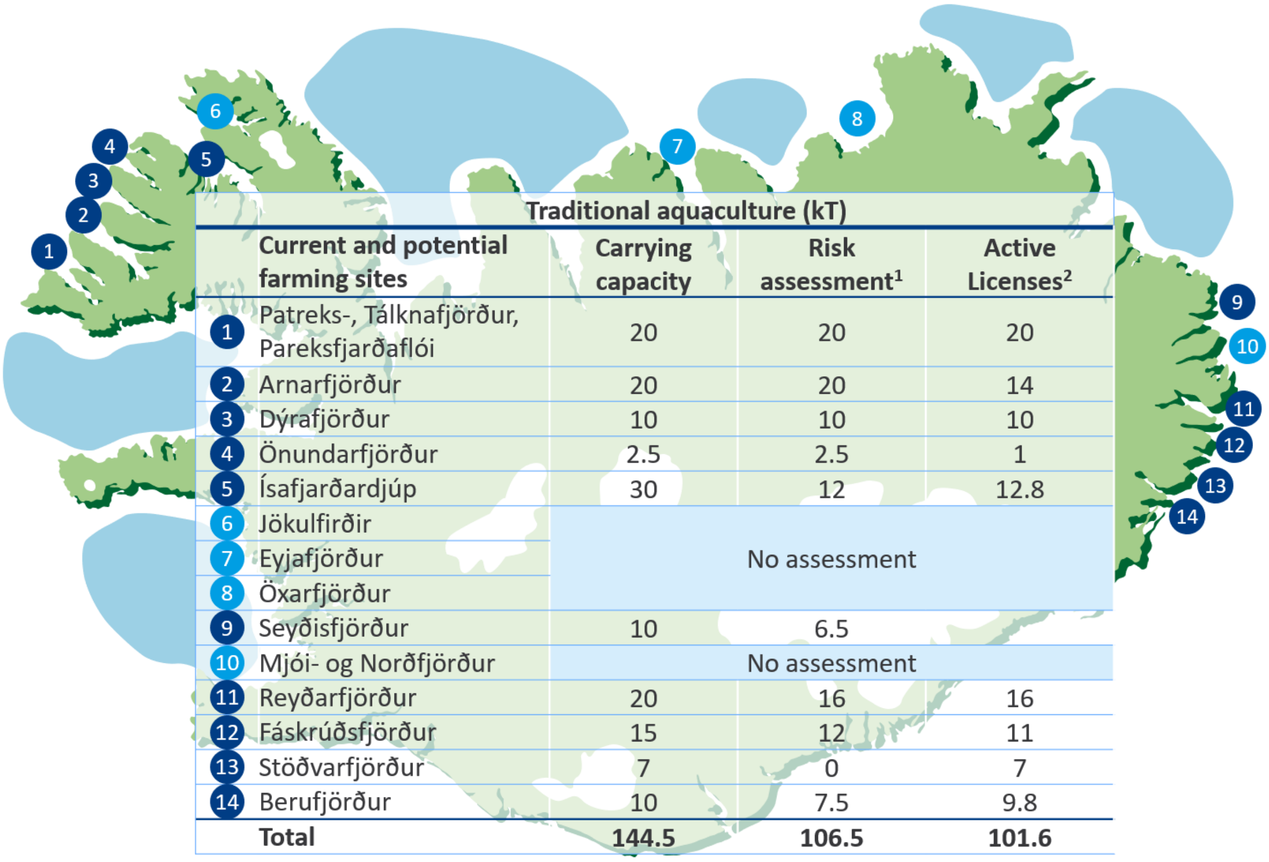
4.6.2 New licenses to fill gap to current risk assessment and carrying capacity

The Marine and Freshwater Research Institute (MFRI) has assessed the maximum carrying capacity in 10 out of 14 fjords that have not been conserved to protect wild salmon stocks. Based on the assessment, the total fish biomass allowed to produce in the fjords is 144.5kT. However, the risk assessment determines the total biomass of fertile salmon allowed to be farmed, and while this is equal to the maximum carrying capacity in four of the fjords, see Figure 4.61, it is lower in the remaining six fjords. Thus, the MAB of fertile salmon is currently capped at 106.5kT, out of which more than 90% of licenses have been allocated (~102kT MAB[233]). Based on the assessments, it is possible to issue licenses for fertile salmon biomass. In addition to this, infertile salmon or other species can be farmed up to the carrying capacity.

[232] Applicable legislations and regulations in Norway and Iceland, Expert interviews, BCG analysis

[233] Including sterile salmon likely to be converted to fertile salmon

FIGURE 4.61: CARRYING CAPACITY, RISK ASSESSMENT AND ACTIVE PERMITS IN ICELAND[234]



Traditional aquaculture (kT)				
	Current and potential farming sites	Carrying capacity	Risk assessment[1]	Active Licenses[2]
1	Patreks-, Tálknafjörður, Pareksfjarðaflói	20	20	20
2	Arnarfjörður	20	20	14
3	Dýrafjörður	10	10	10
4	Önundarfjörður	2.5	2.5	1
5	Ísafjarðardjúp	30	12	12.8
6	Jökulfirðir	No assessment		
7	Eyjafjörður	No assessment		
8	Öxarfjörður	No assessment		
9	Seyðisfjörður	10	6.5	
10	Mjói- og Norðfjörður	No assessment		
11	Reyðarfjörður	20	16	16
12	Fáskrúðsfjörður	15	12	11
13	Stöðvarfjörður	7	0	7
14	Berufjörður	10	7.5	9.8
	Total	**144.5**	**106.5**	**101.6**

Conservation area · Production area · No official risk assessment

1. Fertile salmon, 2. Fertile and sterile salmon. Active licenses for fertile salmon are ~90kT

4.6.3 Lower risk could lead to increased MAB of fertile salmon

Moving production areas further away from rivers could increase MAB of fertile salmon

The risk assessment considers the distance between production areas and salmon rivers, dictating the biomass of fertile salmon that can be produced. The decision on which production areas are used for salmon farming today occurred gradually when license applications based on farmer preferences were processed (see further the next section). Consequently, production areas were not selected based on a holistic assessment with the aim to find the combination of areas that would enable the highest amount of biomass.

Under the current risk assessment, MAB can therefore likely be increased by moving production areas further away from salmon rivers. Figure 4.62 is illustrative to this effect, where several different options

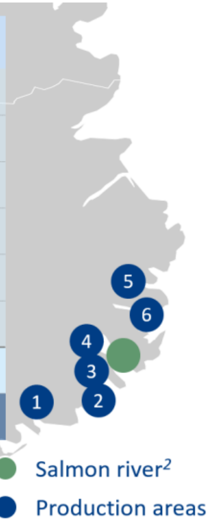
[234] The Food and Veterinary Authority in Iceland, BCG analysis

Note: Risk assessment covers fertile salmon, whereas active permits include fertile and sterile salmon production of production allocations are considered in the Eastfjords, resulting in possible MAB increase of ~-2.5-+10kT.

FIGURE 4.62: EXAMPLE OF HOW BIOMASS FOR FERTILE SALMON COULD INCREASE IF FARMING AREAS ARE MOVED[235]

East Fjords	Current allocation '20	Option 1	Option 2	Option 3
1 Berufjörður	7.5kT	10kT	3.5kT	1kT
2 Stöðvarfjörður	-	7kT	-	-
3 Fáskrúðsfjörður	12kT	0	15kT	15kT
4 Reyðarfjörður	16kT	16kT	20kT	20kT
5 Seyðisfjörður	6.5kT	6.5kT	10kT	10kT
6 *Mjóifjörður*				*Up to 6kT*[1]
Total	42kT	39.5kT	48.5kT	52kT
Impact on total MAB		**-2.5kT**	**+6.5kT**	**+10kT**

1. Assumption, risk assessment for Mjóifjörður not available
2. Non-exhaustive – River shown is important for the risk assessment



This is a theoretical study and the practical complexities and societal impact involved with reallocating production capacity is fully acknowledged. Implementing such changes would require cooperating with farmers carrying licenses in negatively impacted fjords, as well as collaborating with and supporting communities affected and other stakeholders' changes might impact. However, while this possibility could only be undertaken after careful consideration, it does present the potential to increase the MAB of traditional aquaculture in Iceland.

Reducing escapes can increase MAB of fertile salmon

The MFRI assesses the risk of genetic introgression of farmed and wild salmon as often as it is considered necessary and at minimum every third year. The next risk assessment is expected to be conducted in 2023. If the results of a new risk assessment led to an increase in MAB of fertile salmon, the farmers who currently hold licenses that are limited by the risk assessment, can increase their production volume accordingly. If there are multiple farmers in a fjord impacted by changes in the risk assessment, the biomass increases, or decrease is allocated proportionally based maximum amount stated in current operating licenses.[236]

As discussed in section 4.3.2, The MFRI monitors salmon rivers to assess how many farmed salmon escape and based on this assessment determines the maximum allowed biomass for fertile salmon. Thus, reducing escapes from sea pens could lead to an increase in the allowed biomass of fertile salmon. To this end, there are several solutions being developed in the industry to reduce the risk of salmon escapes, and hence intrusion rates. If applied and proven effective, these could result in changes to the risk assessment that would allow more biomass in fjords in Iceland. Such solutions include closed cages

[235] BCG analysis

[236] Article 24 (2) in the Icelandic regulation on fish farming no 540/2020

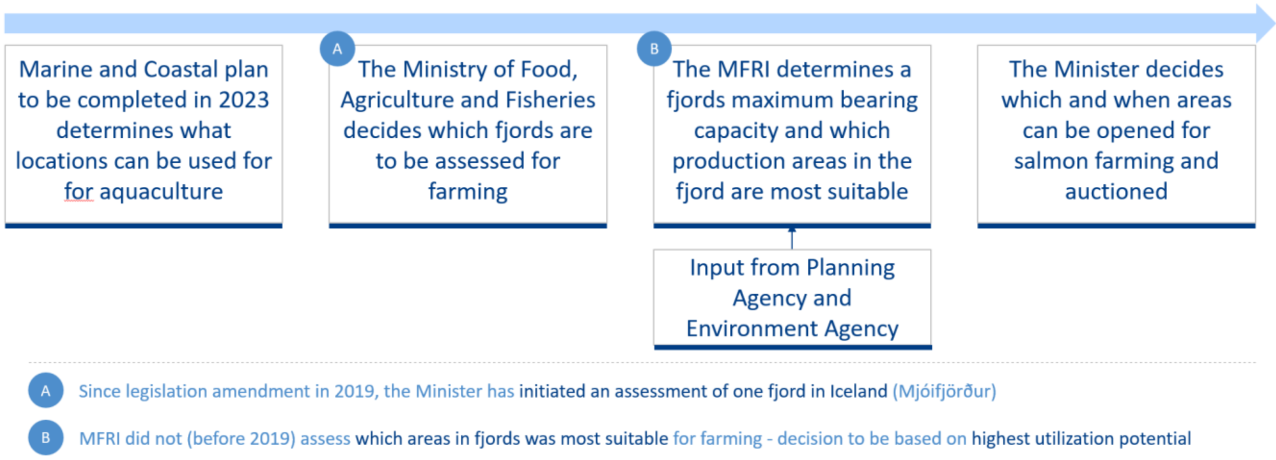
in sea that also allow for gathering of organic load, limiting impact on seabed and sea lice issues as well as double net-technologies limiting the risk of damages to pens; several methods of mitigating or limiting environmental impact have been discussed in section 4.4.

It is important to note that there is significant skepticism around the validity of the intrusion measurement in Iceland. It relies on image recognition available in a select number of rivers and self-reporting by anglers, both with limitations, e.g., not many anglers can easily identify the difference between a wild and farmed salmon with visual inspection. Strengthening the surveillance of intrusion and minimizing the risk of escapes is very important to safeguard the genetic integrity of the wild North Atlantic Salmon.

4.6.4 Exploring possibilities beyond current carrying capacity

Iceland can further increase its harvest volume by opening new production areas in three fjords not used for farming today and are not conserved or likely to be conserved based on the Marine and Coastal plan. The Ministry of Food, Agriculture and Fisheries decides when an environmental assessment should be conducted in a specific fjord.[237]

FIGURE 4.63: THE PROCESS OF AWARDING SALMON FARMING LICENSES IN NEW FJORDS IN ICELAND[238]

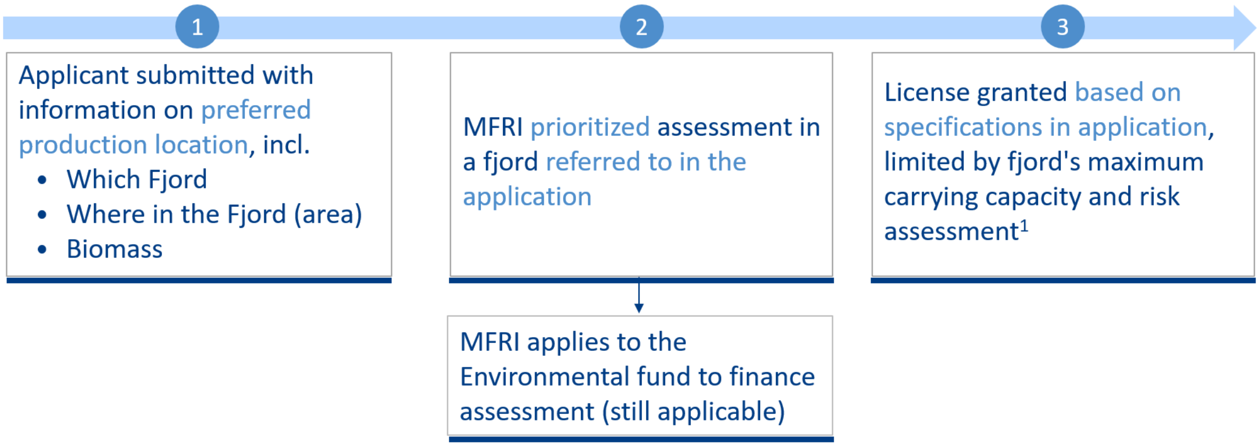


The decision process illustrated by Figure 4.63 was implemented in 2019. Since then, one fjord assessment has been initiated (Mjóifjörður) with results pending. Before the legislation amendment in 2019, a decision on which fjord should be utilized for salmon farming was largely driven by companies applying for licenses.

[237] Lög nr. 101, 1. júlí 2019, um breytingu á ýmsum lagaákvæðum sem tengjast fiskeldi (áhættumat, úthlutun eldissvæða, o.fl.)

[238] Lög um fiskeldi nr. 71/2008, Lög nr. 101, 1. júlí 2019, um breytingu á ýmsum lagaákvæðum sem tengjast fiskeldi (áhættumat, úthlutun eldissvæða, o.fl.), Expert interviews, BCG analysis

FIGURE 4.64: THE PROCESS OF OPENING FJORDS FOR SALMON FARMING BEFORE LEGISLATION AMENDMENTS IN 2019[239]



1. Risk assessment implemented in 2017

4.6.5 Sub-conclusion

Already growing faster than the global industry, Iceland's traditional aquaculture sector has the potential to more than double in size. While much of this growth is expected to follow as the industry matures and more farms reach their full production capacity, additional growth can be fueled by several levers. These include regulation changes to allow biomass to be moved between production areas, the development and successful application of new technology that lowers the risk of escapes and a holistic review of production area locations with respect to the risk assessment.

Improving the quantity of harvested salmon produced from the current total MAB, which ultimately allows current active licenses to produce more, can be approached in several ways. Increased efficiency can be driven by salmon farmers through improvements to fish health and mortality, including increasing smolt sizes. Higher utilization may also be approached from a regulatory standpoint by assessing the possibility of being able to move licensed MAB between fjords.

The last avenue for increasing productivity for traditional aquaculture involves increasing the areas available for farming by opening new fjords. Contingent on the outcome of the Marine and Coastal plan, this will Minister decision followed by assessment and approval from MFRI.

As many of these growth levers involve environmental improvements, the use of "green" development licenses could encourage farmers to invest in the new technologies and methodologies needed. In Chapter 8, several future scenarios based on these possibilities for growth are further considered.

4.7 Conclusion: Traditional aquaculture has growth potential

Traditional aquaculture, as the largest aquaculture sector, will be important to the future of the industry in Iceland. Despite rapid growth over the last decade, significant growth potential still exists. An

[239] Expert interviews, BCG analysis

understanding of dynamics, policies and regulations, taxes and fees, environmental impact, and fish welfare across markets can help ensure that aquaculture policy enables sustainable growth of aquaculture with a positive impact to Iceland as a whole.

Policies and regulations differ by focus supply markets, with varying degrees of limitation on traditional aquaculture. Iceland's coastline is more limited than those of Norway and the Faroe Islands due to the creation of conservation areas. Some markets, especially Norway with its traffic light system, offer a clearer path to increasing MAB; in markets such as Iceland and Scotland, MAB remains constant unless an alternative decision is made. Currently, if excluding license costs, Norway has a competitive advantage in terms of total fees and taxes farming companies are subject to. Assuming the proposed resource rent tax will be implemented in Norway and similarly the production fee amendments in Iceland and Faroe Islands, total levies will be highest in Norway.

A key challenge for traditional aquaculture is environmental impact. Salmon escapes and waste disposed from operations, can cause genetic introgression with wild salmon stocks and negative impact on the seabed. While regulation varies across markets, prospective farmers as a rule must complete an environmental impact assessment to obtain an operating license. Additionally, fish health is a major concern for both economic and environmental reasons, as mortality directly impacts the bottom line and fish diseases can spread to wild fish. Biological challenges differ across markets depending on factors such as temperature. While Iceland has not experienced as many outbreaks as more mature markets, recent outbreaks of sea lice and ISA underline that Iceland should take effective measures now to limit the risk of future incidents.

5. Land-based farming

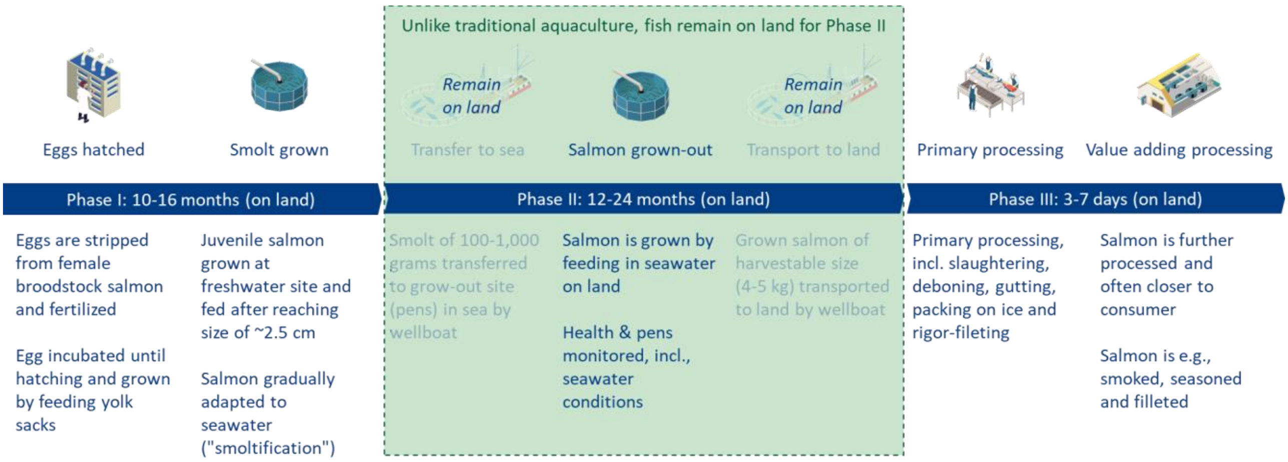
The aim of this chapter is to provide an overview of the land-based aquaculture sector and explore its potential in Iceland. It includes an overview of the sector, including market dynamics and trends; differences in production technologies from traditional aquaculture, as well as how this impacts fish health, productivity, and environmental footprint. Regulation of the land-based sector is then explored, followed by a study of the financial profile of the land-based sector compared to the traditional. The chapter concludes by reviewing the potential of land-based salmon farming in Iceland and the role of government.

5.1 Sector overview

5.1.1 Land-based farming seen as potential solution to traditional challenges

Land-based aquaculture is increasingly being explored as an alternative to the main challenge of traditional aquaculture: a strain on growth due to capacity limitations. Land-based aquaculture involves raising the fish to full maturity in tanks on land, as opposed to moving them to pens in the sea, where biomass limitations apply in all supplier markets (see further in Chapter 4).

FIGURE 5.1: LAND-BASED PRODUCTION CYCLE[240]



This sector is being tested for its potential to overcome several of the challenges faced by traditional aquaculture beyond capacity, including fish health, variability in production, and environmental impact. On-land tanks offer the ability to monitor and control production to a higher degree, e.g., through optimizing water quality (oxygen, salinity) and temperature. By keeping fish in a controlled environment throughout their lifecycle, the land-based sector can limit the spread of sea lice and other contaminants and parasites found in the sea. They can also improve predictability and stability in production as the fish are not subject local ecosystem and weather conditions, providing a commercial advantage towards customers demanding stability and predictability in supply. The environmental impacts associated with traditional aquaculture can also be controlled, as keeping the fish out of the fjords removes the risk of genetic introgression of wild salmon and allows waste to be treated before disposal instead of directly entering the fjords. Instead, water and energy consumption drive

[240] Kepler Cheuvreux, Food 360

environmental impact on land. Finally, land-based aquaculture can circumvent the regulatory and geographical limitations that are currently constraining the growth of traditional farming. Overall, proponents of land-based aquaculture highlight its potential for relatively unconstrained growth and lower environmental impact compared to traditional aquaculture.

Despite these favorable attributes, the land-based aquaculture sector is still nascent, and several challenges remain in reaching planned capacity. Salmon farmers have long used land-based systems for the freshwater stage of salmon development (smolt), and therefore the idea of land-based salmon farms is not new. However, the technology needed for the larger tanks and saltwater conditions is still in early stages. With no large-scale (10kT+) farms yet producing, different technologies are competing to be proven the best, and relatively few companies are at the stage of harvesting full-grown salmon (see 5.1.3). Although many companies cite the possibility of using waste as fertilizer, this ambition has not yet been realized in Iceland.[241] The capital expenditures required for the establishment of a land-based farm are also high, estimated by some to be fifteen times that of traditional farms (discussed in 5.4).[242] Thus, the technology and methodology remain to be proven at a large scale, and as such land-based aquaculture is not yet at its full maturity.

FIGURE 5.2: INDICATIVE ADVANTAGES AND DISADVANTAGES OF THE LAND-BASED SECTOR COMPARED TO TRADITIONAL[243]

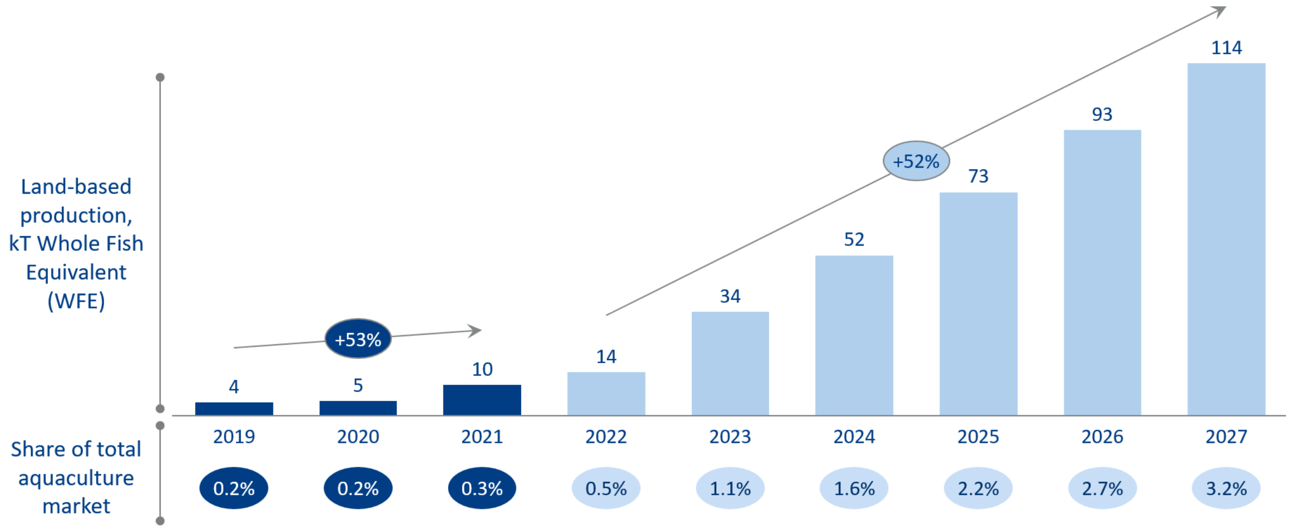
	Potential advantages	Potential disadvantages
Global	• Less capacity limitation (currently) • Lower local impact on fjords/seabed • Lower mortality and health/de-licing costs due to closed system (to be validated) • Faster growth due to temperature control • Predictable & stable production due to control of tank environment (incl. temp.)	• High CAPEX required • Risk of technology-related failures: tech. not proven at large (10kT+) scale • High level of water and energy use can have environmental impact • Recent public failures may make it difficult to attract investment
Iceland-specific	• Access to affordable, renewable energy • Access to clean water within optimal temp. range for salmon farming • Can be located near population dense areas: better access to labor than trad. • Can be located close to sea- and airports: better access to end markets than trad.	• Further from end markets than some other locations (e.g., land-based facilities in USA) • Smaller labor market and less aquaculture expertise than e.g., Norway

[241] Explored elsewhere, see for example report from Climate Change and Environmental Sustainability: Fish waste recovery into fertilizer (2021)
[242] BNP Paribas Exane (2021)
[243] BNP Paribas Exane (2021), Expert interviews, BCG analysis

5.1.2 Land-based market is still small but has a strong foothold in Iceland

As noted above, fully land-based salmon farming is still in its early stages relative to the traditional sector, with no large or well-established operations yet. Thus, the market for current production is small relative to traditional aquaculture, yet it is projected to grow faster than traditional aquaculture.

FIGURE 5.3: SIZE AND PROJECTED GROWTH OF THE GLOBAL LAND-BASED MARKET[244]

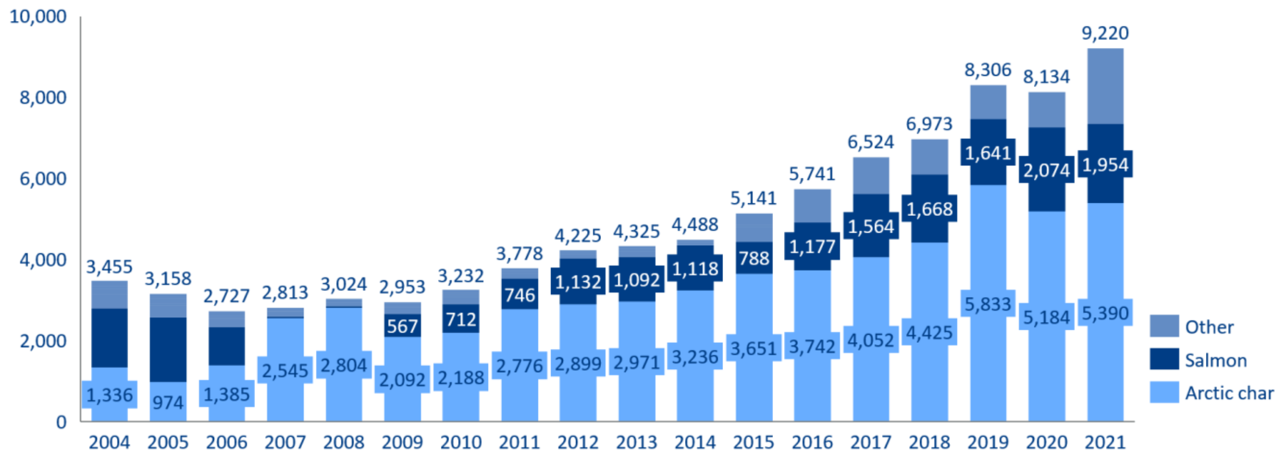


Despite its low share of the global aquaculture market, land-based aquaculture has attracted significant investment[245] in Iceland, driven by access to clean water and affordable energy. It already accounted for 16% of total aquaculture production in 2021, though primarily driven by Arctic char. Arctic char has been grown on land for several years and, in 2021, accounted for 65% of land-based harvest volume, as shown below. New projects, however, are focused on growing salmon. This report therefore mainly focusses on land-based salmon farming.

[244]Kepler Cheuvreux, Food 360

[245] According to news sources, upwards of 50m EUR (IntraFish, AquaFeed)

FIGURE 5.4: LAND-BASED AQUACULTURE PRODUCTION IN ICELAND BY SPECIES (TON)[246]

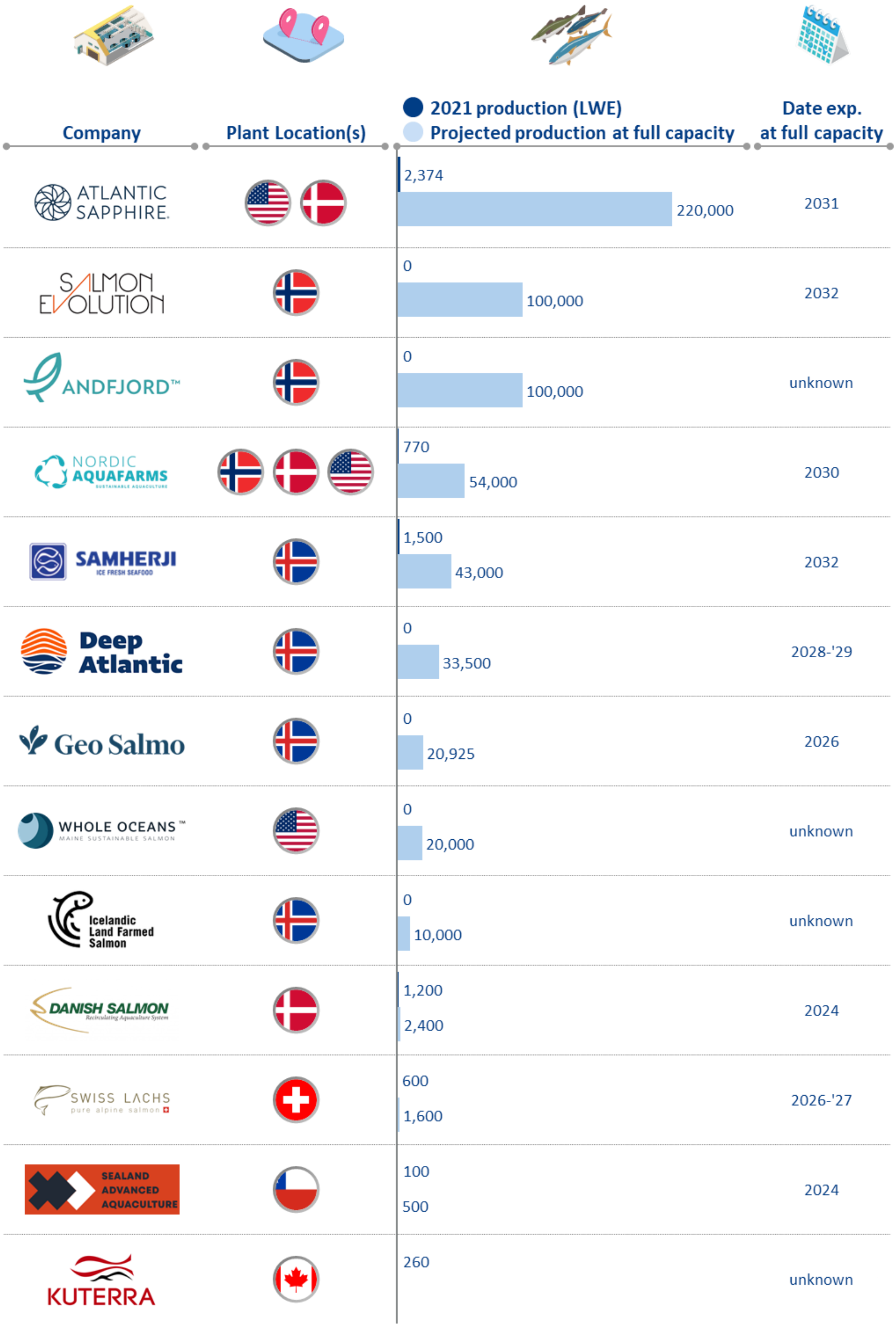


5.1.3 Many projects in infancy, with a few players already harvesting

Although 117 projects have recently been identified globally, promising to produce 2.7mT of fish, most of these projects are not yet producing, with under 10kT estimated to have been produced in 2022.[247] The selection of land-based farming players and projects in Figure 5.5 illustrates the nascent state of the land-based sector today.

[246] Food and Veterinary Authority in Iceland, BCG analysis
[247] SalmonBusiness and iLaks

FIGURE 5.5: SELECT PLAYERS AND PROJECTS GROWING ATLANTIC SALMON ON LAND (TON)[248]

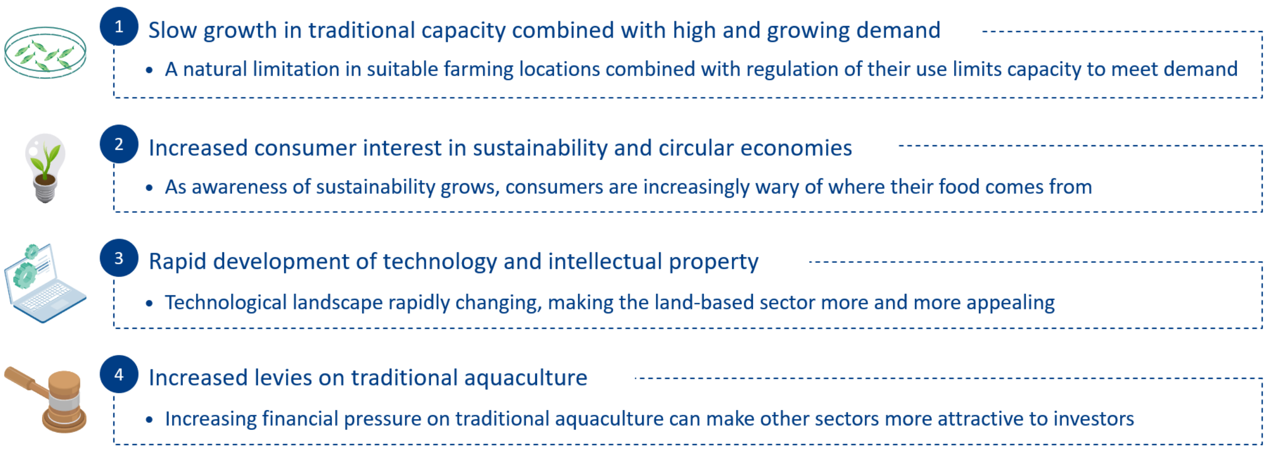


Atlantic Sapphire leads production globally, despite various setbacks in the past few years.[249] The Icelandic company Samherji follows, having harnessed their technology and experience from farming Arctic char on land to produce salmon in a pilot facility in Öxarfjördur. There are also several larger land-based farms under construction, including Samherji's new facility. Landeldi has around 500k of salmon in seven tanks and expects production in 2024 to reach 8.5kT. As these Icelandic companies' activity shows, there have been large investments into land-based salmon farming in Iceland, and some of them are already bearing fruit. This sector is therefore becoming an important part of the future of aquaculture in Iceland, nascent though it currently is.

5.1.4 Growth driven by four key trends

Growth in land-based aquaculture is primarily driven by the current supply-demand imbalance, the growing emphasis placed by consumers on sustainability, the rapid development in technology, and the increase of levies on traditional aquaculture.

FIGURE 5.6: OVERVIEW OF LAND-BASED AQUACULTURE MARKET TRENDS[250]



1. Slow growth in traditional capacity combined with a high and growing demand

As noted in previous chapters, the growth in traditional aquaculture is limited by regulation around licenses and the natural occurrence of geologically suitable places for sea pen farming. At the same time, as discussed in Chapter 3, demand for salmon is high, and salmon is expected to play an important role in responding to the growing global demand for sustainable protein. The confluence of these factors creates a vacuum of demand that can be filled by alternative sectors such as land-based farming. Despite high up-front capital expenditures, investors increasingly see land-based aquaculture as a profitable path forward and a way to supply high quality protein to meet global demand.

[249] For example, there were a filtration maintenance error and a fire in the Danish facility, and an Oxygen short shortage due to COVID-19, a design flaw causing abnormal fish behavior, worker injury from fumes in the facility in Florida, USA

[250] Expert interviews, BCG analysis

2. Increased consumer interest in sustainability and circular economies

Over the past several years, consumers have increasingly prioritized sustainability in their choices. Sustainability has thus become a key element in the branding and go-to-market strategies of many companies, several of which have moved towards circular economies as a part of this trend.[251] With sustainability pressures higher than ever, land-based aquaculture farmers assert that this provides an opportunity to gain advantages (e.g., pricing, sales volume) by actively marketing to environmentally conscious consumers. Not only does land-based aquaculture have the potential to address traditional aquaculture's direct environmental impact, but the potential to reuse its waste promotes a circular economy and provides a way to reduce Iceland's imports. However, as the industry is currently in its early stages, this potential remains to be proven.

3. Rapid development of technology and intellectual property

The increased interest and investment into land-based technology has created a virtuous cycle in which rapid improvements in technology attract more would-be farmers to the land-based sector. According to experts, the technological landscape is completely different from what it was five years ago, as land-based farms continue to learn and develop. Indeed, the technology itself has the potential to be a part of the business proposition of early successful land-based farms, as they can hold the intellectual property that allows them to provide "turnkey" solutions for new entrants, thus creating an additional revenue stream.

4. Increased levies on traditional aquaculture

Traditional aquaculture companies are usually taxed and levied beyond basic corporate tax rates, as they are using the common resource of the fjords. These levies appear to be increasing. The recently proposed resource rent tax of Norway (announced September 28, 2022) puts additional financial pressure on traditional aquaculture companies. As alternative sectors such as land-based farming are exempt from these levies,[252] these become more attractive financially as traditional levies increase. Even though this effect is specific to Norway, it has the potential to accelerate investment in and development of alternative sectors, which can accelerate technological advancements.

5.1.5 Sub-conclusion

The methodology of recreating salmon growing conditions in a tank on land, though still unproven at scale, has been put forward by many proponents as a way to address the demand vacuum for sustainable protein and the challenges faced by traditional aquaculture. There has been significant investment into farms in Iceland in an effort to explore these possibilities. However, the sector is still very small compared to traditional aquaculture, and it remains to be proven in large-scale operations (10kT+). As such, these claims must be examined in greater detail. The key remaining questions around land-based farming going forward center around production requirements and technological capabilities, environmental impact and animal welfare, the role of the government in regulating the sector, and the financial impact of all these considerations. In the following sections, we take a deeper look into these elements.

---

[251] BCG research on climate and sustainability

[252] Offshore is also exempt from the new tax. See Chapter 4 for more detail on the resource rent tax, and 5.3 for a discussion of land-based exemptions

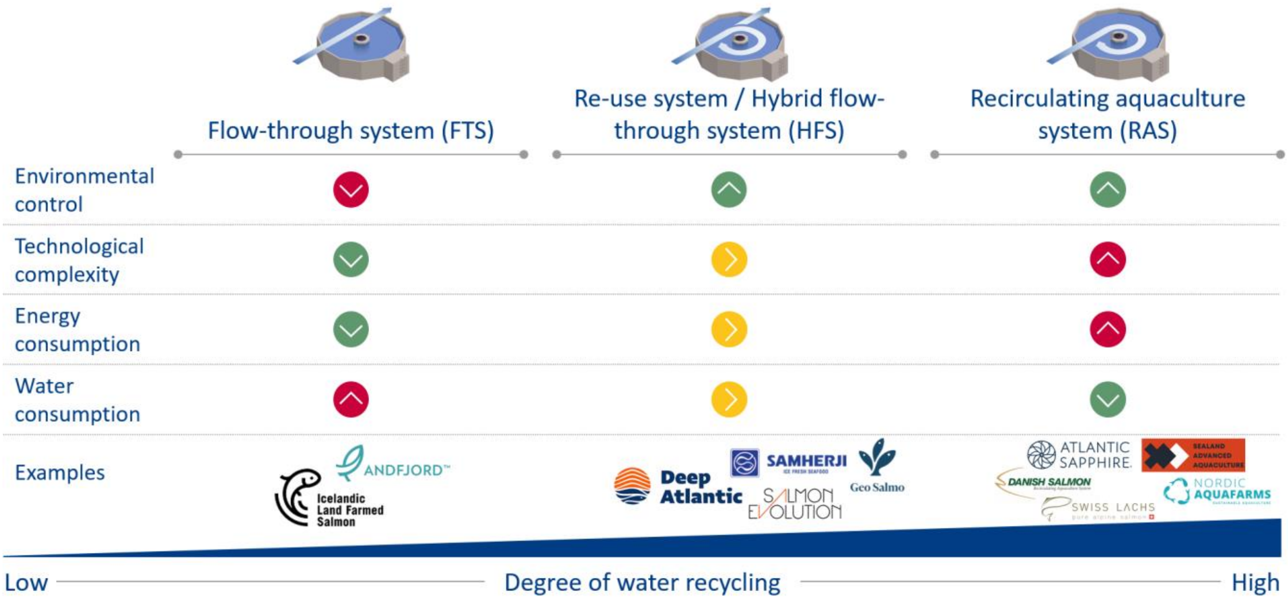
5.2 Production

Land-based methodologies come with a different set of requirements and environmental impact. The following section examines these, aiming thereby to determine the potential viability of land-based farming in the future.

5.2.1 Technology choice balances resource use and environment control

Land-based aquaculture relies on a tank to recreate the conditions of the sea, and there are several prevalent systems currently in use. The main differentiator is whether the tank is constantly fed by new water, or whether the water in the tank is recycled in a closed system. In many cases, a hybrid system is used. These options are presented in Figure 5.7 along with farmers employing them.

FIGURE 5.7: TYPES OF SEAWATER TANK TECHNOLOGIES[253]



Flow-through system (FTS)

This system has new water constantly flowing through tanks. FTS tanks have been in use for a long time, and they require a lower level of technology and consume less energy than the more technologically advanced systems. However, the heavy use of new seawater requires proximity to the ocean, and the flow-through technology does not provide the same level of control of the environment that a recycling system provides. The new water has the potential to bring in risks of contaminants, pathogens, and diseases, and the constant outflow creates much more wastewater than a recycling system. This system is used by Andfjord in Norway and has the lowest capital expenditure requirements but has location constraints as it requires a high level of new water input.

[253] DNB, BNP Paribas Exane (2021), BCG analysis

Re-use system/Hybrid flow-through system (HFS)

A hybrid system reuses some of the water, but not to the same high degree as an RAS (below): the water is reused up to the point where a biofilter is needed, usually about 2/3 of the total water volume. This provides an alternative that brings less risk of building up of gases from full recycling, but that still allows for a higher percentage of water recycling and an increased level of environmental control (including temperature). This type of hybrid has been pioneered by leading farmers such as Salmon Evolution and is the dominant technology in Iceland, used by Landeldi, Samherji, and GeoSalmo.

With a flow-through or hybrid system comes a decision of whether to cover the tank or leave it open in the air (similarly to a traditional sea pen). Overall, covering the tank is more expensive but provides added protection against contamination and avian predators.

Recirculating aquaculture system (RAS)

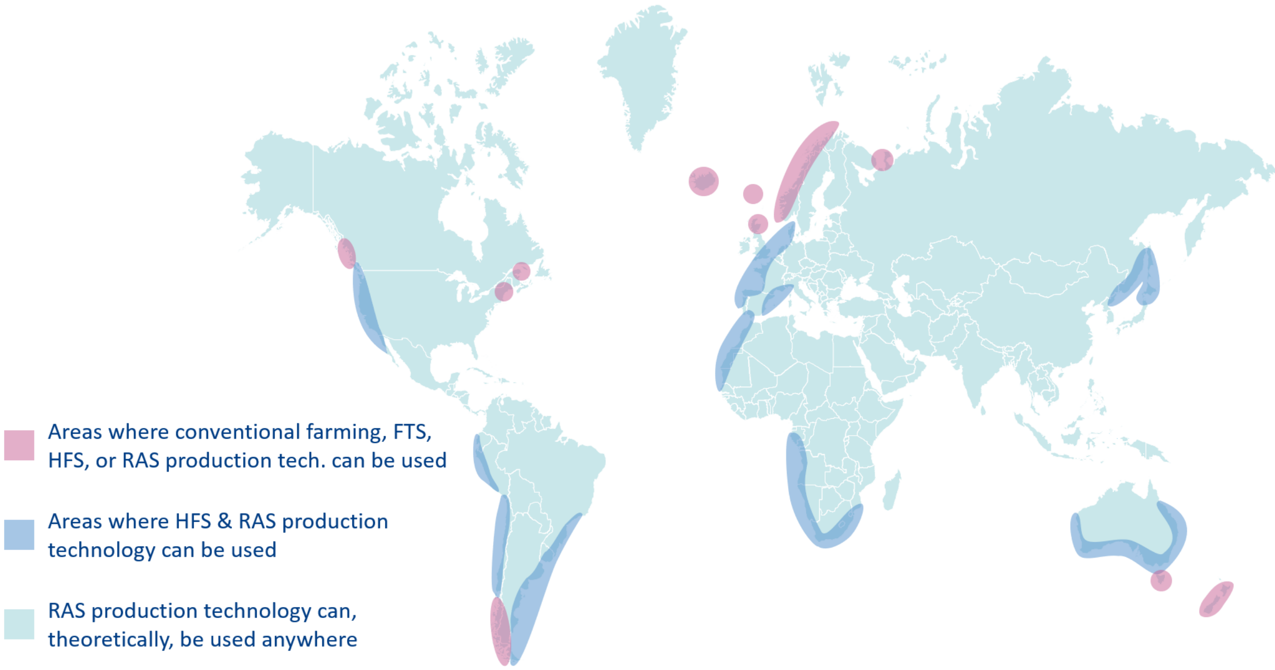
Finally, this system recycles at least 90% of the water in the tank through high-tech filters and pumps. By creating a closed environment, a RAS allows for a high level of control of water quality and temperature, improves wastewater treatment and management, and requires minimal water consumption. However, recycling this much water requires additional treatment with biofilters to remove the CO_2 and add more oxygen, and these additional steps also require energy. The added technological complexity also increases the risk of technological failure. Still, given the benefits of relatively minimal water consumption, it is used by some of the leading land-based players such as Atlantic Sapphire, especially as a way to locally serve end markets that do not have the natural conditions for salmon farming; it is also the tank chosen for the new Islandic Land Farmed Salmon (ILFS) farm on Vestmannaeyjar.

In the above choices, there is a balance to be considered between water and energy use: technologies using less water require more energy, and vice versa. Thus, the choice of technology is directly tied to the choice of location, which determines which resource is more plentiful or costly.

5.2.2 Choice of location linked to technology and resource availability

Land-based aquaculture provides more geographical flexibility than traditional aquaculture, e.g., to increase proximity to end-markets, as the conditions needed to raise salmon can be recreated using technology. Still, using this technology draws on natural resources, and so proximity and access to these resources are important considerations for establishing a land farm. Ultimately, the more a land-based farm can take advantage of natural resources, the lower the energy cost will be.

FIGURE 5.8: SUITABLE AREAS FOR LAND-BASED FARMING BY PRODUCTION SYSTEM[254]



Access to water and energy drive site decisions

Beyond technology, a land-based fish farm requires land, energy and water. The land itself does not have special requirements aside from being able to contain the dimensions of the fish farm However, the ability to take advantage of natural resources can provide an advantage (the possibilities within Iceland are described below). The requirements for water ultimately correspond to the natural habitat of salmon: in the grow-out phase, this is salt water with optimal temperatures for growth at 8-14°C. While proximity to saltwater is thus preferred, it is possible to adjust the temperature, at the expense of energy, if the local saltwater does not match the requirements.

Artificially replicating natural conditions relies heavily on energy to filter, heat or cool, and pump the water into the tank. Here, the source, availability, and cost of the energy are all important considerations. As land-based aquaculture has the potential to be more sustainable than its traditional counterpart (discussed in more detail below), whether the energy is renewable is an important factor in that claim. Given the large amounts of energy required, it is also important for the farmer to secure the long-term availability of that energy. Finally, the cost of energy can make up a significant portion of total costs, and thus is a consideration cited by major aquaculture companies in choosing the location of a land-based farm.[255]

The type of tank used has a great impact on both water and energy consumption. As little as 1% of the water in an RAS tank needs continual replacement, whereas a hybrid system brings in a significant amount of water (often about 1/3 of the total volume). However, RAS tanks require much more energy

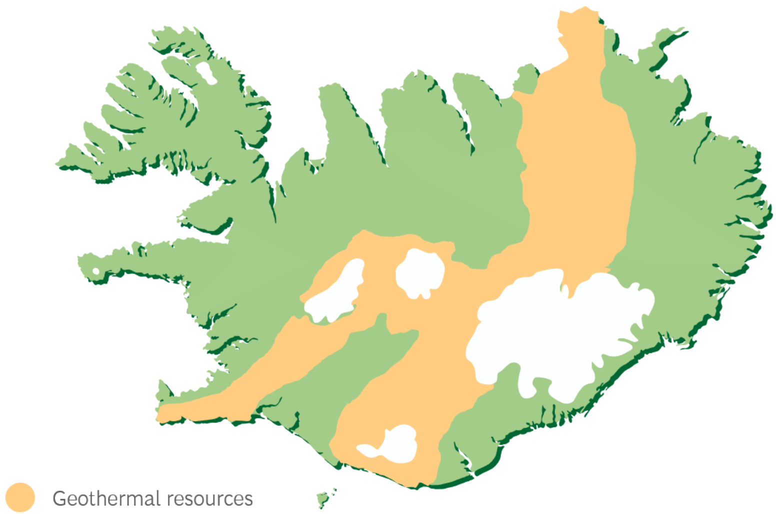
[254]BNP Paribas Exane (2021), BCG analysis
[255] Atlantic Sapphire: Investor materials, Stakeholder interviews

in filtering and degassing to ensure the water is safe to reuse, amounting to 6-8mWh per kT of fish produced.[256] In contrast, a hybrid flow-through system with 1/3 water replacement uses about 1-2mWh/kT.[257]

Iceland's natural competitive advantage

Just as Iceland provides the natural conditions needed for growing salmon in the fjords, its natural conditions also create a competitive advantage for land-based farming. The volcanic rock naturally filters and warms the seawater below ground, so that by drilling boreholes, farmers have access to pristine saltwater at about ~9°C, with no need for additional biofilters.[258] These conditions are found along the volcanic belt and with proximity to the sea. Here, where there is an abundance of naturally filtered seawater, the hybrid flow-through system is logically the system of choice for most of the major land-based salmon farms under construction.[259] However, these resources are not evenly distributed across Iceland; Figure 5.9 illustrates the volcanic belt, where volcanic activity is highest, and the bedrock age is the youngest (under 800,000 years). Along this belt, in areas near the sea, this lukewarm filtered water can be found.

FIGURE 5.9: ICELAND'S VOLCANIC BELT[260]



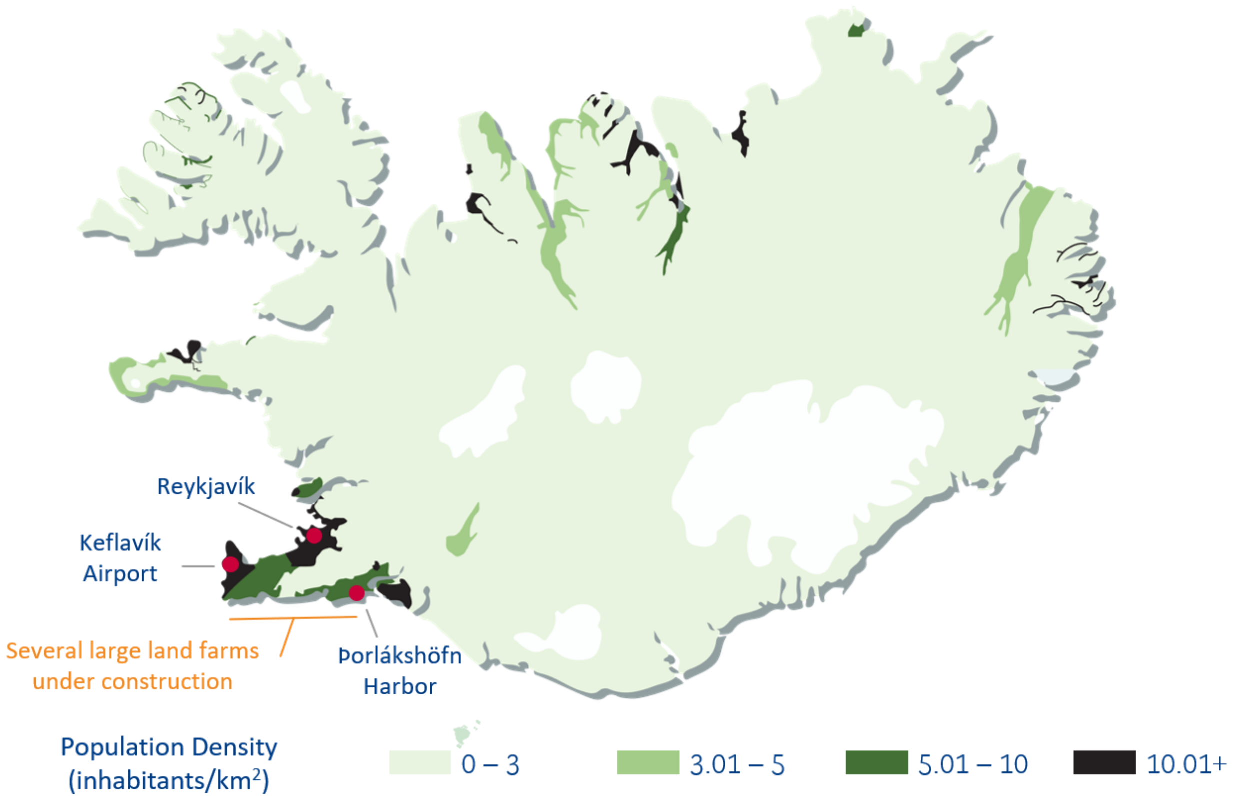
A second competitive advantage of locating on Iceland is the availability of affordable and renewable energy. Although the hybrid flow-through systems require less energy compared to RAS, the energy consumption still contributes meaningfully to operating costs (discussed in section 5.4) and the environmental impact (discussed later in this section). Thus, Iceland is uniquely positioned to host land-based farming operations. However, the energy supply of Iceland is currently limited unless more power plants are established, and therefore energy capacity can become a constraint of rapid growth in land-based farming, as the energy transition to electric power (e.g., to electric vehicles) and particularly

[256] BNP Paribas Exane (2021)
[257] Expert interviews
[258] Expert interviews
[259] Samherji, Landeldi, Geo Salmo
[260] Kepler Cheuvreux, Food 360, BCG analysis

energy-intensive industries all look to benefit from Iceland's renewable energy. Thus, securing a long-term energy supply is vital for Icelandic farmers investing in land-based systems, and energy infrastructure and distribution is an essential consideration for the government as this sector grows.

Land-based aquaculture has additional advantages over the traditional sea-based sector in Iceland, due to different location requirements. Although labor availability can be a challenge to obtain for all aquacultural farmers in Iceland, one of the most optimal sites for land-based aquaculture is on the Reykjanes peninsula,[261] close to Reykjavik and both air- and seaports, where the population is the densest (as shown in Figure 5.10). As land-based farmers also expect to need about half of the labor used in traditional farming,[262] this greatly reduces the challenge of acquiring the right labor pool faced by traditional farmers, though different labor requirements for land-based farms (e.g., geologists) may pose new challenges. Additionally, easier access to markets through reduced transport time to major ports improves costs, environmental impact, and shelf-life.

FIGURE 5.10: POPULATION DENSITY AND SELECTED PORTS IN ICELAND[263]



Despite these advantages, the flexibility of location for land-based farming has resulted in several competitors constructing RAS facilities much closer to end markets than would have been possible naturally. For example, several companies have started farms in the USA, most famously Atlantic

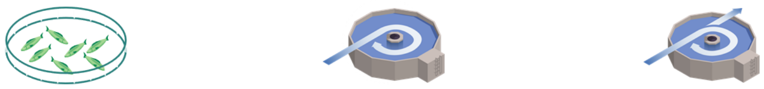
[261] Expert interviews
[262] Fiskeridirektoratet, OECD, MOWI industry report, Expert interviews
[263] European Environment Agency

Sapphire in Florida. There, the natural conditions are too warm for traditional salmon farming, but the RAS facility allows Atlantic Sapphire to pump water from underground and maintain the appropriate temperatures in their closed tanks. Given these competitive entrants marketing fresh (reduced transportation time) and local salmon, Icelandic salmon may be at a competitive disadvantage. However, salmon farming in conditions such as Florida is expected to have a higher energy cost, due to the necessity of keeping the water cooler than outside temperatures and the increased energy required by the RAS facility discussed above.

5.2.3 Land-based can improve health and predictability, despite potential technological challenges

Land-based aquaculture offers a way to eliminate many of the natural risks of traditional aquaculture. At the same time, until the technology has matured, design and operational failures add risks to new projects.

FIGURE 5.11: ELEMENTS IMPACTING FISH HEALTH AND THEIR ESTIMATED RISKS BETWEEN TECHNOLOGIES[264]



Factor	Traditional aquaculture	RAS tank	Hybrid & flow-through tanks
Sea lice	High risk	Low risk	Low risk
Predators	High risk	Low risk	Low risk (Unless top open)
Temperatures	Medium risk	Low risk	Low risk
Toxic gases	Low risk	High risk	Medium risk
Misc. technical failures	Low risk	Medium risk	Medium risk

High risk · Medium risk · Low risk

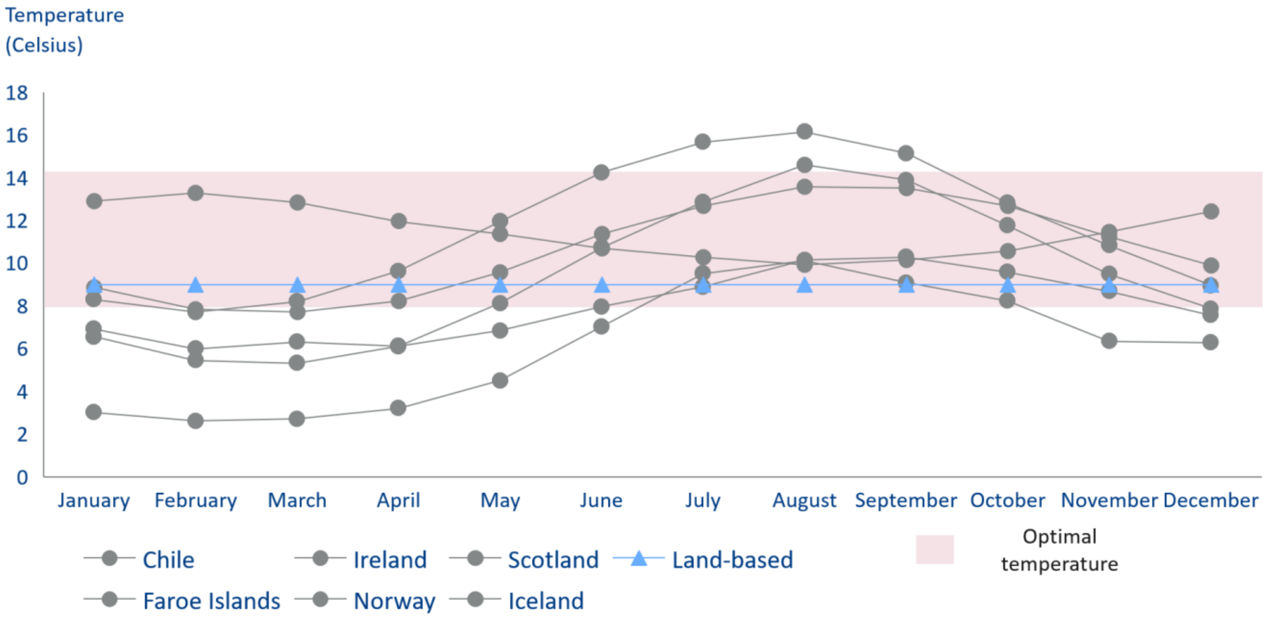
Advantages of land-based farming

A controlled environment has the potential to reduce many of the traditional causes of poor fish health and mortality. The closed tank system reduces contact with external contaminants, thus all but precluding risks of outbreaks from e.g., sea lice or diseases caused by these external exposures. This saves the health and maintenance costs of de-licing and other treatments, reduces disease-related mortality, and increases fish welfare. Additionally, temperature of the water can be controlled, which greatly reduces the variability of fish maturation. The period of most significant growth for salmon is the grow-out period in seawater, and it is heavily dependent on temperatures. Tank-raised salmon are thus not subject to slow-growth periods, such as winter, due to weather—and their growth is also more predictable.

[264] BNP Paribas Exane (2021), DNB Markets (2017, 2019). FAO (2015), BCG analysis

Building upon these benefits, land-based fish farmers can provide a steady and predictable supply throughout the year, rather than being subject to seasonal fluctuations and potential disruptions due to mortality or escapes. This makes it easier to establish stable long-term contracts with buyers, a prospect that appeals to both parties.[265]

FIGURE 5.12: LAND-BASED TANKS CAN MAINTAIN OPTIMAL TEMPERATURES FOR GROWING SALMON YEAR-ROUND[266]



Technological challenges

While on-land tanks eliminate many of the traditional risks to fish mortality, they inevitably introduce the risk of untried and unproven methods and technology. Currently, the land-based technology is still in the "start-up" phase, and there are not yet large-scale proofs of concept for farmers to look to. In terms of fish mortality, the biggest risk is accumulation of toxic gases in RAS systems because they are closed loop: for example, ammonia, ammonium, and nitrate produced from waste products can be toxic to fish; hydrogen sulphide, generated when biological material is decomposed by bacteria without oxygen present or when there is a lack of nitrate in water, affects pH level of water; and CO_2 is 30 times more soluble than oxygen and can thus accumulate if water replacement is insufficient. Some of these risks were seen in Atlantic Sapphire's Danish facility, where clogged filters caused hydrogen sulphide poisoning in 2017 and a design flaw disrupted water flow and caused nitrogen levels to spike in 2020 (after a fire broke out in the Danish facility in 2021, Atlantic Sapphire has since focused production in the U.S.). All these risks mentioned, dependent on the design of the RAS facility, have the potential to cause mass mortality of stock if not mitigated.[267]

The hybrid flow-through system, used by most land farms in Iceland, reduces many of the risks associated with the RAS system by introducing more new water into the tank and thus reducing the risk

[265] BNP Paribas Exane (2021), Expert interviews

[266] Indicative average temperature in countries, Kepler Cheuvreux, DNB Markets, BCG analysis

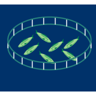
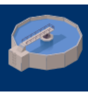
[267] BNP Paribas Exane (2021)

of gas buildup. Not only that, but if deemed necessary, it is possible to increase the percentage of new water to 100% to refresh the tank should unwanted conditions occur.[268] While using a hybrid system with less complexity reduces many of the risks associated with RAS, there are still risks of design flaws as new technologies are developed. Thus, the current risk profile for early players is higher than traditional aquaculture, but as the technology continues to be refined, such risks are expected to be reduced for later market entrants.

5.2.4 Land-based with potential to lower environmental impact

Many land-based farmers market their products as environmentally friendlier than traditional farming, due to the limited interference with local ecosystems. However, the increased energy and water usage must be considered against these benefits. Iceland's access to naturally filtered seawater of the right temperature and renewable energy can mitigate this, and thus make Iceland an ideal location for raising salmon in the most environmentally friendly way possible.

TABLE 5.1: COMPARISON OF ENVIRONMENTAL IMPACTS OF TRADITIONAL AND LAND-BASED AQUACULTURE

	 **Traditional**	 **Land-based**
Primary environmental impacts	• Escapes can lead to genetic introgression • Organic load released directly into sea (instead of filtered from land tanks) • Sea lice and disease can spread to wild stocks (negligible in land-based)	• High energy use (to artificially mimic fjord conditions) • High water use (especially using HFS tanks)
Mitigation	• Closed- and semi-closed pens to catch waste and reduce escapes	• Renewable sources

High water and energy consumption, with impact mitigated by Iceland's resources

Water footprint is one of the key factors considered in an environmental impact assessment,[269] and for non-RAS systems, the water usage is quite high. For example, for a hybrid flow-through system replacing two-thirds of the water in a 20kT tank, the new water needed would amount to 80 cubic meters per second, or 4 cubic meters per second per kT.[270] This amounts to a sizeable river. Although the water under Iceland is considered a vast resource, the use of boreholes to supply land-based tanks at scale is relatively new, and there could be a risk that the resource becomes depleted or that design failures cause contamination. Additionally, in the event of an abandoned facility, the soils can potentially be left eroded and with high salinity levels depending on water containment within the facility. However, current land-

[268] Expert interviews
[269] The European Commission
[270] Expert interviews

based farming facilities in Iceland are not located on sites that are fertile enough to be used for agriculture, mitigating this risk. Thus, the water use, especially of any type of flow-through system, can carry environmental risks.

Replicating natural sea conditions in a tank on land requires extensive amounts of energy, ranging from 1-8mWh/kT depending on the technology used, as noted before. Land-based farms are thus likely to have an increased carbon footprint compared to traditional farms due to their energy consumption. However, Iceland's affordable, renewable energy allows the possibility of sustainable energy use. As noted previously in this report, this energy supply has a limit, but any supply that farmers can secure is likely to be renewable. This is a unique Icelandic advantage.

Reducing disruption to local ecosystems compared to the traditional sector

Keeping fish isolated in a tank reduces the impact of escapes and waste on the local ecosystem. Escaped fish from traditional farming in the sea can have a negative environmental impact if they contribute to genetic introgression with wild salmon. Genetic interaction between farmed fish and wild fish can reduce ability of the wild fish to survive. Not only that, but sea-based fish farms can elevate the rate of sea lice up to 40 miles from the cage, as the high fish concentration causes the sea lice to breed rampantly. On the other hand, in a landed tank, the risk of fish escaping into the sea is negligible. [271]

As the wastewater from a land-based tank is treated before being disposed of, it does not contaminate the fjords, unlike traditional aquaculture, where fish waste directly enters the water. This organic load can cause explosive algae growth, the decay of which takes large quantities of oxygen from the seawater ("eutrophication") and is detrimental to other sea life. Not only does it not enter the fjords, but the wastewater from a land-based system is also more easily collected and processed to produce fertilizer for use in agriculture. This is because fish manure contains phosphorus, which is a limited resource used for fertilizers in agriculture. Alternatively, the sludge separated from the water can be used for biogas production for heat and electricity, leaving nitrogen-rich water that can be used in agriculture.[272]

Aside from limited impact on ecosystems, there are other potential benefits cited by land-based proponents. Due to the controlled environment of the tank, many argue that fewer health treatments of fish such as vaccinations and antibiotics are required (although this has not been proven at scale),[273] making the fish more appealing to consumers concerned with fish welfare or consumption of these. However, it is important to note that at this point, antibiotics are not used in traditional aquaculture in Iceland, either. Additionally, in many other areas of the world, land-based aquaculture is considered as a means to bring production closer to the end market (such as North America and Asia) and eliminate transportation emissions and costs. However, this is less applicable to Iceland, where most production is exported.

Land-based with potential to market "green" product

Several land-based aquaculture farms, including Icelandic ones, are planning to market their product as more environmentally friendly than fish farmed in the traditional sector. In Iceland, the affordable

[271] BNP Paribas Exane (2021)

[272] BNP Paribas Exane (2021), NRK: "Forskere mener mer fisk må ned i bakken". See also Fiskifrettir, "Kraftáburður úr fiski- og húsdýramykju"

[273] Expert interviews

nature of renewable energy makes it possible to produce the fish sustainably. In addition, the abundance of natural seawater in the area reduces the impact of saltwater consumption, as the pressure of the ocean refills the water pumped out of the volcanic rock.[274] To market their product as carbon neutral, land-based farms must naturally consider the whole supply chain and secure carbon neutral inputs, such as feed and smolts, as well as offset the carbon emissions of exports. Still, provided that they do this, Iceland's naturally renewable resources provide the ideal location to produce environmentally sustainable salmon.

While freshwater consumption may be raised as an issue, this is limited to the smolt phase, upon which both land-based and traditional grow-out farms rely. The consumption of freshwater for the tanks used for smolts potentially has a higher impact than the consumption of saltwater, as Icelandic freshwater is a limited resource from underground springs that are also used for other purposes such as drinking water. However, for both the traditional and land-based farming sectors, smolts are grown in freshwater tanks, and thus there is no difference in impact between sectors. Additionally, more and more smolt farms are using RAS technology, which greatly reduces water consumption. Finally, smolt tanks are by nature much smaller than grow-out tanks for the same number of fish, and thus the water consumption is much less than the grow-out phase. Overall, the environmental impact of earlier stages of the value chain is an important consideration for marketing a sustainable product, land-raised or otherwise.

5.2.5 Sub-conclusion

Re-creating naturally occurring conditions on land comes with different benefits and challenges, and Iceland is uniquely suited to meet these challenges. Although land-based farms are not constrained to the finite number of fjords in the world that have the right conditions, creating these conditions in a tank requires advanced technology and significant water and energy use. Here, Iceland has the advantage of natural and renewable resources to support this farming. The availability of filtered seawater at the right temperature has allowed the major players of Iceland to elect a hybrid flow-through tank, which uses less energy than an RAS tank. This technology is also not mature and brings with it the associated risks. Still, when successful the ability to control conditions can improve fish welfare and allow for a steady and predictable output throughout the year rather than seasonal variation. Isolating the fish from the local ecosystem reduces the negative impact of escapes and contamination and though not yet tried in Iceland, the wastewater has the potential to be reused as fertilizer to promote circular economies within Iceland. Thus, despite the challenges posed, Iceland is especially suited to excel in this sector.

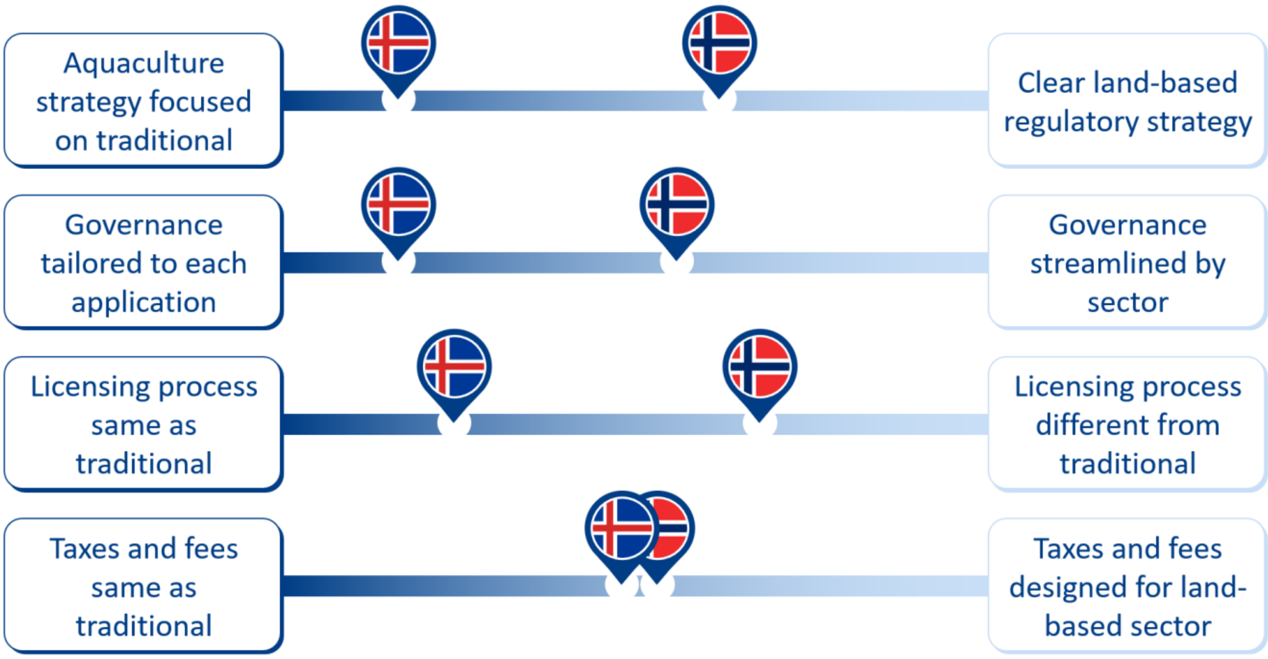
[274] Company reports, Stakeholder interviews, BCG analysis

5.3 Regulation

5.3.1 Icelandic regulation for land-based aquaculture is not fully developed

As established in the previous section, land-based aquaculture has a very different profile when it comes to local resource utilization and methodology. Thus, it calls for different regulation than traditional aquaculture. However, like the sector itself, regulation is still in its early phases.

FIGURE 5.13: REGULATION OF LAND-BASED AQUACULTURE, ICELAND VS. NORWAY[275]



While Iceland has taken steps of creating some regulatory differences between the two sectors, there is not yet an overarching strategic framework for the legislative process, nor a clear pathway to apply for land-based farming licenses. Some stakeholders have therefore noted that the application process can be confusing and does not always match the needs of land-based farms. For example, applications can take a long time as the limited number of staff in governing bodies are unfamiliar with land-based farming and do not have specific guidelines to help them make decisions. Since this methodology is still relatively new in application to the grow-out phase, it is natural that regulation is similarly lacking, but this incongruity can become more pressing as the sector grows.[276]

In regulating a new sector, it is important to have a strategy in place to guide legislative decisions. For example, the Norwegian government expressly wishes to facilitate land-based aquaculture as a contribution to new business and employment, as well as ensure the environmental sustainability and fish welfare of land-based aquaculture.[277] Although Norwegian regulation of land-based aquaculture

[275] National legislations, BCG analysis

[276] Expert and stakeholder interviews

[277] Norwegian Ministry of Industry and Fisheries: Et hav av muligheter

will likely continue to mature and is in many ways similar to that of Iceland, the legislative actions they have taken align with that ambition. The following sections draw upon Norway's land-based legislation as a helpful benchmark.

5.3.2 Governance and licensing tailored to applicant, but no clear guidelines

In Iceland, the same operating and production licenses are required for both traditional and land-based aquaculture farms, but the approval process, including the governing bodies consulted, is tailored to each application. For example, each project must be screened for whether or not they need a full Environmental Impact Assessment (EIA). In practice, both traditional and land-based farms are required to go through the EIA, but for different reasons. As of now, all sea-based aquaculture of 3kT or more must undergo an EIA. For land-based projects, on the other hand, the EIA is triggered by water use as all groundwater extractions of 300L/second or more must undergo an EIA. Once the EIA is initiated, for whatever the reason, the developer completes a scoping document in collaboration with the Planning Agency and consulted parties that describes an environmental impact assessment process tailored to the individual case. During both the screening and EIA process, relevant agencies are consulted. Thus, for example, the municipalities have no role in the traditional farms, where the sea is outside of their jurisdiction, but on land they play a big role when it comes to planning and building permits.[278] The National Energy Authority regulates groundwater use, a role specific to the land-based sector. In this way, with a process that involves consultation with all relevant parties and even the public, the nuances of land-based farming are carefully considered. Even so, not every major aspect of land-based resource use is regulated. Although the National Energy Authority is involved in groundwater use, electricity use is currently not considered. Additionally, it is possible that the licensing process can be made more efficient by establishing clear land-based farming guidelines ahead of time, so that the process does not have to be recreated in the scoping document each time.

As an example of establishing guidelines for the land-based sector, in Norway, where the governing bodies are similar, a regulation for the technical standard of land-based aquaculture facilities was introduced in 2018. This regulation sets requirements for holders of aquaculture licenses, producers, suppliers, certification bodies, design-, executing-, and inspection companies associated with land-based aquaculture facilities. All facilities must have a report documenting the technical condition of the facility, including a condition survey, technical drawings of drainage- and delivery system, risk assessment for operation and delivery, geotechnical survey, and maintenance plan. Additionally, tanks and hoses must fulfill specifications according to Norwegian standard NS 9416.[279] Beyond these requirements, Norway has also removed the upper limit on fish density as monitoring fish health is easier in land-based farming.[280] Thus, land-based players are all held to similar standards, rather than the standards being recreated for each individual case.

[278] Expert interviews
[279] BNP Paribas Exane (2021), Salmon Business: "Land-based salmon farming in Norway – Laws and regulations"
[280] BNP Paribas Exane (2021)

5.3.3 Taxes and fees differentiated, but with unclear strategy

Iceland has already taken the step of excluding land-based aquaculture from some financial requirements that apply to traditional aquaculture. For example, the yearly fee to the Environmental Fund for Aquaculture has been waived for land-based farms, since this fund was created to finance projects related to assessing fjord carrying capacity and limiting the environmental impact of traditional fish farming through risk assessments and surveillance. They are also exempt from paying the fee on harvested fish to the Directorate of Fisheries.

The legislation governing land-based aquaculture in Norway similarly alleviates the financial disadvantage of farming on land. Since 2016, licenses for land-based farms have been free to offset the high capital expenditures of building the facility. Land-based farms are also exempt from the excise duty of 0.4 NOK per kg (HOG) on production of salmonoids farmed in the sea, which applies to all traditional aquaculture companies in Norway.[281] Funding for research through e.g., the Norwegian Seafood Research Fund (FHF), also provides support to land-based projects, such as grants to Nofima for research into water recirculation technology (RAS facilities) for land-based fish farming.[282] The resource rent tax announced on September 28, 2022, also excludes land-based aquaculture.

While the government provides Norwegian land-based companies with exemptions, the Norwegian Seafood Council[283] has not differentiated its requirements. To export fish from Norway, farmers must register with the Norwegian Seafood Council, which involves a 15,000 NOK annual fee as well as a marketing and research fee (0.6% and 0.3% of the FOB value, respectively).[284] As the Norwegian Seafood Council is created to develop markets for Norwegian seafood as a whole, both traditionally farmed and land-farmed exports are included.

5.3.4 Sub-conclusion

Observing Iceland's regulation, it is clear that in several instances, the differences between traditional and land-based aquaculture are taken into account. Yet at the same time, beyond simply adjusting existing legislation to suit land-based aquaculture, a unique overarching strategy and process for regulating the land-based sector does not present itself. For example, considering whether to take a stance like Norway's and support and encourage the growth of land-based farming, versus a neutral or negative stance, can guide governance and legislation around the sector and ensure that the process is fully optimized to suit land-based aquaculture, independently from the traditional licensing system. By considering land-based aquaculture in terms of resources used (land, water, and energy), Iceland can ensure that correct governing bodies are involved. Finally, having a clear guiding principle can facilitate clarity and optimization of the process.

Supporting proper regulation of this sector is likely to push the agencies beyond their current capacity, and thus these considerations go hand in hand with ensuring the capacity to regulate and monitor this industry, especially as significant commercial investment is already being made.

---

[281] Norwegian government, Skattesatser 2022
[282] Norwegian Ministry of Industry and Fisheries: Et hav av muligheter
[283] Norges Sjømatråd
[284] Norwegian Seafood Council

The Norwegian regulations have highlighted that cost is one of the main hurdles to the success of land-based aquaculture. The next section tests this thesis by modeling a cost comparison for Icelandic aquaculture farms of traditional and land based.

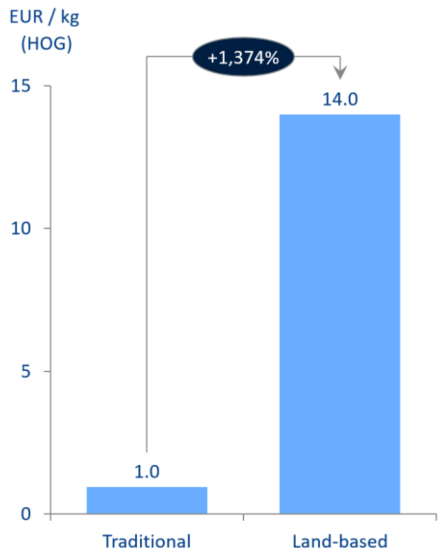
5.4 Financials

A financial view of land-based aquaculture, compared to traditional as a benchmark, supplements the discussion above. The following section presents estimates for the financials of both traditional and land-based aquaculture. In this scenario, costs are based on farming in Iceland, assuming the use of a hybrid flow-through system for a land-based tank.,[285] As in the rest of the report, this analysis is limited to the grow-out phase in seawater and assumes that land-based farming technology reaches its maturity successfully which might take up to 10 years.

5.4.1 Capital expenditures are much higher for land-based technology

A key difference between the two farming sectors are the up-front investments needed in equipment and construction. The setup of a land-based grow-out facility is much more capital intensive than a traditional facility using sea pens. Capital must be spent on e.g., inspection and preparing the land for the site, constructing the pens, purchasing, or developing the technology. Figure 5.14 shows the estimated average capital expenditures for a hybrid flow-through facility as well as a traditional facility, including the fees associated with acquiring a license (though immaterial compared to high equipment costs) but excluding the purchasing price of a license, which is unknown in Iceland but is a substantial cost factor for example in Norway.

FIGURE 5.14: CAPEX FOR TRADITIONAL AND LAND-BASED PER KG, EXCLUDING LICENSE COSTS[286]



[285] The system used by the major planned setups in Iceland, such as Landeldi, Geo Salmo and Samherji on Reykjanes

[286] BCG analysis

As the Figure 5.14 shows, land-based setup costs are about fourteen times higher than traditional costs. This results in a higher depreciation cost, which will impact land-based operating expenses as shown in the following section. As previously stated, the cost of a license is not included but its addition to traditional capital expenditure would level this picture somewhat. As an example, in 2020, licenses were sold in Norway on average for 14,5 EUR/kg and 8 EUR/kg in 2022.

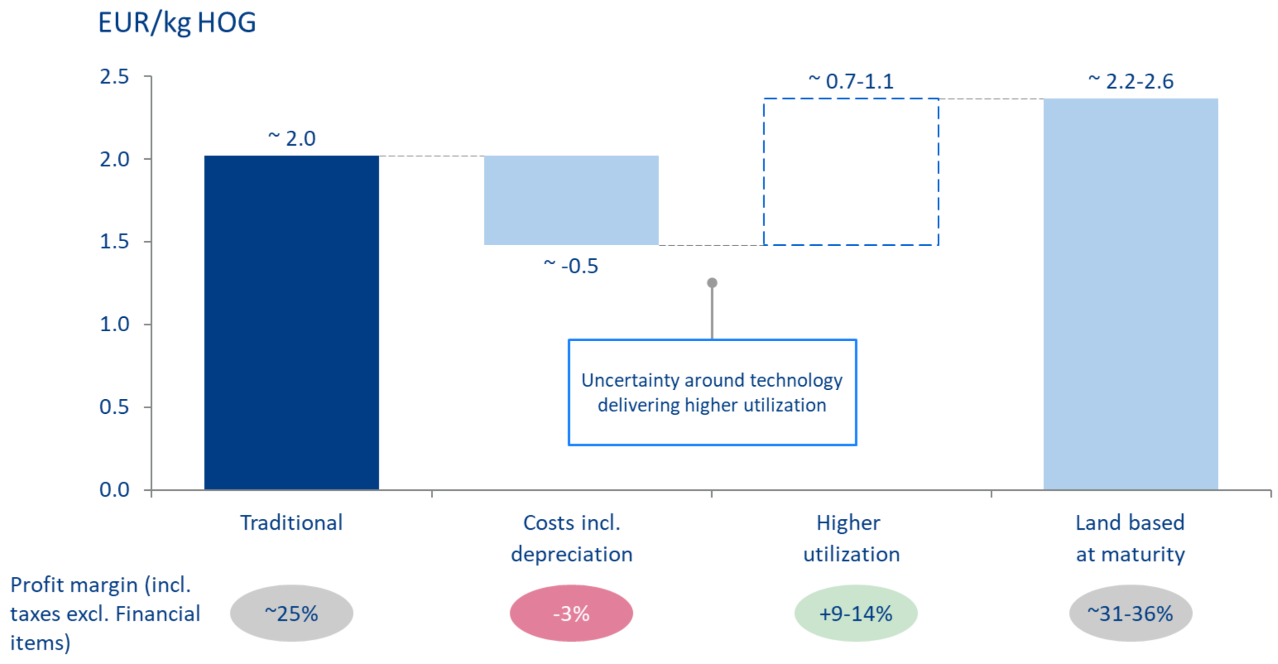
5.4.2 Land-based operations financially viable, even on par due to higher utilization potential

Overall, the analysis suggests that in the long term, operating a land-based farm can be financially viable, and even on par with the traditional sector if utilization expectations are realized. Although the operating expenses are currently higher than for traditional farming, land-based farming still offers a positive profit margin of over 20%; although somewhat lower than traditional aquaculture, this is an attractive standalone business case. Moreover, improvements in utilization arising from better control of the environment hold potential to offset these costs. Mortality risks associated with the external environment (such as predators, low temperatures, and other external contaminants) can be reduced by the controlled environment of the tank, resulting in a higher share of initial smolt population reaching harvest maturity. At the same time, the temperature control ability of a land tank allows farmers to sidestep the slowdown in growth associated with cold temperatures (such as in the winter months) and thus grow salmon at a faster rate than traditional farms. With fewer deaths and faster growth, land-based farms are thus expected to show higher utilization rates of licensed capacity than their traditional counterparts in Iceland. Taken together, despite higher costs, the potential for higher utilization suggests that a land-based farming operation can be as commercially attractive as a traditional farm.

Below is an estimate for the operating profit of traditional compared to land-based aquaculture per kilogram of harvested fish.[287] Like traditional aquaculture, there are risks of diseases (such as from contaminated smolts) that can wipe out an entire tank full of fish. In addition, there are risks of technological failure and human error associated with new technologies. As there is not credible experience of land-based farms operational at large scale, these risks cannot be quantified at this stage and are therefore excluded. The estimates below instead represent the financial opportunity of a land-based farm, given that it does not experience major mortality events. They should thus be taken not as a projection of probable earnings on a farm today, but as an illustration of a farm that has successfully reached maturity in the future. Similarly, the traditional farm is evaluated at the level of fees expected after 2026, since no land-based farms in Iceland expect to reach maturity before this time.

[287] Head-on gutted (HOG) or gutted weight equivalent (GWT) measurement (these are equivalent)

FIGURE 5.152: ESTIMATED LAND-BASED OPERATING INCOME AND PROFIT MARGIN COMPARED TO TRADITIONAL[288]



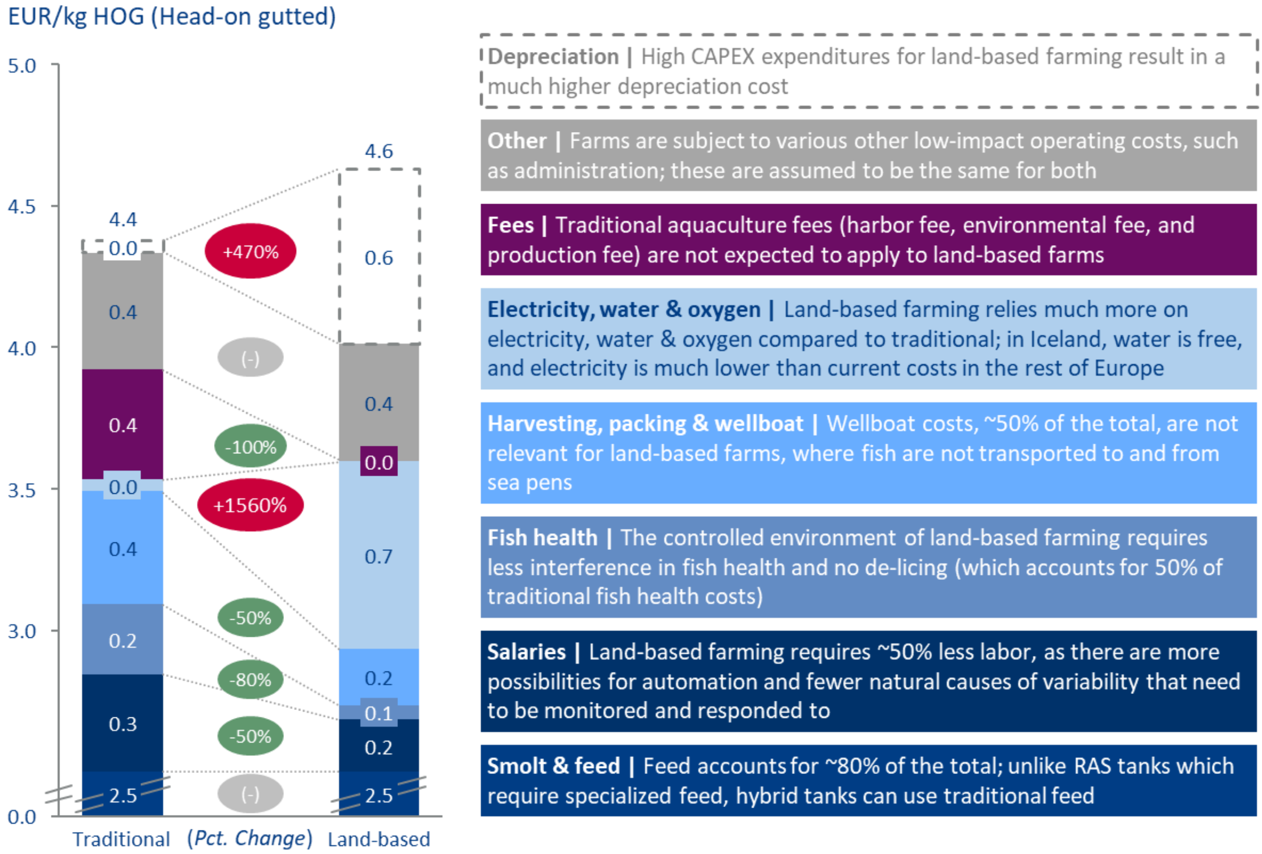
5.4.2.2 Cost comparison

Zeroing in on the breakdown of costs, land-based farming carries both advantages and disadvantages. Figure 5.16 shows a comparison of cost categories between traditional and land-based sectors. In this detail, it can be observed that the cost increases are driven by land-based resource use of electricity, water, and oxygen (although in this model based on Iceland, these costs are not as high as they would be elsewhere). On the other hand, some costs are reduced due to differences in production technique: salary costs are reduced as land-based operations can be more automated and require fewer employees to manage; de-licing costs are reduced as the tank is protected from external contaminants; and the wellboat cost becomes irrelevant as transport to and from sea cages is not needed. Furthermore, as noted in section 5.3, certain regulatory fees do not apply to land-based farms. Overall, these changes result in a difference of ~0.2 EUR/kg (HOG) between land-based and traditional aquaculture.

[288] DNB, BNP Paribas Exane (2021), Fiskeridirektoratet, OECD Data, Nofima, MOWI industry report, Expert interviews

Note: utilization assumed to be 100% as a baseline for both traditional and land-based

FIGURE 5.16: ESTIMATED TRADITIONAL AND LAND-BASED COSTS[289]



Utilization improvement potential

Many expect the controlled environment of land-based farming to improve utilization rates, both by reducing mortality and increasing the pace of salmon growth. Since contaminants are filtered out (in Iceland's case, naturally through the volcanic rock), there are fewer risks to mortality from external contaminants. A closed tank also reduces the risk of predators. Overall, if these benefits are realized, they are expected to improve survival rates by ~5-10%, which translates to a reduction in costs (accounting for increased feed to match biomass) of ~4-7%. At the same time, temperature is a key factor in the speed of salmon growth, and variation in temperatures (such as during the winter months) therefore slow growth and delay harvests in traditional aquaculture. With the land-based tank's ability to control temperatures and not being subject to seasonal cold, land-farmed salmon are expected to undergo a steadier and faster growth rate than traditionally farmed salmon.

Although difficult to isolate one factor impacting salmon growth, it is possible to use temperature-to-growth tables to model growth of salmon based on different temperature conditions.[290] Modeling the speed of growth from smolt to harvest with a comparison of average Northern European sea temperatures to a constant 9°C, the constant temperature results in an increase of ~40-45% volume

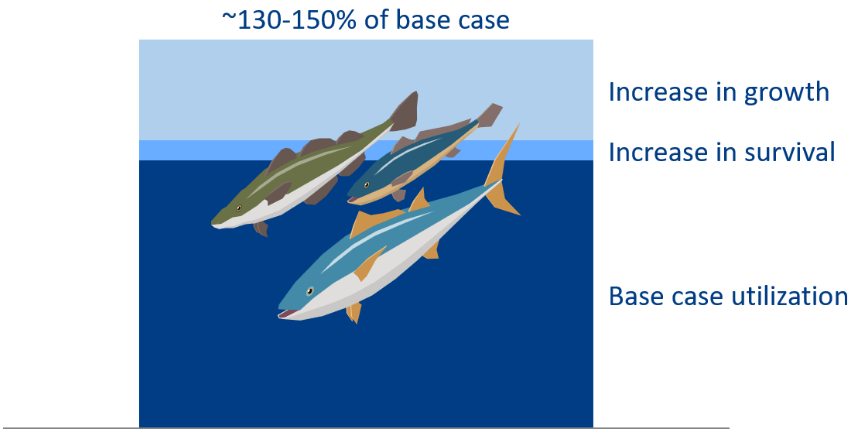
[289] DNB Markets; BNP Paribas Exane (2021), Fiskeridirektoratet, OECD Data, Nofima, MOWI industry report, Expert interviews, BCG analysis

[290] See BioMar Growth Table 2017 (showing growth rates by weight and temperature)

over the same period (assuming harvest at ~4kg).[291] However, this simplistic view may over-index on the impact of temperature, as other factors such as sunshine, oxygen, and current also influence growth experience. In these early phases of the sector, it may also take time for new technologies to be optimized to foster maximum salmon growth. Finally, this utilization must be balanced with the unforeseen risks, such as technological failure, associated with an industry still in a nascent phase (although not all players will necessarily face these). Thus, due to the uncertainty surrounding these improvements, these combined factors are represented by a 25-40% increase in volume due to temperatures.[292]

Combined with the improvement in survival of 5-10%, this allows for a possibility of 30-50% improvement in production volume, as shown in Figure 5.17. This translates to a 15-25% decrease in costs.

FIGURE 5.17: ILLUSTRATION OF UTILIZATION IMPROVEMENT POTENTIAL[293]



5.4.3 Potential additions to revenue can increase profit

Finally, many land-based farmers set their sights on other revenue streams, arising from sustainable premium, reliability, and sale of waste and intellectual property. These possibilities are examined below.

Potential "green" premium

A widely discussed possibility for additional revenue for land-based farming is the potential of charging a "green" premium for a more sustainable product. As noted in section 5.2, land-based aquaculture has the potential to be marketed as more sustainable than traditional aquaculture, primarily due to its lack of organic load discharge and interference with the local ecosystem. In addition, Iceland can deliver carbon-neutral energy. Currently, there is a wide range of experience and prediction around the

[291] BioMar Growth Table 2017, BCG analysis

[292] BCG analysis

[293] BCG analysis

magnitude of the green premium (if any) that these companies would be likely to achieve, while it can likewise be expected that a such price premium will wane as the land-based sector scales up supply.

On the low end of expectations around a premium potential, BNP Paribas Exane expresses the view that salmon is a commoditized product that will not demand a premium.[294] On the other hand, Atlantic Sapphire, and the largest land-based farm already in production, was consistently able to achieve a 50-65% price premium for their US-based Bluehouse premium product in the first half of 2022, compared to the average US price achievement.[295] As this product also has the benefit of being "made in the USA," it is possible that part of this premium may stem from its "local" source. However, there have been reports of European retailers interested in premiums of 40-50%, though the quantities may be small.[296] Furthermore, despite the aforementioned views, BNP Paribas Exane reports that "surveys on related criteria (certification and ecolabelling) suggest that a price premium of around 15% could be attained if independently certified and well-promoted ecolabels are used."[297] Figure 5.18 shows a single digit premium can offset the cost difference between land-based and traditional aquaculture. This scenario assumes successful marketing of sustainable production along with increased consumer awareness. Thus, this premium is not expected to happen automatically for any land-based farm, but rather as the result of a conscious choice and considerable effort. Figure 5.18 shows the increase in profit achievable in such a case.

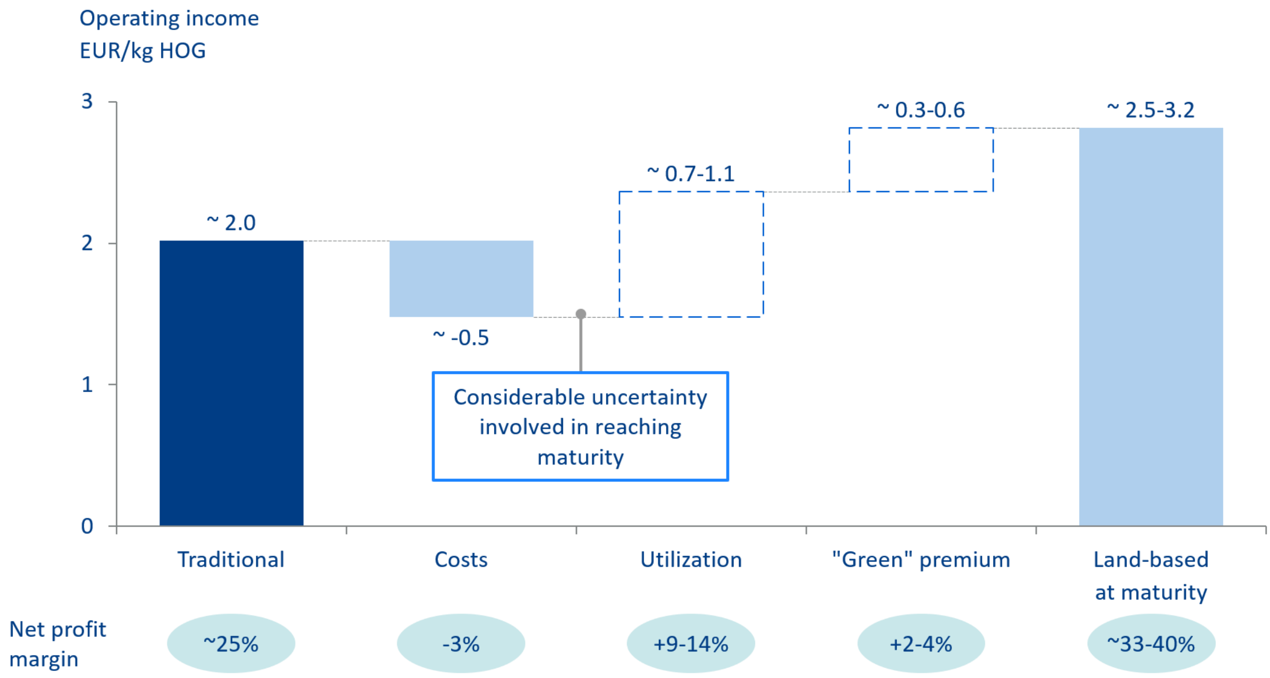
[294] BNP Paribas Exane (2021)

[295] Atlantic Sapphire investor materials

[296] Expert interviews

[297] BNP Paribas Exane (2021)

FIGURE 5.18: ESTIMATED LAND-BASED PROFIT COMPARED TO TRADITIONAL, WITH GREEN PREMIUM ADDED[298]



Commercial leverage associated with decreased variability in production

The controlled environment of land-based farming can decrease production variability, which is commercially valuable. Not only does temperature control allow fish to grow faster, but they will grow at a more constant rate, allowing farmers to predict their output year-round and harvest a steady number of fish every week of the year—rather than, for example, experiencing a slowdown during the winter months. The value of this will be realized in the ability to enter into long-term contracts with vendors, which has the potential to include more favorable terms. Ultimately, this may lead to land-based farmers having a more predictable revenue stream which can also positively impact financing terms.

Revenue streams beyond core operations

Beyond the core operations of selling fish, land-based farming carries with it the potential of additional revenue streams. The two options with the highest expected revenue potential are described below:

- **Sale of waste as fertilizer:** As discussed above, fish waste can be used for fertilizer in agriculture due to its high phosphorus content. The fish waste is combined with other inputs to create the final fertilizer product, and thus requires collaboration with other players to create the product.
- **Sales of intellectual property:** Many land-based farmers are developing technology, in conjunction with partners, to fit their own needs. As the sector grows, other new entrants will

[298] BCG analysis

look to these farms for inspiration, and thus these developments hold the potential to be marketed as turnkey solutions.

5.4.4 Sub-conclusion

While initial investment costs are high at this stage, long-term operating expenses appear supportable for land-based farming. Current CAPEX costs are expected to be at their highest, as technological innovation and efficiency is expected to spread across the industry. Yet companies at the forefront of land-based farming have the potential for additional revenue from their intellectual property as early developers, as well as short- to medium-term effects of a higher green premium. In both cases, profits appear to be positive, with higher costs offset by the technological and environmental advantages of land-based farming.

Despite the potential for financial success shown in this model, it is at this stage a higher-risk venture than traditional farming. Our model shows the case in which experience follows plan, but this experience has not been proven at a large scale (10kT+). Thus, these are early estimates. Additionally, like traditional aquaculture, events such as disease outbreak or human error can wipe out an entire tank or pen. Any operation must therefore take these possibilities into account and plan accordingly.

5.5 Conclusion: Potential to become a leader in land-based farming

Demand for sustainable protein is unlikely to be met by traditional aquaculture alone, and this demand vacuum is giving rise to investment in land-based farming. Although a nascent sector, land-based farming holds potential advantages over the traditional sector, including improved fish health and growth as well as the possibility to market a more sustainable product. The opportunities within land-based aquaculture are strengthened by locating the farms in Iceland, with the availability of naturally clean, heated water along with affordable, renewable energy, making a hybrid flow-through system (and its associated lower risk profile) effective. However, this may be somewhat tempered by distance from end-markets compared to some land-based farms that use recirculating aquaculture systems to allow their proximity to end consumers. Land-based aquaculture also holds potential to improve harvest predictability, solving a problem that has long prevented vendors from guaranteeing long-term supply and price stability and creating a window for sales volume and preferential treatment by buyers. These promising attributes have attracted several investors to land-based aquaculture in Iceland, despite the nascent state of the sector, which is not yet fully operational at a large (10kT+) scale.

Initial investments required for land-based farming are much higher than for traditional aquaculture, and these drive high depreciation costs that result in a total OPEX of 5-10% higher for land-based than traditional farming. However, these costs are expected to be offset when the farm reaches production maturity, due to the potential of land-based facilities to improve operating profits with better utilization. Should a green premium be realized, this could make land-based salmon farming more profitable than traditional farming. However, although land-based farming holds financial promise, this sector has not been proven at the large scale that many land-based aquaculture companies aim for, and thus considerable uncertainty and technological risk remain.

This evaluation suggests that Iceland holds opportunity to leverage the natural advantages offered by the country (water and green electricity) to support a successful land-based aquaculture sector. Chapter 8 offers considerations for how Iceland can best develop this sector.

6. Offshore farming

The aim of this chapter is to provide an overview of the current state of the offshore aquaculture sector and assess the potential for its establishment in Iceland. This includes an overview of current developments and technologies, a review of offshore costs compared to the costs of the traditional sector, potential areas for offshore farming in Iceland, and the role of government in establishing the industry.

6.1 Sector overview

Offshore farming has received increasing attention over the last decade as an alternative to traditional aquaculture, driven primarily by growth limitations in the traditional sector. Apart from additional capacity, offshore holds the potential to deliver a variety of potential advantages by mitigating current challenges related to fish health, such as sea lice and diseases, as well as environmental impacts, however more experience and research is needed before concluding on these advantages.[299] Offshore farming technology is still in its early stages, with only eight projects ongoing worldwide compared to over 100 land-based projects. As offshore projects require high investment over long time periods, predictability around the future regulatory framework of the industry is key to induce continued investment and support further growth.

Offshore aquaculture, as indicated by its name, is located farther into the ocean relative to traditional aquaculture. For practical purposes, offshore aquaculture is sometimes further segmented into offshore and semi-offshore. By this definition, offshore is in the open sea, while semi-offshore is located closer to the coastline, yet not inside fjords. Due to their location in the open sea, offshore structures are generally exposed to harsher conditions (e.g., higher waves and stronger currents) than semi-offshore structures. Here, the distinction between offshore and semi-offshore will be applied in some instances, but generally, the term offshore is used to cover both.

6.1.1 Offshore has the potential to increase output, however large investments and new regulation are needed

Offshore is expected to hold three main advantages compared to traditional aquaculture:

- **Less capacity constraint**: Much of the world's current fjord- or near shore-based licenses have already been granted. Offshore farming operates outside of fjords and is therefore not subject to the same type of carrying capacity constraints as traditional aquaculture. Capacity will not be unlimited, but once licensing regimes are established, the expectation is that they will be less constrained than those for traditional.
- **Improved fish health and productivity:** The stronger currents and more stable temperatures of offshore facilities in the open sea resemble the natural habitats of salmonoids more closely compared to fjords, and thus they hold the potential to create a better living environment for salmonoids. Offshore structures also hold the potential to decrease density as they are less

[299] Offshore aquaculture of finfish: Big expectations at sea (2021)

constraint by other nearby commercial interest. This may result in a lower impact from parasites, lower mortality, and faster growth.[300]

- **Lower environmental footprint:** Geographic distances between sites, greater ocean depths and currents are expected to result in larger dispersion of waste and quicker dilution.[301]

However, offshore aquaculture is an emerging sector with technology in development. These benefits are yet to be proven on a commercial scale and there have been incidents of e.g., sea lice issues and fish escapes. These and more challenges are the focus of innovation in technology and are starting to be addressed by the latest developments.

Apart from technology, the sector also faces challenges from a regulatory and funding perspective. Overall, this increases the risk associated with investment in offshore projects. The four key challenges are highlighted below:

1. **Increased technological requirements:** More extreme weather conditions at sea require more robust facilities, including stronger anchors to fix the structures at more depth as well as stronger cages to withstand higher waves and stronger currents.
2. **Lack of planning and regulatory frameworks:** In most areas, locations for farming sites have not been identified nor planned, regulatory frameworks have neither been developed.
3. **New infrastructure and labor requirements**: Special infrastructure is required to service offshore, e.g., offshore support vessels and labor with new capabilities. Here, offshore in some areas benefits from synergies with other offshore sectores, e.g., energy.
4. **Higher investment needs and longer time horizons**: Due to new and increased requirements, capital expenditure is significantly higher in offshore than traditional aquaculture. Furthermore, more time is likely needed before operations can reach full scale and deliver returns on investments.

Some potential mitigators exist for governments seeking to support the growth of offshore aquaculture. To mitigate challenges 1 and 4 outlined above, the cost of a license, set by governments, can be used to offset the significant investment premium compared to traditional farming and help financially enable technology development before operations reach commercial scale. To address challenge 3, given the complementarity of assets and capabilities, fish farmers can seek partnerships with offshore solution providers. This is already the case for some of the ongoing projects. To mitigate challenge 2, governments can initiate research aimed at identifying suitable sites, while at the same time develop the regulatory framework to create certainty and predictability among private players and investors. Moreover, to further incentivize early investment, governments can split regulation formulation into two steps: a) Issue short-term development/research licenses with specific environmental requirements, and b) Establish a longer term regulatory and licensing framework.

[300] DNV: Marine Aquaculture forecast (2021)
[301] Offshore aquaculture of finfish: Big expectations at sea (2021)

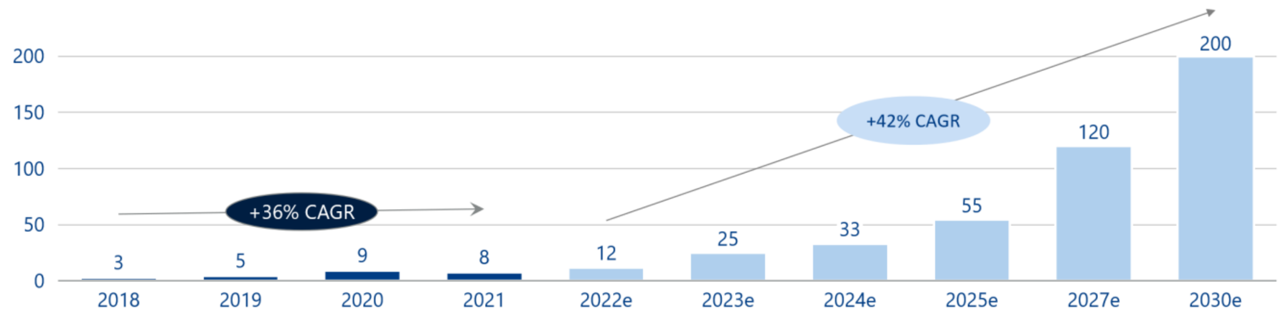
6.1.2 Nascent industry, currently driven by research licenses

Norway and Norwegian companies are pioneer developments in offshore salmon aquaculture. SalMar launched operations of Ocean Farm 1, the world's first offshore salmon farm, in 2017.[302] Since then, several projects have started as seen in Figure 6.2. To enable and stimulate the development of offshore aquaculture, Norway issued so-called development licenses from 2015 to 2017. These licenses were granted without payment, reducing the initial investment needed from private actors. Additionally, the development license scheme has enabled players to launch projects before the full regulatory framework is in place. In exchange for the research licenses granted, offshore farmers are required to share their knowledge and designs with the broader industry.[303] This scheme encouraged investment, research, and development within the sector in Norway, resulting in Norway having the most offshore projects underway.

6.1.3 Despite medium-term growth, offshore is likely to remain small in global context

Despite strong growth, the contribution of offshore farming to global production will, in the medium term, be small in comparison to other farming sectors. In 2021, global offshore production amounted to ~8kT (0.3% of total supply) and is expected to reach 100-300kT by the end of the decade.

FIGURE 6.1: EXPECTED VOLUMES FROM OFFSHORE FARMING (KT)[304]



Medium term growth is expected to be mostly driven by eight current projects and new projects developed by the same industry players. Most current projects are in Norway, driven by the developmental licensing scheme, relative maturity of the Norwegian regulatory framework, and likely also benefitting from synergies with the Norwegian offshore energy industry.[305] Scotland and Chile also have semi-offshore projects ongoing, with one already operational since 2018 in Orkney, Scotland.

Semi-offshore has been a natural starting point for the industry, as complexity and cost generally increase with distance from the coastline. All but one of the current projects can be classified as semi-offshore, that is, planned or approved sites are within a few kilometers of the coast. SalMarAkerOcean's Smart fish farm (SFF) is the exception, with an application in process for a site ~90 km from the

[302] Fish farming company SalMar worked with offshore service provider Aker to develop the world's first (semi) offshore fish farm. The companies have since entered a joint venture, SalMarAkerOcean to lead their future offshore investments

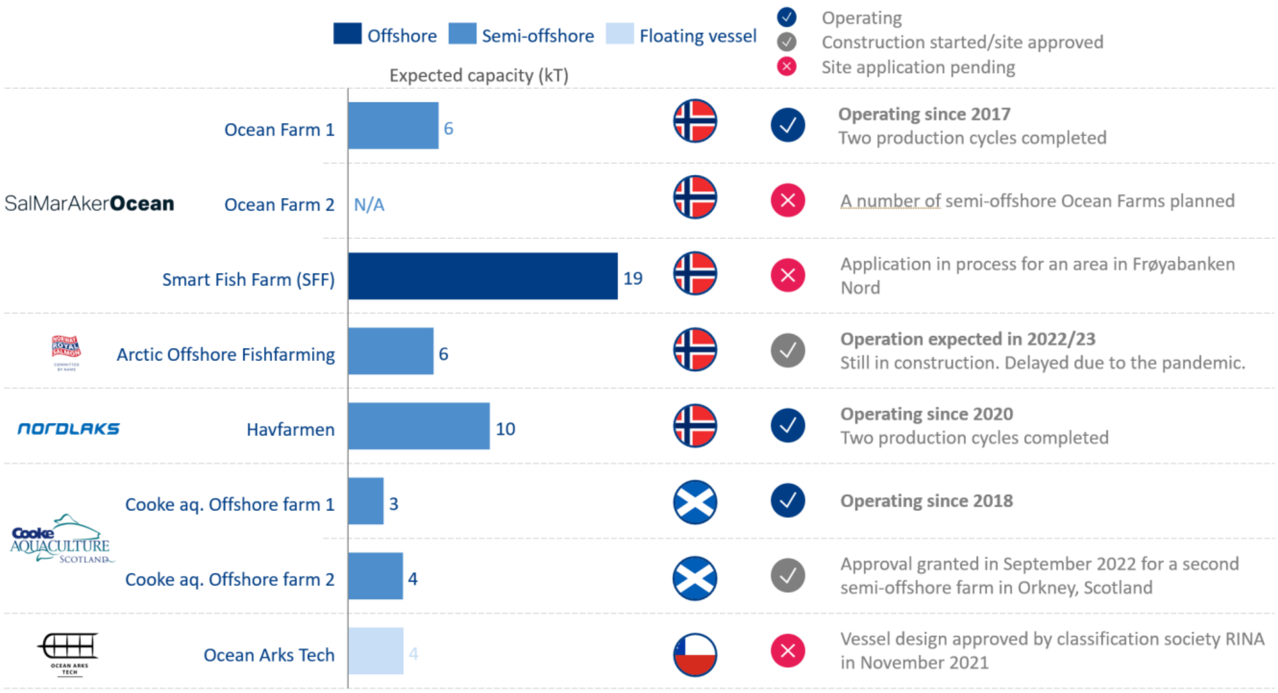
[303] See Section 6.4 for more information on the Norwegian government's offshore aquaculture policy history

[304] Pareto Securities, BCG analysis

[305] Expert interviews

Norwegian coast. As an industry in its early stages of development with many challenges to overcome, current projects utilize different technical solutions. Over time, however it is likely that a common standard, with some nuances to cater for local requirements, will emerge as industry best practice.

FIGURE 6.2: WORLDWIDE OFFSHORE SALMONOID PRODUCTION PROJECTS[306]



6.1.4 Sub-conclusion

The primary motivator for the development of offshore aquaculture is increasing capacity, beyond traditional aquaculture and other framing sectors, to meet future demands. Beyond capacity, offshore farming may hold advantages in terms of improving fish health and limiting environmental impact. Offshore is however a nascent industry, with high initial investment costs and longer timeframes to establish commercially viable operations compared to traditional aquaculture. This makes investments inherently riskier and amplifies the need for clarity around regulation and licensing. Norway is today most progressed in this regard, attracting several players to start offshore projects some of which are already operational although not at full planned capacity. Scotland and Chile also have ongoing projects.

Contingent on positive developments in the sector, including overall financial viability, offshore has the potential to become an attractive addition to global aquaculture. In this regard, Iceland may benefit from already now starting to plan potential sites and formulating a regulatory framework, and potentially following Norway's example of issuing development licenses to attract interest from private actors. These possibilities are explored in the following sections, which cover the financial and geographical potential of offshore, followed by the potential role of the Icelandic government.

[306] Company statement, Fiskeridirektoratet, BCG analysis

6.2 Financials

To support further exploration of the attractiveness of offshore aquaculture, the following section includes an illustrative study of the costs of offshore aquaculture, compared to the traditional sector. Beyond functioning as an additional indicator of the overall attractiveness of offshore farming, this analysis can be used to consider the need for a dual licensing and auctioning system that treats traditional and offshore farming differently to incentivize investment in an emerging sector. The following comparison assumes a deep ocean offshore farm such as SalMarAkerOcean's SFF in terms of investment needs and production capacity.

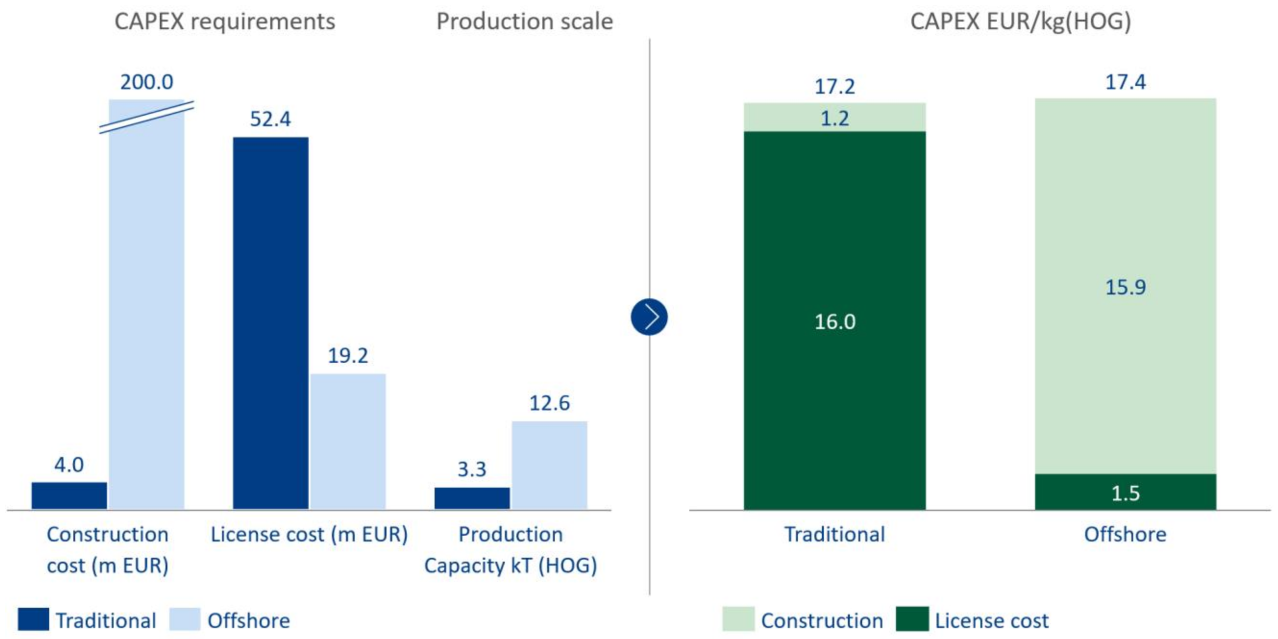
6.2.1 Capital expenditures are substantially higher in offshore aquaculture

Offshore farms can partly mitigate higher investment costs with scale to achieve a lower ratio of capital expenditure (CAPEX) to each ton of produced salmon. As an example, the current average production of a traditional salmonoid farm in Iceland is 3.5kT (LW) per site, while SalMarAkerOcean expects that the SFF will be able to contain a capacity of up to 19kT MAB (~16.9 LW assuming 89% utilization).[307]

Despite this difference in scale, offshore projects still require substantially higher CAPEX/kg of produced salmon. To partly offset this, offshore projects in Norway have received research licenses at negligible costs. Figure 6.3 shows the cost expenditure for traditional and offshore farming in Norway. The comparison is made on current facilities and cost figures. Standardization of designs and scaling of facility production may result in lower investment requirements in the future.

[307] Here referring to utilization as share of MAB for the specific production area. The MAB utilization in Norway was 89% in 2021 (MOWI industry report)

FIGURE 6.3: INVESTMENT COMPARISON OF OFFSHORE AND TRADITIONAL PRODUCTION IN NORWAY[308]



Based on these assumptions, to achieve parity with traditional farming's CAPEX/kg (HOG) levels, there is limited room for license costs. In this example, license costs are around one tenth of those for traditional farming. It is important to note that the costs of offshore projects can vary substantially as they are highly influenced by the price of raw materials (e.g., steel). Overall, however, their cost competitiveness in relation to traditional aquaculture relies on the large discrepancy of license costs between the two sectors.

This example indicates that, to promote offshore projects and attract investors, a different licensing regime to traditional aquaculture is likely required. This is explored further in Chapter 8.

6.2.2 Higher operational expenditures may be mitigated by improved fish health

Only a handful of production cycles have been completed in offshore farming. Empirical data is therefore limited, making a concrete comparison of the operational expenditure in offshore and traditional aquaculture challenging. Some indications have been witnessed so far, e.g., lower mortality but these are based on experience from production cycles at lower capacities. It therefore remains to be seen if they translate to production at full scale. Regardless it is expected from current investors that, as the offshore sector matures, it will realize operational benefits compared to the traditional sector.

Overall, including depreciation from high investments, operating costs are expected to be higher. some attributes of offshore farming naturally imply higher operating costs. This includes operating further

[308] MOWI industry report, Kepler Cheuvreux, BCG analysis

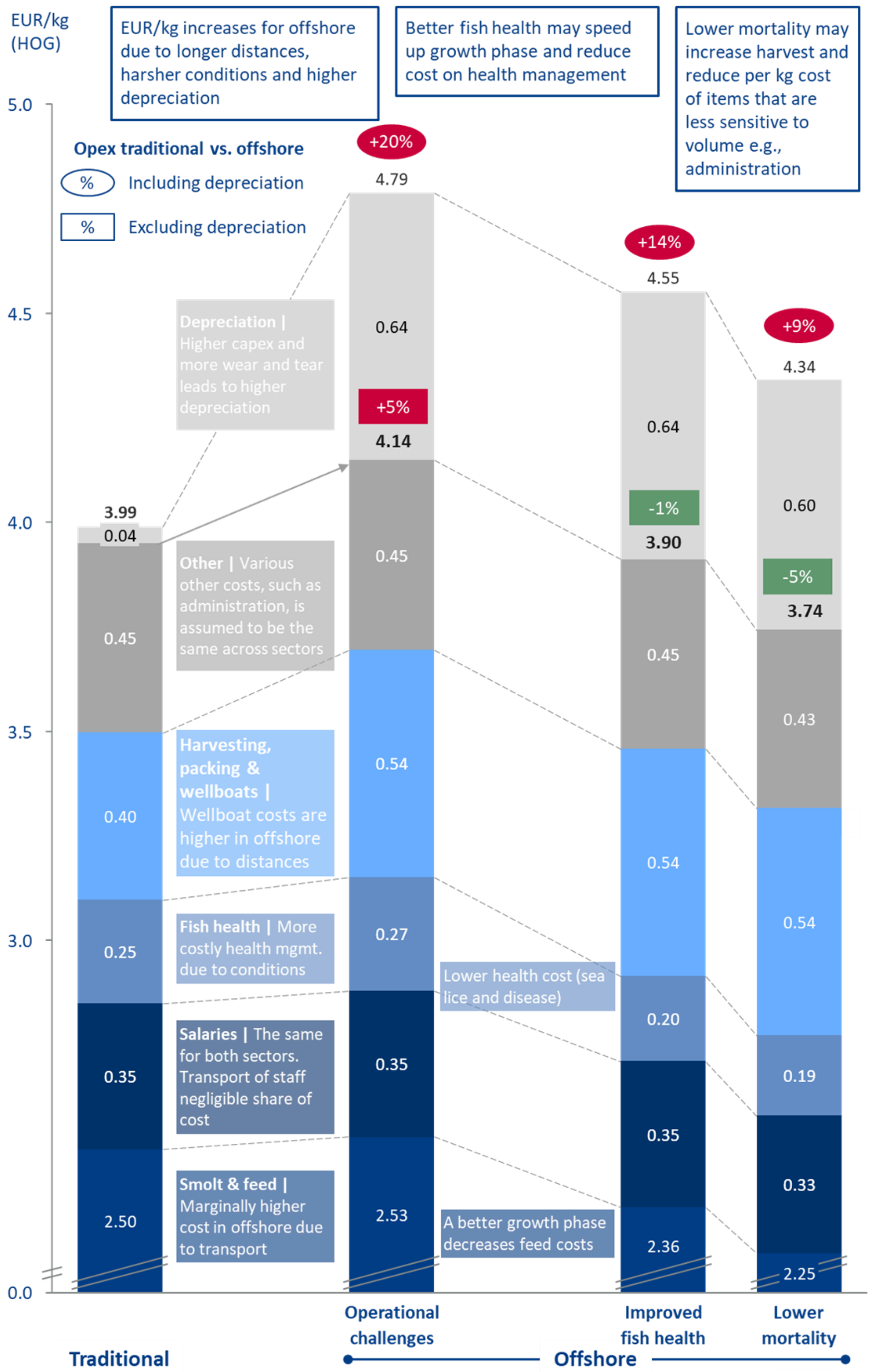
Note: Figure uses average license costs in Norway 2020 and assumes MAB and license utilization of 100%. A deep ocean offshore facility is assumed to contain 15kT (LW) from the coastline means distances covered by service vessels and wellboats are longer. Extreme weather conditions introduce wear and tear that requires higher levels of maintenance resulting in depreciation of the facility investments. Other operations, such as safeguarding fish health, become more complicated due to stronger currents and higher waves. Despite these factors, as feed and smolts are by far the largest cost drivers in production, the overall impact on OPEX/kg (HOG) excluding depreciation is expected to be ~5% higher compared to traditional. The picture changes if expectations of offshore having a positive impact on fish health i.e., translating into less disease and sea lice management, lower mortality, better feed conversion and faster growth phase. Improvements in these factors all deliver substantial cost benefits that, if realized could deliver a cost saving of around ~5% (excluding depreciation) compared to traditional.[309] Figure 6.4 shows the outcome of an illustrative study, excluding fees for both sectors.[310]

[309] SLUTTRAPPORT, Ocean farm 1, Sluttrapport Havfarmen 1

Note: In the first cycles of OF1 and HF1 there were no need to de-lice the production and the producers found substantially smaller concentrations of female sea lice

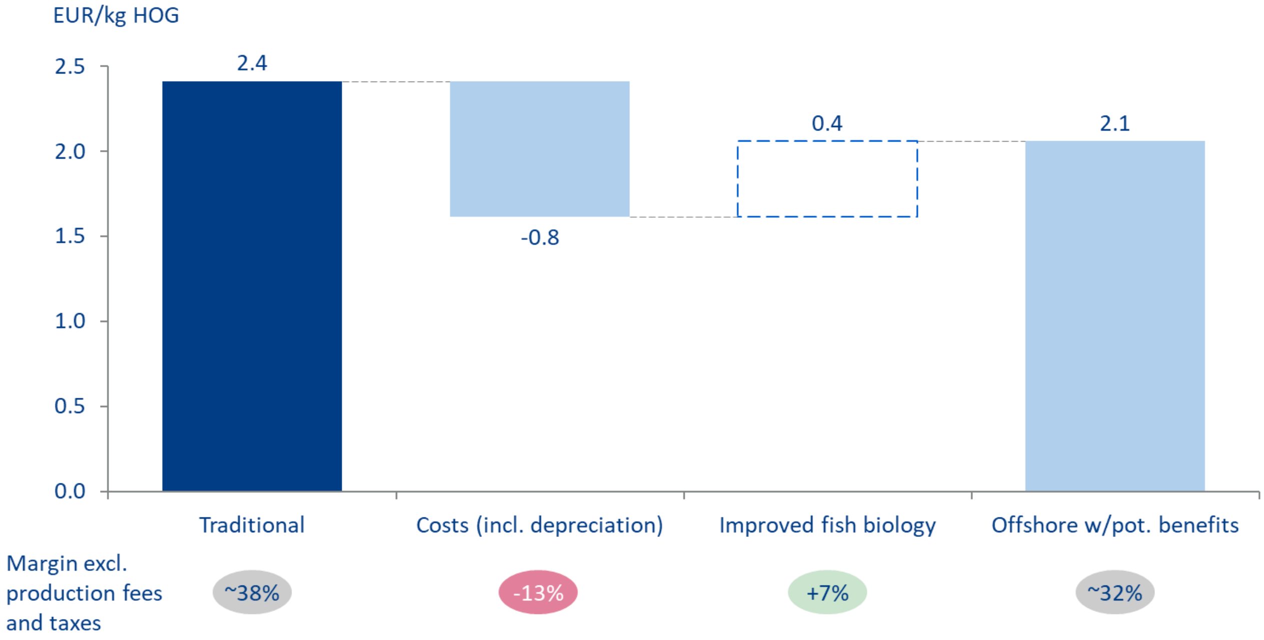
[310] Currently, with no offshore-specific regulation in Iceland, the relationship between traditional and offshore fees are uncertain

FIGURE 6.4: OPEX COMPARISON OF OFFSHORE VS. TRADITIONAL (EUR/KG HOG)[311]



The largest impact to the operating expenses of offshore compared to the traditional counterpart is the depreciation of the CAPEX, which is much higher. Even after assuming potential biological advantages of offshore, when including depreciation, costs may be as much as ~9% higher than for traditional aquaculture. Figure 6.5 illustrates this difference. Although depreciation reduces offshore profitability below that of traditional aquaculture, it remains a viable business model with at ~25-32% EBIT margin with current salmon prices (excluding fees).[312] This indicates that if salmon prices stay at current levels, it will still be financially viable operate offshore aquaculture in Iceland.

FIGURE 6.5: ESTIMATED OFFSHORE OPERATING INCOME AND PROFIT MARGIN COMPARED TO TRADITIONAL[313]



6.2.3 Sub-conclusion

Offshore fish farms have substantially higher CAPEX expenses and despite potential for significantly larger capacity, CAPEX/kg (HOG) is likely substantially higher compared to traditional aquaculture. Operating expenses are much more comparable between the two sectors, with potential future upside for offshore if the technology fulfils its promise of improving fish biology and leading to better feed conversion ratios. Overall, the CAPEX costs involved in establishing an offshore fish farm indicate that the sector will be sensitive to license costs. Countries wanting to promote offshore farming will therefore need to consider a dual licensing regime to attract private investment.

6.3 Suitable locations in Iceland

This section examines the feasibility of offshore farming in Iceland. Key factors determining location feasibility are considered for Icelandic waters, resulting in an indicative map of areas where the right

[312] See Section 4.4 for an overview of fees in Iceland, Faroe Islands and Norway

[313] MOWI industry report, Kepler Cheuvreux, BCG analysis, Note: A salmon price of 6.4 EUR/kg (HOG) is assumed and fees are excluded in both sectors

environmental conditions are likely to exist for offshore farming. This relies on research and experience gained through established offshore projects in Norway. However, further research is required to validate the suitability of these areas and determine optimal locations for sites within them.

In the following sub-sections, we look at the following seven factors as the most relevant for offshore farming locations in Iceland:

TABLE 6.1: CONDITIONS FOR OFFSHORE FARMING IN ICELAND

Factor	Optimal conditions
Temperature	Between 8-14°C
Water current velocity	Not exceeding 60cm/s and on average less than 20cm/s
Wave height	Less than 6 meters (new technology to extend limits)
Environmental impact	Limited impact to wild salmon stocks (escapes, diseases, and sea lice), spawning areas of various species, vulnerable ecosystems and from organic load
Sea depth	Less than 400 meters
Seismic activity	None or very limited
Interference with other commercial interests at sea	Mitigation of conflicts with fishing areas and sea traffic

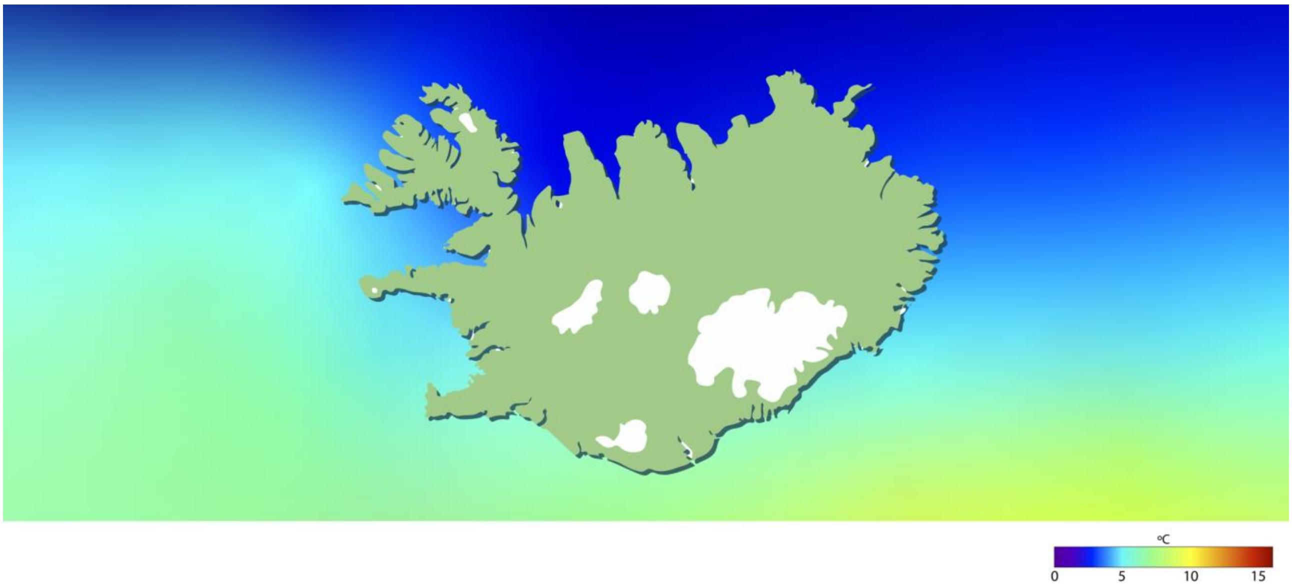
The preliminary analysis that follows indicates that the waters West and South of Iceland would be most attractive for offshore salmonoid farming.

6.3.1 Temperature

As discussed in Chapter 3, salmonids are best suited for temperatures between 8-14 °C. Besides potential frost injuries, low temperatures impact growth and swimming ability, which in turn affect ability to withstand stronger currents. Thus, it is important to consider temperature when selecting optimal offshore locations.

Seawater temperatures off the coast of Iceland vary by location, influenced by sea currents. The North Atlantic drift and the South Irminger current bring warm water from the Gulf Stream to the South of Iceland during winter. This impacts water temperatures along the south coast that rarely get colder than 5 °C, providing a suitable environment for salmonoid production throughout the year. The East Greenland current brings cold Polar water to North Icelandic waters, making it less suitable for offshore sites.

FIGURE 6.6: AVERAGE SEA WATER TEMPERATURES IN FEBRUARY[314]



The average sea temperature of Icelandic waters can be seen in Figure 6.6 during February, historically the month where sea temperatures are lowest. The image indicates that the areas off the South and West coast may be best suited for offshore farming with temperatures in the 6-8°C range.

6.3.2 Current velocities

Current velocity is important for salmonoid health and growth. At low current velocities, the salmonoid will swim around in circular structures at voluntary speeds. As current velocity increases in a fish farm, the salmon breaks from the circular structure and starts to stand on the current, swimming at speeds required to avoid being pushed against the farm's structures. As the current velocity increases, salmonoids will reach critical swim speed, a speed they can only sustain for a short amount of time. Critical swim speed is generally used to define an absolute maximum current velocity an offshore farm should be exposed to; see Table 6.2 for an overview of swimming behavior at different current velocities.

TABLE 6.2: SWIMMING BEHAVIOR OF ARCTIC SALMON AT DIFFERENT CURRENT VELOCITIES[315]

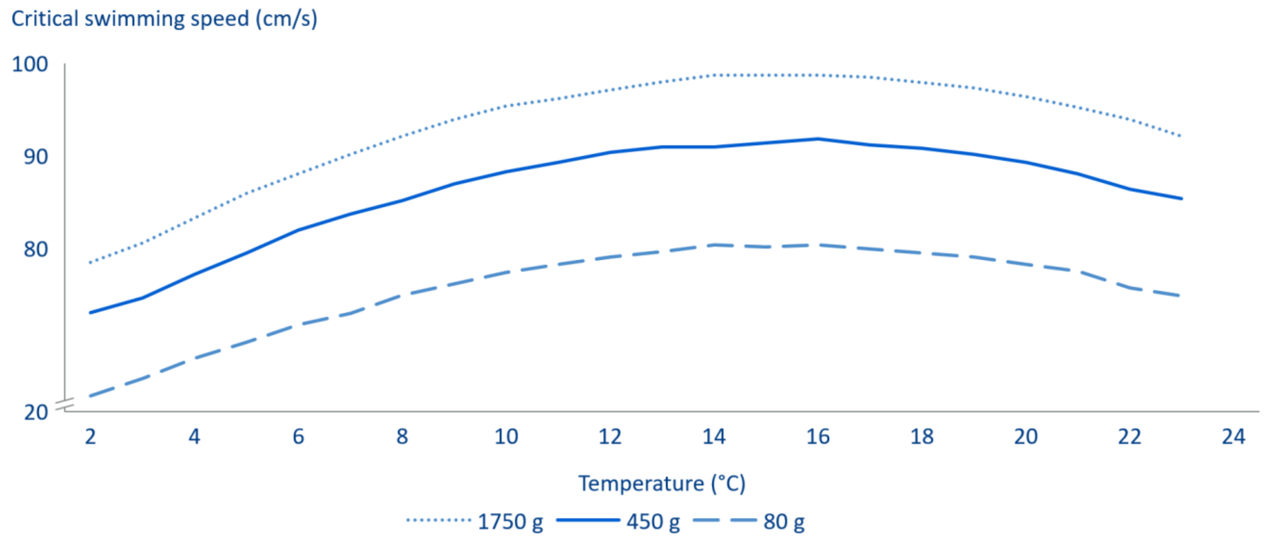
Current Speed (cm/s)		Swimming behavior
0-10	Very weak	Swimming freely
10-20	Weak	Swimming freely
20-40	Moderate	Circular pattern disrupted; some standing on current
40-50	Substantial	Most fish standing on current
50-60	Strong	All fish standing on current
>60	Very Strong	Exceeds critical swim speed

314 COBE Sea Surface Temperature data provided by the NOAA PSL (Colorado USA), University of Miami RSMAS, BCG analysis

315 Havbasert oppdrett: Hvor mye vannstrøm tåler laks og rensefisk? (2019)

Strong currents increase collision risk and inhibit growth as the fish expenses energy at forced swim speeds. Two factors, salmonoid size and sea temperature are considered to increase salmonoid ability to sustain currents. Larger salmonoids are generally able to swim faster, while water temperatures, colder or warmer, than optimal salmon conditions can lower their swimming ability.

FIGURE 6.7: TEMPERATURE IMPACT ON CRITICAL SWIM SPEED OF ARCTIC SALMON[316]



Furthermore, the Lump fish, which is widely used as a cleaner fish in sea lice control, have a critical swim speed of less than 35cm/s for the above temperatures. This makes it even more advantageous to have relatively stable and slow currents.

Currents around Iceland can generally be characterized as relatively weak. An exception to this is where the seabed is relatively steep as this can cause water to flow faster. Such conditions are generally more common East of Iceland where water currents are higher. The combination of colder water and relatively strong currents off the East coast may make it suboptimal for offshore fish farming.[317]

[316] Expert interviews, BCG analysis

[317] Expert interviews

Note: Future technological advancements where fish are protected from currents and cold temperature could change this conclusion

FIGURE 6.8: CURRENT VELOCITIES IN ICELANDIC WATERS[318]

In summary, offshore salmonid farms should be located where they are unlikely to be exposed to currents stronger than 60cm/s, and optimally where average current velocities are 20cm/s or less. Only considering current velocities, most areas in Icelandic waters are feasible, except for potentially the waters off the East coast. Furthermore, the relative cold waters of Iceland suggest that Icelandic offshore farming would benefit from larger smolt sizes, increasing their ability to swim faster.[319] Transporting the smolts offshore during the summer months, when water temperatures are higher, can also help them sustain stronger currents.

6.3.3 Wave height

Offshore farms are generally exposed to substantially larger waves than traditional aquaculture farms. Typically sheltered in fjords, traditional farms are generally subject to waves under 2 meters, while offshore farms need to sustain waves of at least 4 meters.[320] Strain on farming structures increases with wave height and, which can lead to cage and net damage, resulting in escapes and increased cost from maintenance. Early-stage research also indicates that larger waves can increase the possibility of collisions between fish and the farming structures with impact on fish health.

These challenges have been experienced by ongoing offshore projects and have intensified efforts to build stronger nets and cages as well as develop new designs and technologies, such as where the cages are placed below the surface of the water to limit the impact of waves and by creating double netting to limit the chances of fish escapes.

[318] OceanCurrents.rsmas.miami.edu

[319] The smolt size at Ocean farm I had an average weight of 250 grams in its first production cycle

[320] Technological innovations promoting sustainable salmon (Salmo salar) aquaculture in Norway (2022)

The Icelandic Road and Coastal Administration (IRCA) forecasts wave height, period, and direction in Icelandic waters. IRCA also operates buoys in several locations for capturing empirical measurements. In 2021, the IRCA issued a memo based on a preliminary simulation-based analysis of wave height off the South coast of Iceland. The analysis simulates maximum wave height to be expected in a given period measured in years. The results are summarized in Table 6.3, generally with higher numbers occurring farther from the shore.

TABLE 6.3: SIMULATED MAXIMUM WAVE HEIGHTS ALONG THE SOUTH COAST OF ICELAND (PRELIMINARY ANALYSIS)[321]

Period	South- and Southwest coast	Southeast coast
1 Year	9-11 meters	6-9.5 meters
10 years	10.5-12 meters	9-13 meters
100 Years	11-12.5 meters	10-16 meters

The results, although preliminary, indicate that with technology that enables offshore facilities to sustain up to 15-meter waves, offshore farming along the full South coast is feasible. Further research is, however, needed to validate these indicative findings. Similar wave heights are expected to occur along the West and North coastlines but validating that also requires more research.

6.3.4 Environmental impact

Several environmental impact factors need to be considered when exploring suitable locations for offshore farming. Offshore farms may impact its surrounding environment in several ways. Both travelling species such as wild salmon as well as stationary species such as coral reefs and sponges could be impacted by the presence of an offshore facility. Furthermore, although unlikely to occur, the spread of diseases and sea lice between offshore facilities and current traditional facilities also needs to be considered and modelled. Example factors to be considered are summarized in Table 6.4.

[321] Icelandic Road and Coastal Administration: Preliminary study (2021)

TABLE 6.4: ENVIRONMENTAL FACTORS TO BE CONSIDERED (NON-EXHAUSTIVE)

Factor to be considered	Potential consequences
Fish escapes and likely travelling routes under such events	Escapes can lead to genetic mixing with wild salmon stock
Spawning areas of various species	Disturbance to spawning areas of species might change natural fish behavior and disturb ecosystems
Presence of vulnerable ecosystems (such as sponges and coral reefs)	Biological waste and other farming operations may cause harm to vulnerable ecosystems
Spread of diseases, and sea lice	Offshore sites might be able to spread diseases and parasites to traditional aquaculture and wild stock
The dilution of organic load and impact on seabed	With higher biomass, despite faster dilution of organic load, it may impact the seabed and other sea-based lifeforms

Fish escapes are a key parameter to the risk-assessment for aquaculture in Iceland (see Chapter 4). In offshore farming, the biomass is typically much larger which may lead to higher volume fish escapes. On the other hand, the distance to the salmon rivers is higher compared to traditional. A greater understanding of migration from fish escapes is however needed to determine how a risk assessment system should be adjusted to accommodate for the specificities of offshore production.

Due to stronger currents at open sea, sea lice and diseases can generally travel farther than from traditional sites; however, the level of dilution is also higher. Generally, there is a higher possibility of the spread of diseases and lice from an offshore facility to an onshore than the other way around.[322] Although there is no clear limit to when diseases have been diluted enough to not cause infection, the Norwegian Directorate of Fisheries (Fiskeridirektoratet) considers the spread of diseases from sites more than 20-30 nautical miles from the coast is negligible. The travelling distance and possible spread of diseases depend on current direction and velocity implying that a similar analysis would have to be made for Iceland to determine such limits.

This implies that analysis and modelling of disease and parasite spread from an offshore facility to traditional sites needs to be performed before large scale operations are established. Nevertheless, modelling of infection pressure in Norway shows that the possibility of lice and diseases is lower for offshore and decreases with the distance to the coast.[323]

6.3.5 Sea depth

Currently, all offshore farming projects except for the Chilean Ocean Ark require anchoring to the seabed. Examples from the energy industry show that mooring in deep seas, even if feasible from an engineering standpoint, increases costs significantly.[324] Establishing offshore farms at modest sea depth is therefore considered advantageous. The three semi-offshore projects in Norway have all been built at

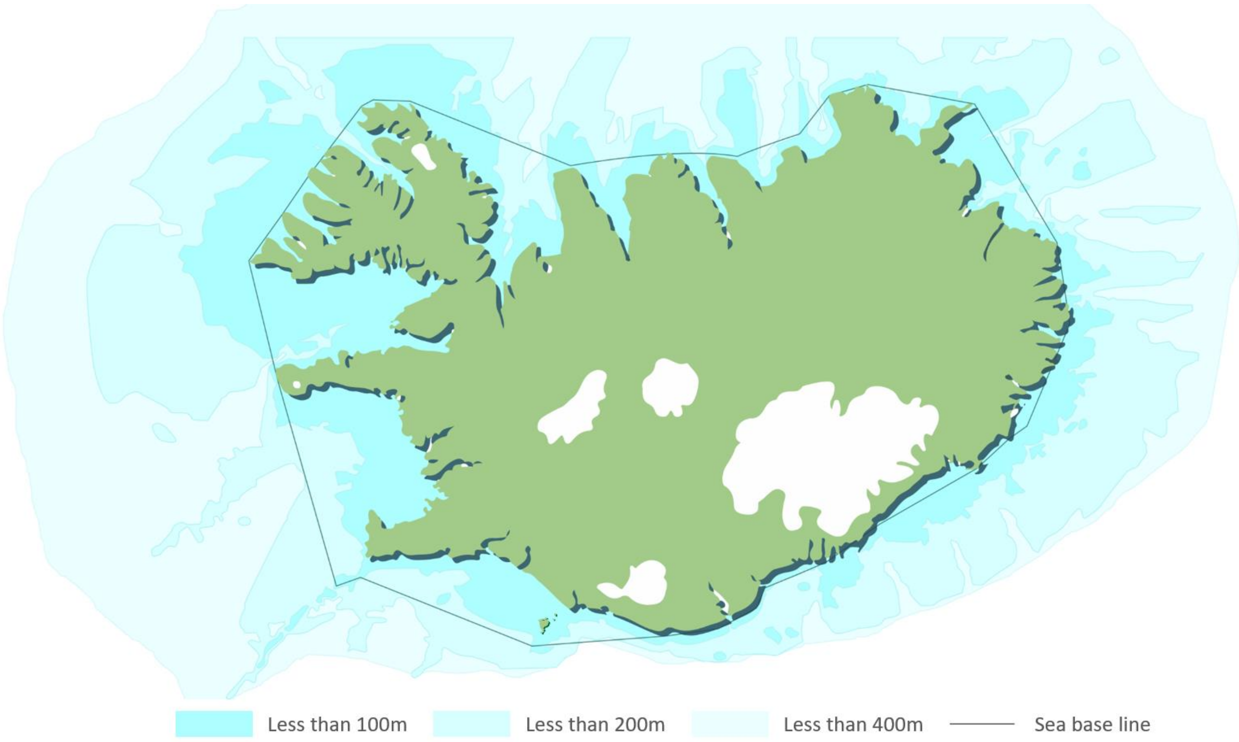
[322] Bjørn Ådlandsvik: Havbruk til havs smittespredning (2019)

[323] Fiskeridirektoratet: Kartlegging og identifisering av områder egnet for havbruk til havs (2019)

[324] Expert interviews

a sea depth of less than 150 meters. SalMarAkerOcean have applied for their offshore SFF in "Norskehavet" at a sea depth of ~350 meters.[325] Other projects are also considering ocean depths at ~200-500 meters.

FIGURE6.9: SEA DEPTH IN ICELAND (METERS)



Purely from a sea depth perspective, many areas in Iceland are feasible for offshore farming. Closer to the shore, sea depths are less than 100m, a depth which is ideal for semi-offshore facilities. The Westfjords and Eastfjords have areas at moderate sea depths that also can suit well. Other areas such as Faxaflói and Breiðafjörður also look promising but are closed off for aquaculture. The area South of Reykjanes, towards Vestmannaeyjar, looks especially appealing with a large area of seabed at moderate depths. The same applies to some areas along the Southeast coastline. Going beyond semi-offshore facilities opens more options around Iceland, especially in the West, where the seabed remains relatively shallow further out in the ocean. Areas in the vicinity of protected areas must however be examined especially with regards to potential escapes as mentioned in 6.3.4. Overall, sea depth does not seem to be a constraining factor for establishing offshore farming in Icelandic waters.

6.3.6 Seismic activity at sea

Iceland is located on the Mid-Atlantic ridge, the boundary of the North American and Eurasian tectonic plates, along which an active volcanic belt also sits. This causes significant seismic activity when tension in the tectonic plates is released. Earthquakes also occur due to the movement of magma. Earthquakes

[325] Kartverktøyet Yggdrasil

Note: Arctic Offshore Farming, Havfarmen and Ocean Farm 1 were placed at a sea depth of 98m, 130m and 150m respectively are common in Iceland but rarely reach a magnitude of 7 or higher on the Richter scale. There were, however four earthquakes of magnitude six or more in the period 1976 to 2008 that caused mild to severe damage to land-based structures and roads.[326] In the last few decades, earthquakes at sea in Iceland mostly occur in the North seas, with activity from Öxarfjörður running past Grímsey to Kolbeinsey, Iceland's northernmost point. The area Northwest of Eyjafjörður also has significant activity in comparison to other areas. In the South, activity mostly occurs along the Mid-Atlantic Ridge, also with some activity in the area between Reykjanes and Vestmannaeyjar.

Icelandic building regulations dictate that specific precautions are to be made in areas of seismic activity. Offshore facilities in such locations are also likely to be subject to similar regulation. Depending on the anchoring technology applied for offshore farming in Iceland, they may or may not be affected by seismic activity. The offshore energy facilities, due to their structure are more exposed to seismic activity, regardless rigs have still been successfully established in areas of moderate seismic activity. Vessel-based offshore farms, like the Ocean Arks Tech being planned in Chile, would naturally be less affected.

In summary, seismic activity in Iceland is unlikely to limit offshore aquaculture. Engineering solutions have been successfully developed and deployed for offshore structures more exposed than anchored aquaculture farms. With that, more research needs to be conducted and areas of no or limited activity would naturally be better suited for the operations.

6.3.7 Inference with other commercial interests at sea

Ideally, offshore farming sites should be located where they minimize interference with other commercial interest at sea, such as the fishery industry, general sea traffic, potential future windfarms and the tourism industry.

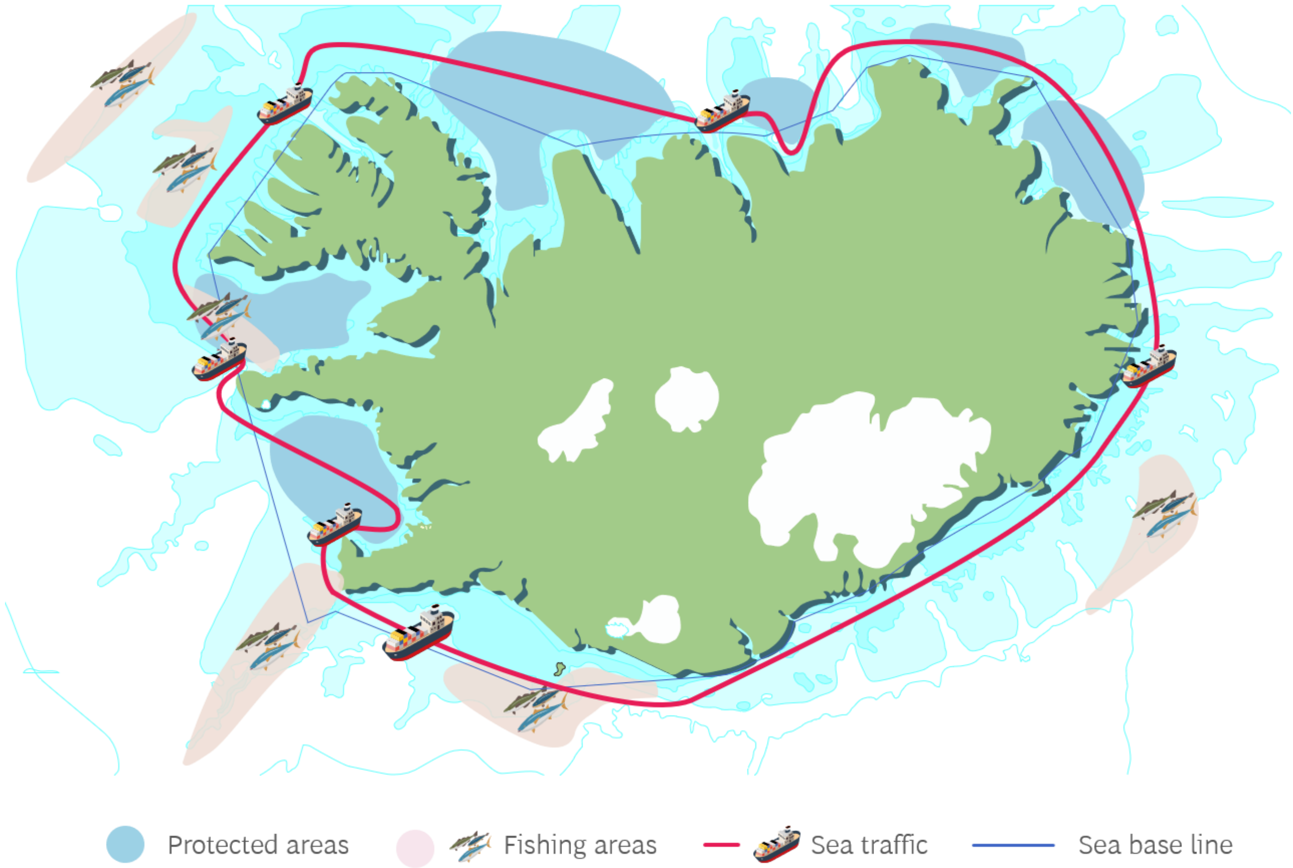
Sea traffic generally occurs close to the coast of Iceland with the heaviest traffic in Faxaflói, Breiðafjörður, Ísafjarðardjúp, Eyjafjörður, in the fjords around Reyðarfjörður and around Vestmannaeyjar.

Fishing in Iceland is relatively concentrated in a few areas.[327] To limit conflicts of interests at sea, offshore aquaculture should generally avoid hotspots of economic activity in other industries.

[326] National Geophysical Data Center: Significant Earthquake Database

[327] Hafsjá, BCG analysis

FIGURE 6.10: SEA TRAFFIC AND MAJOR FISHING SITES IN ICELAND[328]



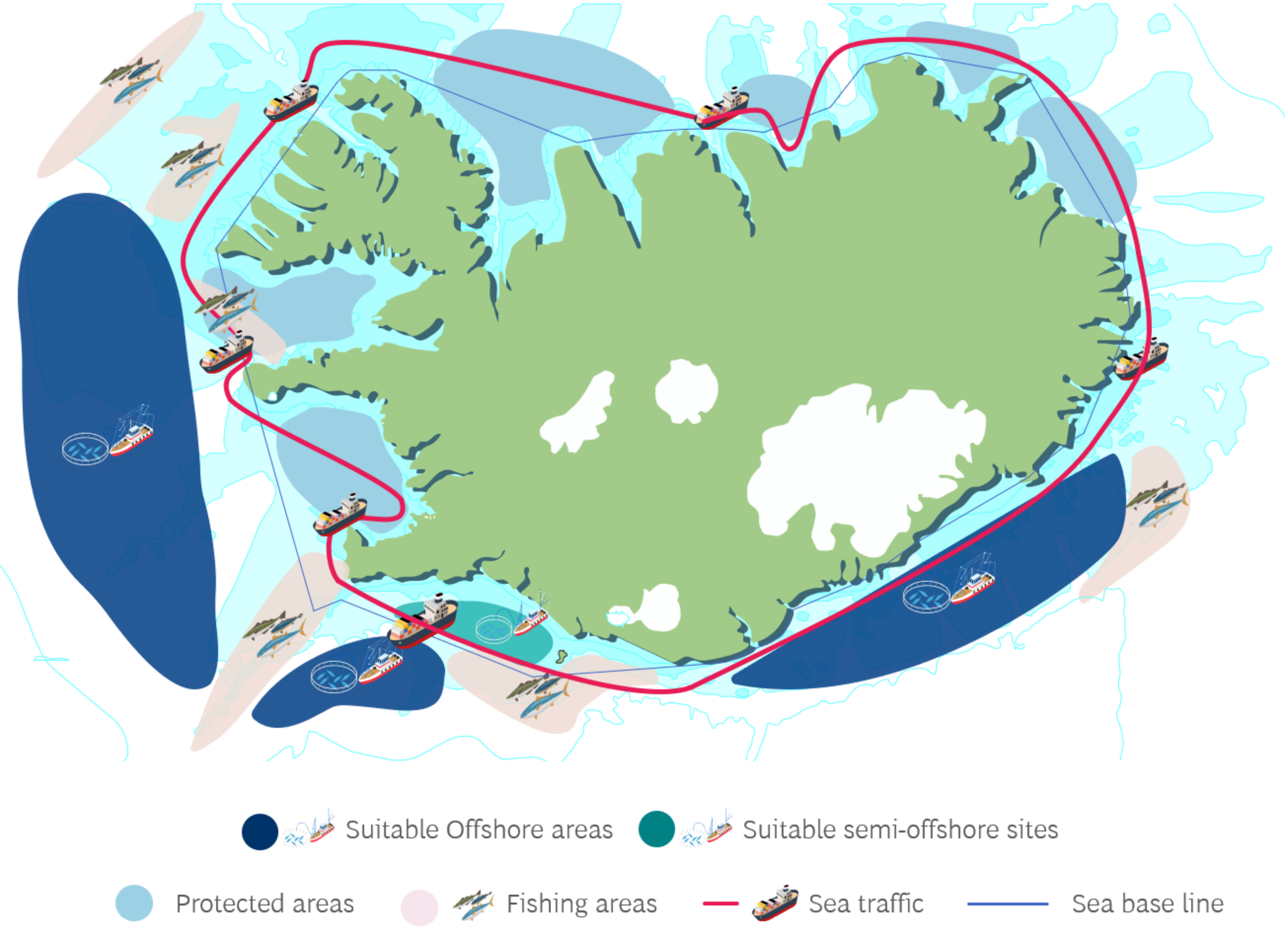
6.3.8 Sub-conclusion

Applying the seven criteria covered, the waters West and South of Iceland appear to be most attractive for offshore salmonoid farming. These areas provide relatively warm and stable temperatures throughout the year as well as relatively low current velocities and suitable wave height conditions. In these areas, farms can also be placed where seismic activity and interface with other interests at sea is limited. These areas also offer relatively shallow sea depths of less than 400 meters.

[328] Hafsjá, BCG analysis

Note: Protected areas highlight areas that are currently protected against aquaculture due to the possible inference with natural wild stocks. Red line shows main sea traffic around Iceland. The ship icon is located at more concentrated areas of sea traffic

FIGURE 6.11: POTENTIAL SITES FOR OFFSHORE AQUACULTURE IN ICELAND BASED ON THE SIX CRITERIA[329]



The area between the Reykjanes peninsula and Vestmannaeyjar appears to be suitable for semi-offshore aquaculture. Here it will also benefit from synergies with current land-based projects and infrastructure development around Þorlákshöfn. There is, however, greater sea traffic in this area to be considered, as well as some seismic activity.

These results should be seen as highly indicative as they are based on experience gained from a few projects in a relatively young sector. Research covering at a minimum the seven factors investigated here needs to be conducted to validate the suitability of offshore farming in Icelandic waters.

[329] Hafsjá, BCG analysis

6.4 Sector establishment

6.4.1 Norway can provide inspiration for establishing a new sector

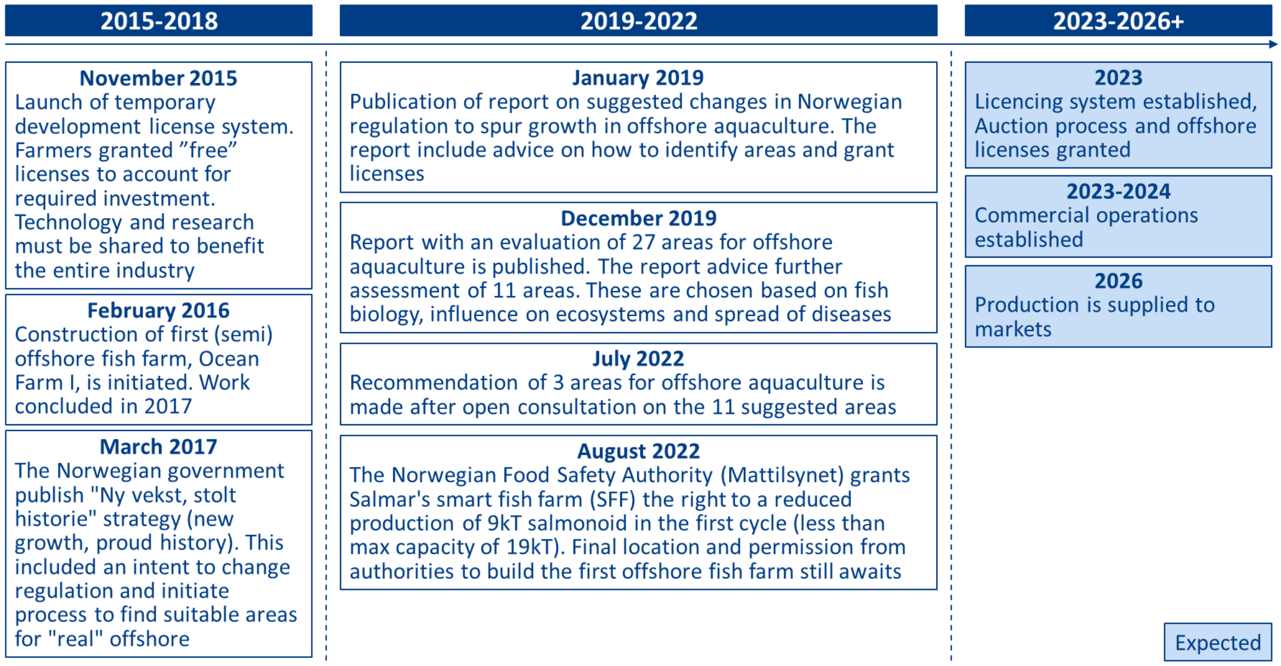
Offshore aquaculture has received growing interest in recent years, mainly due to limitations in expanding production capacity from traditional aquaculture. If Iceland were to pursue establishing an offshore sector, inspiration can be drawn from recent developments in Norway.

Norway introduced developmental licenses in 2015, spurring investment in new equipment and technologies such as offshore. This temporary scheme ran from 2015 to 2017, with licenses granted for up to 15 years. These licenses can be converted to commercial licenses, conditional on certain requirements being fulfilled.[330] Each farmer has the option to apply for multiple development licenses with the option to convert them at a cost of 10m NOK (~1m EUR) per license (Consumer Price Index adjusted). Each converted license entails harvesting rights of 780kg MAB without time restrictions.

Norway is currently preparing regulation for the sector. In July 2022, three suitable areas were offered for offshore farming, and a new offshore licensing regime and auctioning process is expected to be ready in 2023.[331] The industry has argued that to sustain growth in offshore salmonoid farming, the new licensing and auctioning system should account for the additional investments required for offshore farming. If licenses are priced at the same level as for traditional farming, it may compromise financial viability. Nonetheless, SalMarAkerOcean applied for operations in one of the three areas offered by legislators with plans to construct the Smart Fish Farm (SFF) and use their converted development licenses there.[332]

[330] Licenses can be converted once trial period is expired and the criteria for the development licenses have been fulfilled. Both Havfarmen 1 and Ocean Farm 1 have converted their development licenses to commercial licenses
[331] Kepler Cheuvreux 2021
[332] Fiskeridirektoratet

FIGURE 6.12: NORWEGIAN HISTORY OF OFFSHORE AQUACULTURE[333]



Although the development license system was not specifically intended to spur the offshore sector, the projects created under the system caught governmental attention. This led to offshore aquaculture becoming a priority in the government's 2017 growth strategy, "Ny Vekst, Stolt historie" (New Growth, Proud History). Since then, work has been done to identify potential sites and create a long-term licensing and auctioning framework that accounts for the large investments associated with offshore facilities. With the expiration of the development license system, the industry is waiting for the new framework, expected to be finalized in 2023. Although still subject to a hearing process, the proposed resource rent tax in Norway is set to exclude offshore production at the writing of this report, as long as it is further than 20-30 nautical miles from the shore.[334]

Drawing inspiration from Norway as the most progressed market for offshore salmonoid aquaculture, Iceland can follow a similar path in ensuring investment and capabilities are attracted to Iceland, identifying suitable areas where offshore farming can take place, creating a licensing and auctioning framework that allows offshore to remain competitive, and ensuring infrastructure and surveillance is in place. Chapter 8 explores these possibilities in more detail.

[333] Fiskeridirektoratet: Anbefaling av tre områder for havbruk til havs (2022), Fiskeridirektoratet: Kartlegging og identifisering av områder egnet for havbruk til havs (2019), Regjeringens havstrategi: Ny vekst, stolt historie (2017); Kepler Cheuvreux

[334] Høringsnotat Grunnrenteskatt på havbruk

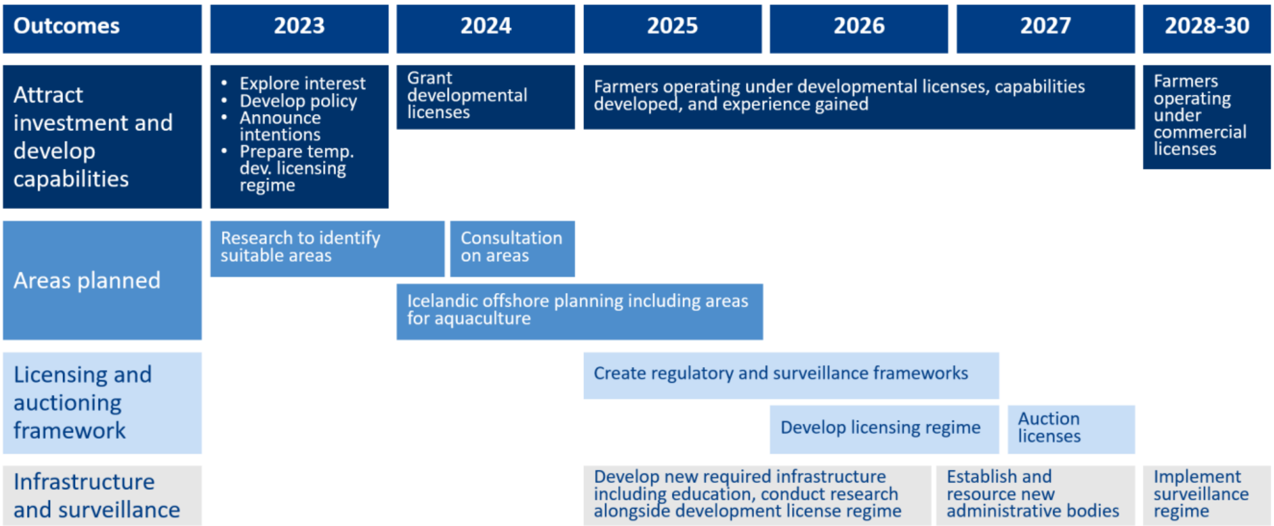
Note: distance depends on which production area the facility is located in

6.4.2 Despite clear intent, establishing an offshore sector in Iceland will likely take 6-10 years

Based on these considerations, if Iceland were to pursue the opportunity of an offshore aquaculture sector, it would likely take 6-10 years before commercial operations are established. In contrast to Norway, Iceland benefits less from synergies with an established offshore energy sector, and this may impact the development timeline. However, the sector will continue to develop in Norway, Chile, and Scotland, bringing forward new technology advancements that may negate this effect.

A potential timeline for establishing an Icelandic offshore aquaculture sector is portrayed in Figure 6.13. These steps are explored further in Chapter 8.

FIGURE 6.13: POTENTIAL TIMELINE FOR OFFSHORE AQUACULTURE ESTABLISHMENT IN ICELAND



6.5 Conclusion: Offshore can become a thriving sector in Iceland

Offshore aquaculture is a nascent sector that has attracted sizeable investment in the last few years. As aquaculture countries are running out of space for traditional aquaculture, the offshore alternative can provide a way to supply increasing global demand with technology that holds promise to be more sustainable than traditional aquaculture.

Despite this, it remains to be seen if the industry is economically feasible and if the promise for improved fish biology holds. Offshore sites require high investments and operating them in a profitable manner may require governments to treat the sector differently than traditional aquaculture, especially with regards to license costs. Furthermore, to induce investment, predictability is essential. The countries that pioneer work on legal frameworks and licensing regimes will naturally attract the early movers.

The preliminary research performed here, in line with other similar studies, suggests that Iceland has suitable areas for offshore aquaculture. A more thorough and comprehensive analysis is needed to validate these findings, with special focus on environmental impact. Furthermore, broader planning needs to be conducted to limit conflicts with current economic interest at sea as well as planned (e.g., in the offshore energy sector).

In summary, there seem to be limited natural constraints that indicate that offshore cannot become an aquaculture sector in Iceland. With technology advancement and investor interest, it holds the potential of contributing to Icelandic aquaculture growth. Whether that can be achieved with a lower environmental footprint compared to traditional aquaculture, remains to be proven. It will however take time, likely at least six to ten years, after being set as a strategic priority until the first Icelandic commercial offshore operations are established.

7. Algae farming

This chapter explores the potential for Iceland to expand its algae farming sector by examining global market trends, potential regulatory frameworks, suitable locations for cultivation as well as opportunities and challenges.

7.1 Sector overview

Understanding the market for algae production can help Iceland anticipate demand and tailor its sector to meet future needs. This section first gives an introduction to algae farming and provides an overview of the market, including size and growth across both micro- and macroalgae markets. An analysis of the market in Iceland follows. An outline of global market trends is then presented to consider future growth both globally as well as in Iceland.

7.1.1 Two distinct segments that share similar end uses

Algae are characterized as photosynthetic marine and freshwater aquatic plants that lack true roots, stems, and leaves. They are diverse in terms of species and include both unicellular and multicellular organisms. Globally, algae are a widely used commodity, with end uses that include food, feed and pharmaceuticals. Algae production is considered to have several benefits, including the potential to support coastal communities and human health while combatting climate change and promoting environmental sustainability.[335]

As wild algae stocks are limited,[336] algae aquaculture has gained traction to meet a growing demand. Algae farming can generally be split in two segments: microalgae and macroalgae production (marine macroalgae also referred to as seaweed). Microalgae are produced in highly controlled industrial environments to recreate optimal levels of lighting, nutrients, and temperatures for growth. Conversely, macroalgae is often cultivated in ocean-based locations and regulated more similarly to fish aquaculture. Different cultivation, harvesting and processing methods characterize each segment, see Figure 7.1.

[335] Duarte et al. 2017

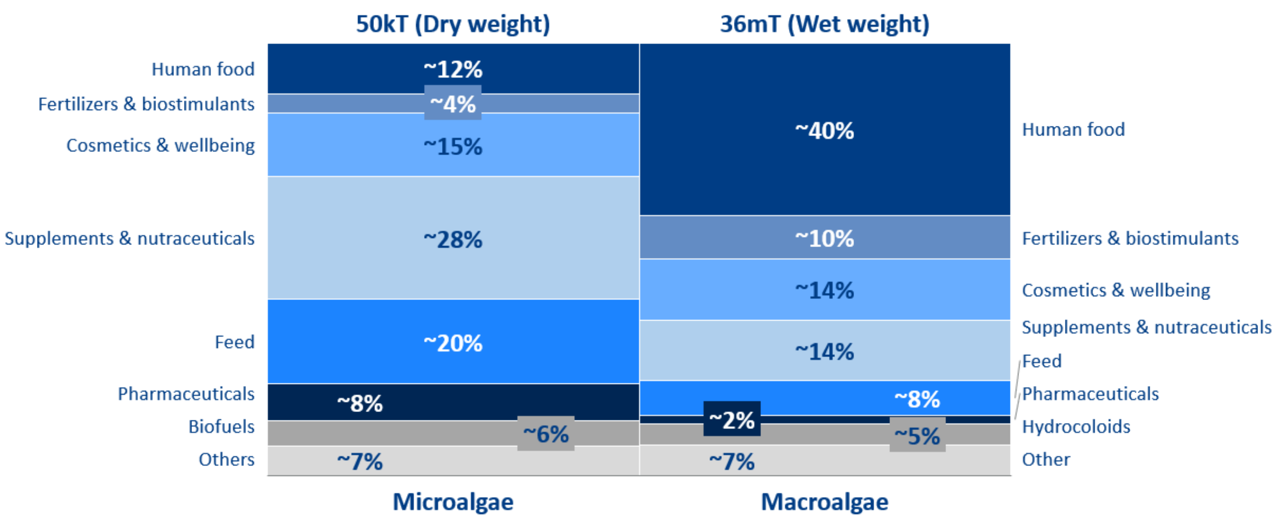
[336] MFRI advises that when the precautionary approach is applied the total annual harvest of rockweed (Ascophyllum nodosum) in Breiðafjörður in the years 2018–2022 should not exceed 40,000 tons

FIGURE 7.1: COMPARISON OF MICRO- AND MACROALGAE AQUACULTURE[337]

	Microalgae	Macroalgae
Description	Unicellular organisms (phytoplank)	Multicellular organisms (red, brown and green algae)
Commonly harvested species	• Arthrospira sp. (Spirulina) • Chlorella sp. • Haematococcus sp. (β-carotene & astaxanthin) • Nannochloropsis sp.	• Laminaria sp. (Kelp) • Porphyra sp. (Nori, Laver) • Gelidium sp. (agar) • Chondrus sp. (carrageenan)
Cultivation systems	• Photobioreactors (PBR) • Open raceway ponds • Fermenters • Hybrid systems	• Onshore (seeded ropes) • Offshore (seeded ropes) • Land-based (tanks)
Production conditions	Sufficient access to fresh water, nutrient inputs and affordable energy	Optimum temperature, wave, light and depth conditions
Harvesting and processing	• Rapid biomass growth in controlled environment • Separation from growth medium • Dewatering and/or drying	• Manual or mechanical harvesting • Removal of foreign objects • Chopping or milling • Dewatering and/or drying
Production costs	Investments: Depending on system, buildings, production equipment and lighting technology Operating expenses: Energy and labor	Investments: Depending on system, anchored lines harvesting machinery, boats, and processing facilities Operating expenses: Energy and labor

While processes for micro- and macroalgae production differ materially, as seen in Figure 7.2, they share many similar end-uses: microalgae are primarily used in nutraceuticals and animal feed, while macroalgae in human food products and fertilizers.

FIGURE 7.2: GLOBAL PRODUCTION END-USE SPLIT FOR MACROALGAE AND MICROALGAE IN 2020[338]



Microalgae production is a new sector in Iceland, where operations have developed over the past ten years. On the other hand, macroalgae has traditionally been hand harvested in small batches from the

[337] FAO, Barkia et al. 2019, BCG analysis

[338] Araujo et al. 2021, FAO, BCG analysis

wild. Today, larger scale commercial macroalgae operations have focuused on wild harvesting, with limited macroalgae cultivation to date. Analyses across the rest of Chapter 7 will segregate between micro- and macroalgae where necessary.

7.1.2 Global algae markets are growing, with increased presence in Europe

Globally, the algae market has been growing significantly with further growth in Iceland anticipated over the next 10 years.[339] Demand has shifted from algae being predominately a traditional foodstuff in regions of Asia, to being a more widely used product across the world. This has created new markets and an opportunity for new players to fill this demand.

Microalgae

The recent expansion of the microalgae sector has been fueled by the emergence of new technologies and end uses. In 2021, the market for microalgae was valued at ~10bn EUR with an estimated output of ~50kT of dry weight. Growth has been estimated at ~+7-9% p.a. reaching ~15-20bn EUR over the next 10 years.[340] That said, value and volumes are largely uncertain and concrete information is hard to come by as there is limited standardization in tracking and reporting. Increased production has been primarily driven by the dietary supplements industry. Specifically, Spirulina, a blue-green algae with powerful antioxidant benefits, is contributing to rapid sector growth. Other majorly produced species include Chlorella, Dunaliella, Haematococcus and Nannochloropsis.

The sector for microalgae is a highly competitive space with major international players. The largest market players are in Asia and North America.[341] While players are large, algae are often a niche area for them. Consequently, few players are producing at a large scale (+1kT a year).[342]

Europe has increased its scale in microalgae production over the past years. In Europe, Germany, Spain, and Italy host the largest number of microalgae production facilities, with the European market dominated by Spirulina (~45% of total production).[343] Generally, production is located on inland sites using photobioreactors (PBR). Iceland is an emerging player, contributing to more than 10% of total non-Spirulina biomass in Europe.[344]

Macroalgae

The global macroalgae sector has been growing at +6% p.a., largely dominated by Asian markets. In 2020, the market for macroalgae reached 16.5bn EUR, with over 36mT of wet weight harvested.[345] Growth has been estimated at ~+8-10% p.a., reaching ~35-40bn EUR over the next 10 years.[346] Over 200 species are harvested, dominated by the production of red and brown algae for foodstuff.[347]

---

[339] FAO, Facts & Factors, Iceland Ministry of Industries and Innovation

[340] Facts and Factors, Vieira et al. 2022

[341] Largest global players include Fuqing King Dnarmsa Spirulina Co.ltd, Earthrise Nutritionals LLC, Cyanotech Corporation

[342] Facts and Factors, Vieira et al. 2022

[343] Araujo et al. 2021

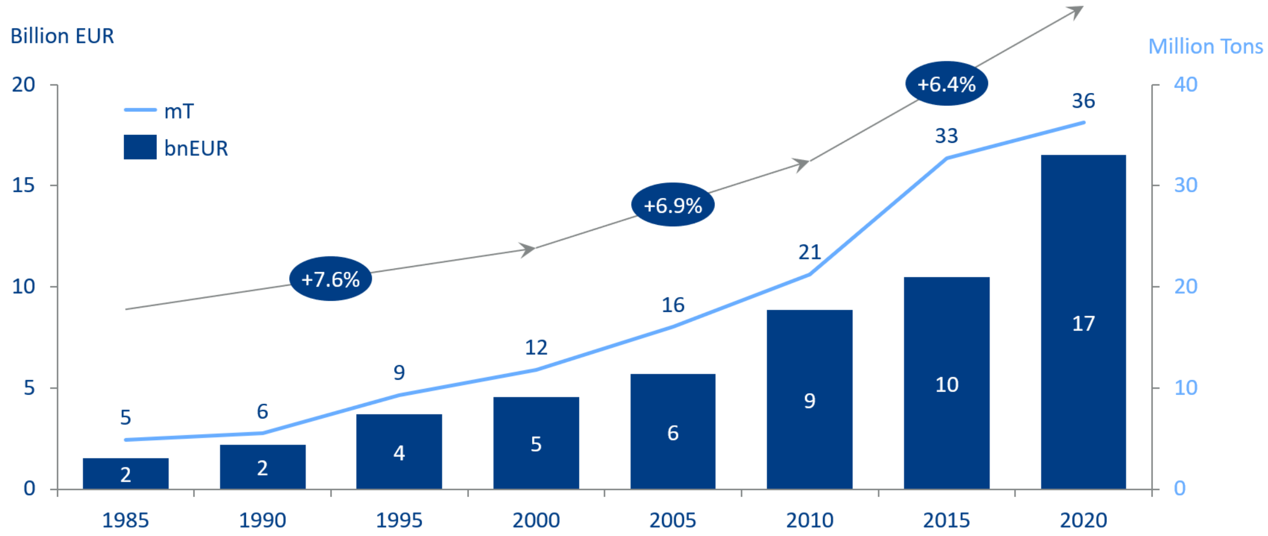
[344] Algalíf

[345] Does not include red calcareous algae as it is often classified as minerals and mining

[346] Mordor Intelligence, BidsInfo, Fortune Business insights, BCG analysis

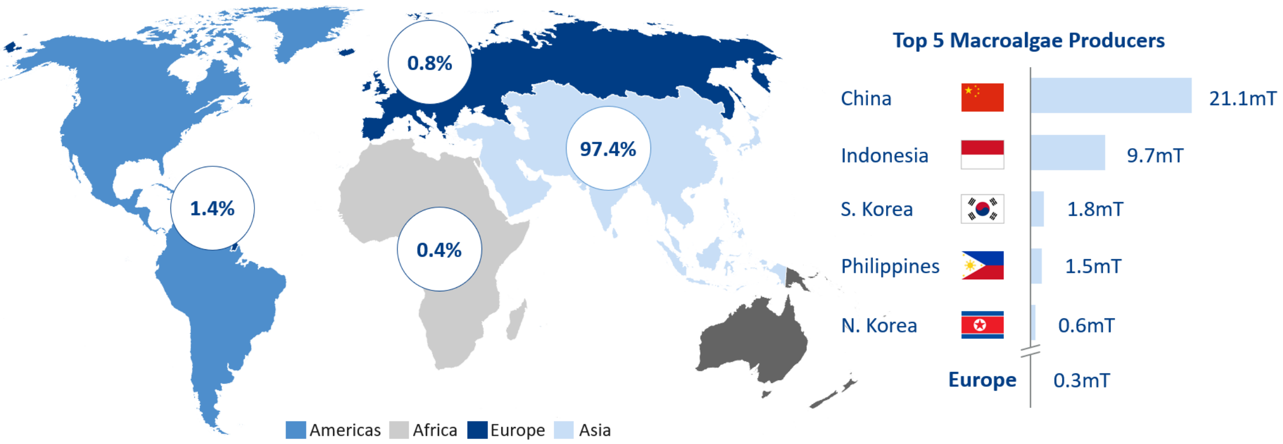
[347] FAO, GRASS, BCG analysis

FIGURE 7.3: THE GLOBAL MACROALGAE MARKET[348]



Production sits almost entirely with large-scale producers in Asia,[349] see Figure 7.4. Macroalgae markets in the Americas and Europe are nascent with opportunities for growth, especially through cultivation.

FIGURE 7.4: TOP MACROALGAE PRODUCERS IN THE WORLD IN 2020[350]



In Asia, 97% of macroalgae is cultivated through aquaculture compared to wild harvesting. In Europe however, only ~0.5% of production is cultivated.[351] Wild stocks are a limited resource where year-to-year output can vary. Cultivation has allowed Asian producers to reach current scale, meanwhile Europe is currently experimenting with production methods and new species to grow its production.

[348] FAO, BCG analysis

[349] Innovation Norway

[350] FAO, BCG analysis

[351] Marine Pollution Bulletin

In 2020, ~300kT of seaweed (marine macroalgae) was produced in Europe across 13 countries. Norway produced around half of this output with <0.1% cultivated through aquaculture.[352] In Europe, around 75% of macroalgae cultivators have operations at sea (onshore or offshore), while others conduct land-based activities.[353] The most widely cultivated species in Europe is Saccharina latissima due to its wide geographical range, early availability of production protocols, high yields, and rich nutritional content. This species also grows wild in Iceland, implying that ocean conditions could be suitable for cultivation.

7.1.3 Algae cultivation is a nascent sector in Iceland with expansion potential

While wild seaweed has traditionally been harvested in Iceland, algae aquaculture is a new and developing sector. Current algal biomass primarily supplies nutraceutical and cosmetics processing, with interest growing in supplying the fish feed sector. The algae sector has a handful of players in both micro- and macroalgae with the majority still operating at a small scale.

Microalgae

There are currently 6 companies in Iceland producing different species of microalgae, see Figure 7.5. Total sales from these microalgae producers were approximately ~14m EUR (~2bn ISK), with an output of ~125 tons dry weight in 2020.[354] In the same year, the sector reported financial losses. However, the sector is expected to start turning a profit with increased scale and development. Significant value growth is also expected for the sector, in the medium term, up to 10x, with increased support for research, development and marketing in the sector.[355] A significant source of competitive advantage for Iceland is the abundant source of freshwater, natural CO_2, cool climate as well as accessible and affordable renewable energy required for production. As energy is the largest input, microalgae producers in Iceland have an operation cost advantage in the production of temperature sensitive species over their foreign competitors.[356] Labor costs are however relatively high in Iceland compared to other markets.

Due to competitive market conditions, some Icelandic producers are focusing on high-value species that are technologically complex to produce and require large energy inputs and environmental control. For example, Algalíf, Iceland's largest producer in terms of value, is set to be the largest global producer of Haematococcus for astaxanthin by 2023, a species that can yield prices of more than 50x greater than Spirulina in the global market.[357] Even though production is currently at small-scale, many producers in Iceland play in niches where they can gain competitive advantage. See Figure 7.5 for overview of products produced.

[352] Seaweed for Europe

Note: Does not consider calcareous red macroalgae

[353] Araujo et al. 2021

[354] Orbis, Skatturinn

Note: Some companies may sell other products than algae. Sales revenues were divided by average price by species to find volume

[355] Iceland Ministry of Industries and Innovation, Orbis, Skatturinn

Note: Some companies may sell other products than algae

[356] Expert interviews

[357] Araujo et al. 2021, Algalíf

FIGURE 7.5: KEY PRODUCERS IN ICELAND FOR MICROALGAE[358]

Macroalgae

Macroalgae species in the Nordic region differ to those found in Asian markets. Nutrient dense species, ideal for value-added processing, such as Laminaria and Saccharina latissima thrive in cold waters surrounding the country.[359] These advantages could allow Iceland to meet demand in emerging algae markets and avoid competition with Asian markets over commoditized products.

Total sales for macroalgae producers were ~15.5m EUR (~2.2bn ISK), with an output of ~110kT wet weight in 2020, see Figure 7.6.[360] Industry estimates imply that the sector is expected to grow considerably over the next 10 years, with advancements in technology, processing, and the potential for algae aquaculture.[361]

[358] Skatturinn, company reports, BCG analysis

[359] Expert interviews

[360] Based on published volumes by the largest operators. Includes red calcareous algae (excluded from global outlook)

Note: Some companies may sell other products than algae. Sales revenues were divided by average price by species to find volume

[361] Iceland Ministry of Industries and Innovation, Skatturinn

FIGURE 7.6: KEY PRODUCERS IN ICELAND FOR MACROALGAE[362]

Non-exhaustive

Company	Location	Sales in 2020 (EUR)	Product
Íslenska Kalkþörungafélagið	Bíldudalur	~9.5m	Lithothamnion
Þörungaverksmiðjan hf.	Reykhólahreppi	~5m	Ascophyllum & Laminaria
Íslensk hollusta	Hafnarfjörður	~360k	Multiple
Taramar	Sandgerði	~180k	S. latissima
Hafkalk	Bíldudalur	~130k	Lithothamnion
Hyndla	Reykjavík	~75k	Multiple red algae
Íslensk bláskel & sjávargróður	Stykkishólmur	~70k	S. latissima
Marinox	Kópavogur	~40k	F. Vesiculosus
UNA	Reykjavík	~20k	F. Vesiculosus
Nordic Kelp	Patreksfjörður	N/A	S. latissima & A. eculenta
Eldey Aqua	Bolungarvík	N/A	S. latissima

Animal feed · Human food · Neutraceuticals & supplements · Cosmetics · Biotechnology · Raw

Wild harvest · Land-based cultivation · Ocean-based cultivation

Despite an expectation of significant growth, there are currently limited macroalgae aquaculture operations in Iceland, as it has not yet been legislated specifically for commercial use. However, in addition to the existing capacity within wild harvest, scale is developing with cultivation experiments, investments in processing as well as research and collaboration.

1. Existing wild harvest capacity in Iceland, yet growth to come from aquaculture

There is a long history of wild macroalgae harvest in Breiðafjörður, where Þörungaverksmiðjan (Thorverk) harvests brown algae and exports their products as flakes and ground meal. There is a wild harvest cap of 40kT per year in Breiðafjörður. However, currently yearly harvests from the area only amount to around half that amount.[363] Although there is room for additional wild harvest, expansion beyond current limits will likely require aquaculture. As for red calcareous algae (Lithothamnion),[364] which make up most of Iceland's output, Íslenska Kalkþörungafélagið has permission to produce 120kT. Further investigation is needed to determine how much harvest can expand. These species cannot be easily cultivated and are therefore outside the scope for aquaculture.[365]

2. Aquaculture experiments in progress, yet regulations needed for scaling

Three main companies are experimenting with macroalgae cultivation. Hyndla cultivates red algae on-land while Nordic Kelp and Eldey Aqua are trialing onshore cultivation lines. While land-based cultivation is not subject to ocean-based aquaculture licensing, commercial onshore cultivation cannot yet proceed without legal permitting from the government.

3. Increasing investments into processing capacity, indicating market belief in growth

Despite lack of specific legislation, investments in the industry are being made, indicating belief in growth. This includes the existing seaweed processing and drying facility using geothermal heat near Breiðafjörður in the Reykhólar community. Investments also include a 13.5m EUR investment by Icelandic Kelp (Íslandsþari) in a seaweed processing plant for Laminaria hyperborea in Húsavík.[366]

4. Research capacity and cross-country collaboration are increasing, including both commercial and academic actors

Beyond commercial operations, the Icelandic Algae Centre in Reykhólar was established in 2022, through a collaboration between Matís, Reykhólahreppur and Þörungaverksmiðjan. The aim of the Centre is to promote and increase shared knowledge on the production and use of algae through wild harvesting and cultivation. The center will serve as a research hub, providing training, resources and support to institutions and companies working to increase value creation in algae production.[367]

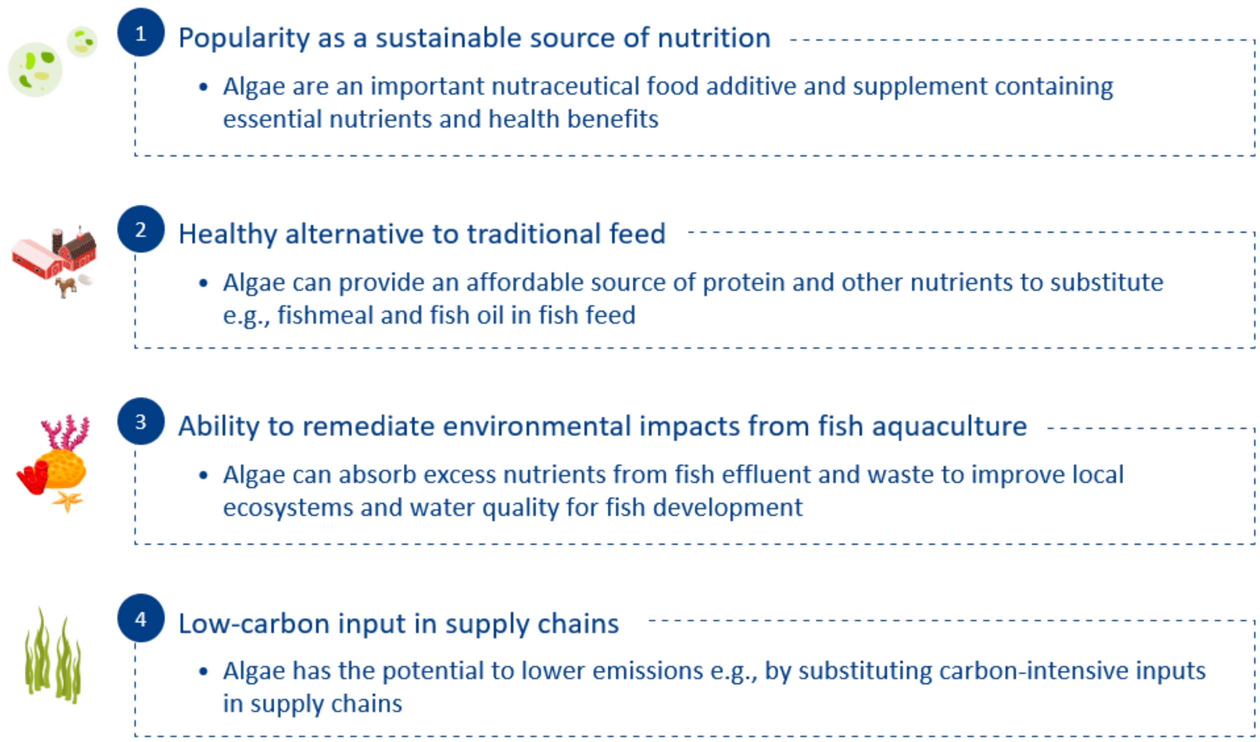
[362] Skatturinn, company reports, BCG analysis
[363] Marine and Freshwater Research Institute
[364] Often classified under mining and minerals
[365] Magill et al. 2019
[366] Iceland Monitor
[367] The Icelandic Regional Development Institute, Morgunblaðið

Additionally, there are projects ongoing in macroalgae aquaculture to determine feasibility for Iceland. Recently, algae cultivation lines were trialed under the Sustainable Cultivation of Seaweed (SUSCULT) project,[368] determining that the best species for cultivation in the Nordics are sugar kelp (Saccharina latissimi / beltisþari) and winged kelp (Alaria esculenta / marinkjarni).[369] Additionally, Nordic Kelp is designing a guide for macroalgae production in the Nordics to share best practices across the sector.[370] Synergies are also being explored with the fish aquaculture sector to increase efficiency and reduce impact from waste. Eldey Aqua has worked with Arctic Fish, to cultivate sugar kelp (S. latissima) with salmon and Icelandic scallops in an integrated multi-trophic aquaculture (IMTA) system (more details on IMTA follow).

7.1.4 Key trends hold potential to drive growth in Iceland

As previously described in section 7.1.1, algae aquaculture has experienced rapid growth and is expected to continue growing. This is driven by several key trends, of which, the following four are most relevant for Iceland:

FIGURE 7.7: OVERVIEW OF ALGAE MARKET TRENDS



[368] Funded by the Nordic Working Group for Oceans and Coastal Areas GOAL

[369] Sustainable Cultivation of Seaweed (SUSCULT)

[370] NORA

1. Algae have become increasingly popular as a sustainable source of nutrition

Both micro- and microalgae are widely used in nutraceuticals, often processed into food additives and supplements. Algae consumption is associated with several health benefits, providing antioxidant, anti-inflammatory, and neuroprotective properties. A range of essential nutrients can be found in algae, such as omega-3 and omega-6 polyunsaturated fatty acids, vitamins (A, C, E and B12), and dietary fibers.[371]

2. Algae constitute a sustainable alternative to traditional feed

There is growing competition for feedstuff in the animal protein sector as land space to grow grain becomes increasingly sparse.[372] To support the future growth of livestock husbandry and fish aquaculture, and their associated feed requirements, new sources of sustainable and nutrient rich feed will likely be needed. Microalgae such as Chlorella, Nannochloropsis, and Haematococcus can provide an affordable and sustainable source of protein, nutrients, and pigment e.g., to replace fishmeal, fish oil and synthetic coloring supplements in fish aquaculture. Although algae are not yet produced at a large enough scale to be cost-efficient compared to traditional animal feed, production expansion could bring costs down significantly and provide environmental benefits such as reduced emissions.[373]

3. Algae can remediate environmental impacts from sewage and fish aquaculture

Activities such as wastewater discharge and traditional fish aquaculture can release excess organic load which can accumulate in surrounding ecosystems and disturb marine life.[374] Macroalgae cultivated near marine outfall and fish aquaculture can provide bioremediation benefits by absorbing excess nitrogen and other nutrients.[375] For example, macroalgae has been used in coastal municipal zones to remove pollutants.[376] Some fish farmers[377] have also experimented with integrated multi-trophic aquaculture (IMTA) systems, cultivating different species in a polyculture. Growing fish, mollusks, and algae in proximity to each other can provide synergistic benefits such as improving water quality for fish health while supplying essential nutrients for mollusk and algae development.[378] Additionally, cultivated algae can be processed and used as a feed supplement for fish in the system.

[371] Sorrenti et al. 2021, Wells et al. 2017

[372] Breewoods and Garnett 2020

[373] Araujo et al. 2021, Aas et al. 2022, SINTEF

[374] Brana et al. 2021, Alkhalidi et al. 2022

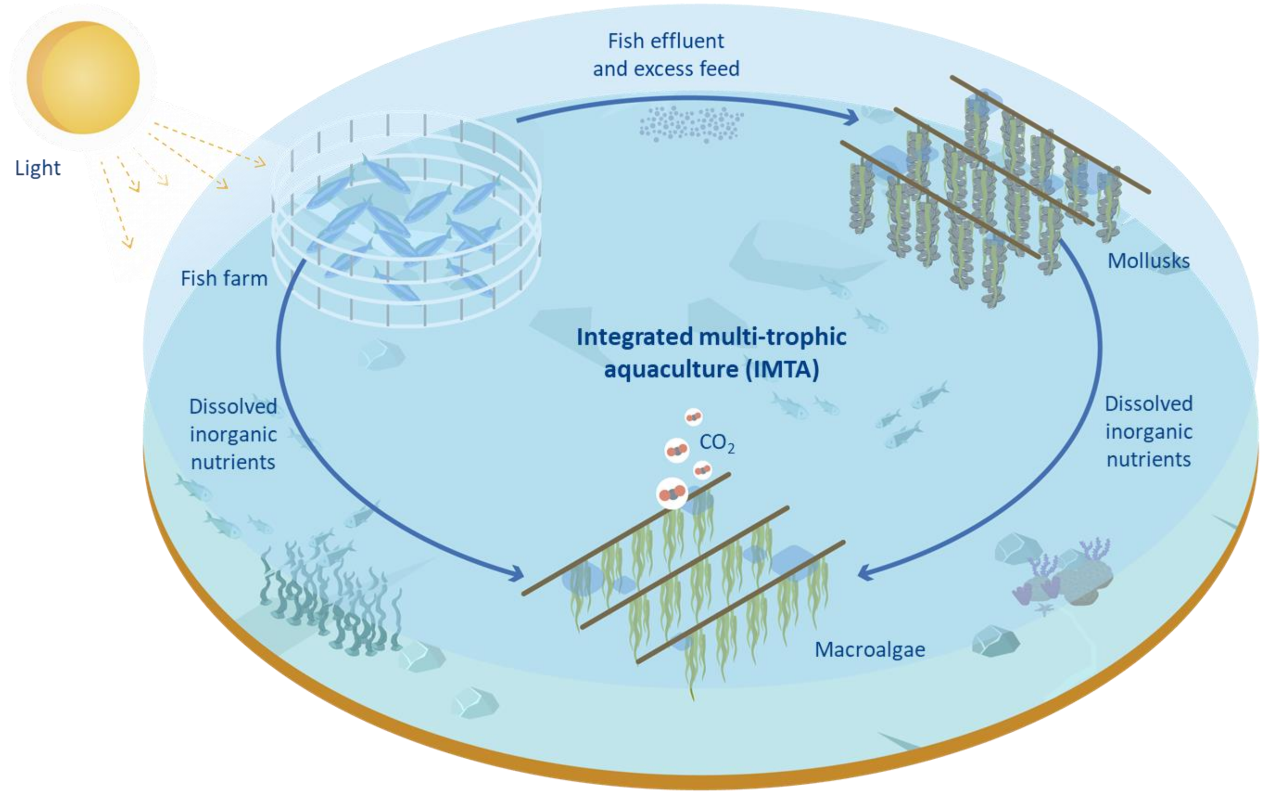
[375] National Oceanic and Atmospheric Administration

[376] For example, seaweed planted to extract nutrients in a bioremediation project in the Bronx (Kim et al. 2015)

[377] China and other Asian producers practice IMTA on a commercial scale. In Iceland, Arctic Fish has collaborated with Eldey Aqua to cultivate S.latissima and Icelandic scallops on an experimental level

[378] The University of Maine Center for Cooperative Aquaculture Research

FIGURE 7.8: AN INTEGRATED MULTI-TROPHIC AQUACULTURE SYSTEM (IMTA)[379]



4. Algae can act as a low-carbon input in supply chains

While wild macroalgae stocks serve as an important blue carbon sink, removing around 85-175 teragrams (Tg) of CO_2 equivalent per year, the sequestration potential of cultivated algae is likely less impactful.[380] Using cultivated algae can therefore reduce potential pressures on wild stocks and help keep them intact as a carbon sink. Additionally, use of cultivated algae has the potential to help mitigate emissions by replacing carbon-intensive inputs in the supply chain. For example, algae can replace certain fossil-fuel intensive fertilizers in agriculture,[381] be used as a bioplastic in packaging and as an input into cosmetics. Some projects have also experimented with integrating seaweed in livestock feed to reduce methane in cattle productions, with some results showing reductions of over 80%.[382]

7.1.5 Sub-conclusion

Data and expectations indicate that the market for both micro- and macroalgae will grow globally as well as in Iceland, underlined by increasing activity in Iceland among both commercial and research

[379] Araujo et al. 2021, BCG analysis

[380] Duarte et al. 2017, Howard et al. 2017

[381] Ammar et al. 2020

[382] Roque et al. 2021, FAO, Ocean Rainforest, ClimeFeed

stakeholders. Consequently, Iceland can benefit from this growth, fueled by macro trends such as increasing popularity as a sustainable source of human and animal nutrition, as well as algae's ability to reduce environmental impacts and emission in supply chains. Moreover, Iceland holds key natural advantages to establish a position within algae:

Microalgae

Iceland holds the advantage of stable and affordable renewable energy which can provide a competitive advantage in terms of production cost. Additionally, Iceland also holds an advantage in the production of species that require cooler temperatures as natural conditions in Iceland reduce the need for cooling costs. Focusing on high value species which require more complex processing, and consequently more energy use, can distinguish it from largescale producers, e.g., of Spirulina, which is a less complex product to produce, unlike e.g., astaxanthin.

Macroalgae

Growth in Europe is largely driven by demand within industrial products. Nutrient dense species thrive in the cold waters around Iceland, which has advantages for processing into nutraceuticals and other industrial products. To be competitive, Iceland can focus on high-value processed goods as opposed to commoditized (lower value per kg) seaweed products in which Asian markets currently dominate and are expected to continue given scale, labor availability and cost.

However, in order to drive growth, current legislative barriers within macroalgae need to be addressed (farming currently not regulated specifically), as the market currently is dependent on limited wild harvest output. Regulatory changes allowing macroalgae farming are thus likely the largest impetus for future growth. Consequently, section 7.2 will consider the regulatory framework. It can also be implied that the infrastructure to process raw macroalgae into higher value-added products needs to expand, albeit first steps have already been taken.

7.2 Regulation

As algae aquaculture is a nascent sector in Europe, most countries do not have sector-specific government guidance and regulation. This has likely acted as a barrier to the expansion of the sector, delaying license approvals and halting investment.[383] In microalgae, production is often lightly regulated, relative to macroalgae, with similar processes to other biotechnology related operations. In macroalgae, licensing has often fallen under fish aquaculture and been complex to navigate.[384] That said, many countries are recognizing the attractiveness of the sector and now moving towards macroalgae specific licenses to support growth.

The following section describes the regulatory environment in Iceland and draw on examples of best practices from neighboring countries. It concludes by outlining potential implications for Iceland.

[383] COASTAL

[384] Finnish Environment Institute

7.2.1 Clear policy frameworks for algae production can support sector growth

Microalgae

Regulatory frameworks are often not set specifically for microalgae. For example, in the EU, microalgae producers instead follow various regulations for food supplements, new (novel) foods, feed additives, foods for specific groups, nutrition and health regulation for food and medicinal products.[385]

In Iceland, like the EU, there are no specific regulatory frameworks for microalgae. Operators are subject to general commercial food operations regulations. They must have a land permit for their facilities and conduct regular health and safety checks. Additionally, they must negotiate resource (freshwater and energy) contracts with their respective municipal utility providers to ensure sufficient inputs.[386]

Regulation surrounding microalgae cultivation in Iceland is likely not a barrier to the sector's expansion. However, having a clear framework for tracking output volumes as well as establishing a greater understanding about different cultivated species and associated production technologies and processes could aid the government in better supporting the sector.

Macroalgae

With current legal frameworks, many European countries are not well positioned to support rapid growth in the macroalgae sector. A survey conducted in the Nordic and Baltic regions[387] found that applications for a seaweed cultivation license took anywhere from 9 months to 5 years due to a lack of clarity on seaweed specific legislation.[388] Regulatory uncertainty is therefore likely slowing investment and development of the sector.

Iceland currently does not regulate commercial macroalgae cultivation specifically, making it a challenge for start-ups to scale operations. Some companies researching the cultivation of macroalgae, have collaborated with fish aquaculture to utilize ocean space[389]. Legislation exists for wild harvesting, prioritizing sustainable utilization of the natural resource.[390] However, current regulations lack specifics for algae aquaculture, which must consider different factors such as location suitability, interaction with native stocks and other aquaculture, and environmental risks.

Norway, Faroe Islands, Denmark, and Scotland have recently adopted seaweed specific licensing frameworks. These frameworks have increased clarity and sped up processes for approvals. They have also increased certainty around investment and development in the sector, supporting further growth.

Figure 7.9 provides an overview of select relevant regulatory elements across these countries that may serve as an inspiration for a similar framework to be established in Iceland.

---

[385] Fernandes et al. 2021

[386] Expert interviews

[387] Included responses from Norway, Denmark, Finland, Estonia

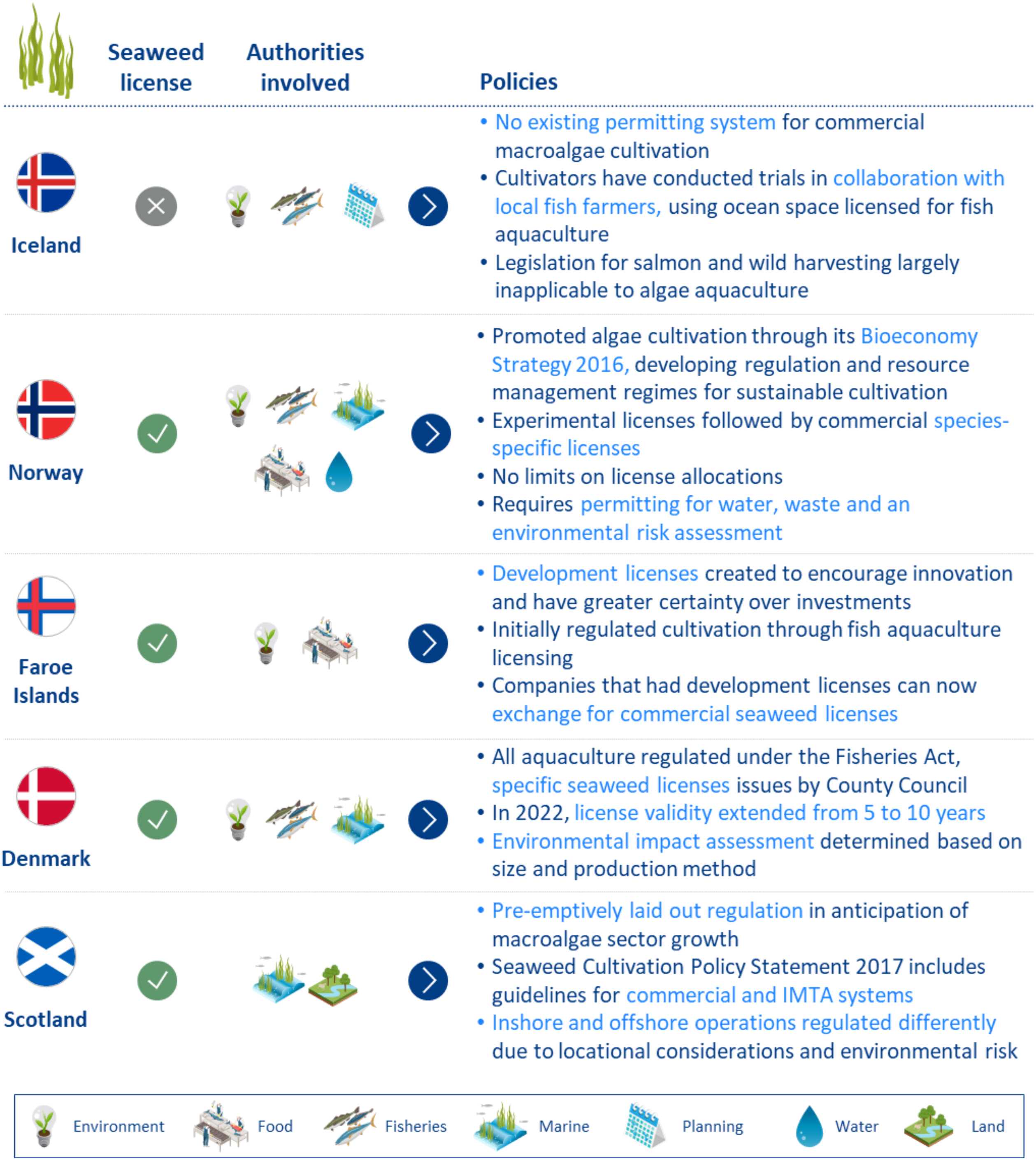
[388] COASTAL

[389] Finnish Environment Institute

Note: For example, Eldey Aqua was originally in collaboration with Arctic Fish to experiment with the synergies between salmon and seaweed aquaculture.

[390] Ministry of Industries and Innovation

FIGURE 7.9: OVERVIEW OF POLICIES ON MACROALGAE CULTIVATIONS[391]



Norway promotes algae cultivation through its Bioeconomy Strategy

Seaweed was included in Norway's Bioeconomy Strategy 2016, recognizing the need to develop a regulation and resource management regime for sustainable cultivation.[392] As a result of defining the value potential of macroalgae in policy, species-specific licenses were developed, granting licenses to 16 operations along the western coast. The sector is still relatively nascent, producing 111 tons through aquaculture in 2021,[393] and currently no limits on license allocations have been defined. Allocation process includes an environmental risk assessment as well as permits related to water and waste management. Thus, to grow the local sector, Iceland could follow suit and prioritize development through a national strategy and the creation of macroalgae specific regulations.

The Faroe Islands and Norway have used development licenses for innovation

The Faroe Islands and Norway both initiated development licensing schemes which allowed companies to experiment with cultivation. This developmental period tested the viability of algae cultivation in the country, while gaining experience to inform how commercial licenses should be regulated. For example, in the Faroe Islands, Ocean Rainforest, a company that demonstrated their viability during the development phase, was able to convert their license to a commercial one in 2020 once seaweed-specific licenses were created.[394] Adopting a similar development licensing scheme in Iceland could support algae producers in making greater investments and demonstrate the economic viability of larger-scale cultivation.

Denmark has increased the license period, giving greater certainty to producers

In Demark, licenses for seaweed cultivation are issued by the County Council and the Danish Coastal Authority and are valid for a period of 10 years. Up until 2022, licences were only valid for 5 years, after which operations required a revaluation. The short permit duration made it difficult for entrepreneurs to secure funding and establish their operations.[395] Especially given that licenses have generally taken around 15 months to be approved.[396] If Iceland where to create a licensing system, granting longer permit validity, once necessary operational plans and environmental assessments are reviewed, may allow operators to make larger investments and scale more rapidly.

Scotland pre-emptively laid out regulation in anticipation of macroalgae sector growth

Scotland has anticipated high growth in algae production (to reach around 80m EUR by 2040)[397] and, thus invested in its development. Despite currently small output volumes, a dedicated regulatory framework has been put in place to seize the opportunity and ensure environmental sustainability. The Seaweed Cultivation Policy Statement (SCPS) 2017 includes policies for commercial and integrated multi-trophic aquaculture systems (IMTA, see section 7.1.4), offering guidelines to potential farmers to support sustainable growth. These regulations have subsequently resulted in eight operators being licensed to date.[398] Inshore[399] and offshore operations are regulated differently due to locational considerations and environmental risks.[400] Iceland is in a similar position with small output volumes. It is thus expected that Iceland can benefit from anticipatory policies to facilitate growth while ensuring that the sector is established in a way that limits environmental harm and compatibility with other marine activities.

---

391 Finnish Environment Institute; Scottish Government, Stevant et al. 2017, Møre og Romsdal County Municipality, BCG analysis

392 Norwegian Ministries

393 Norway Directorate of Fisheries

394 Finnish Environment Institute

395 Dansk TANG

396 Finnish Environment Institute

397 The Fish Site

398 Marine Scotland

399 Inshore is classified as up to 12nm offshore

400 Camarena- Gomez et al. 2022

7.2.2 Sub-conclusion

Iceland has the potential to support its algae sector through mechanisms used by other European countries to grow their industries. In Iceland, microalgae production is currently lightly regulated. Having a clear framework, tracking output volumes, and establishing a greater understanding about different cultivated species and their associated production processes could aid the government in better supporting the sector. Additionally, long-term clarity and predictability for access to key resources (water, energy) will support further growth in the sector.

Macroalgae cultivation is not yet legislated specifically which has halted research and development for commercial production. Learnings from Norway, the Faroe Islands, Denmark, and Scotland can serve as an inspiration for Iceland to support growth. These include recognizing the potential benefits of algae in national strategies, granting temporary development licenses, ensuring commercial licenses are of sufficient duration, as well as delineating a clear framework and licensing system for sustainable macroalgae production. A first step could be to establish developmental licenses, which has successfully been done in Faroe Islands and Norway – in close conjunction with rules and research to ensure environmental stability, e.g., avoiding harm to existing environment and species. In parallel the process to create a long-term regulative framework could begin, like in Norway and/or prepare anticipatory policies as in Scotland to create medium to long-term predictability for private actors. Moreover, given the early stage of the macroalgae industry, it can be beneficial to adapt license pricing e.g., making them free or low cost initially, or having fixed pricing for operations of different scales.[401] Prices could also consider the potential environmental benefit (i.e., ability to remediate environmental impact from fish farming and/or ability to absorb carbon)

7.3 Suitable locations

Identifying optimal production locations for algae aquaculture would allow Iceland to better legislate production and plan for the physical expansion of the sector. Additionally, it is required to enable the issuing of development licenses for macroalgae. It is a prerequisite to both the planning of private actors as well as for the biological research required to ensure environmental sustainability. In this section, the key parameters required for algae cultivation across both micro- and macroalgae are presented, in turn the resulting potential areas for cultivation are outlined.

7.3.1 Multiple parameters to be considered to determine suitable locations

Microalgae

Microalgae production is dependent on the availability and affordability of key resource inputs, notably energy and freshwater. Iceland has access to freshwater and renewable geothermal and hydropower energy in many municipal areas.[402] To establish production facilities, land and infrastructure is needed in areas that have been planned for industrial operations. Favorable locations may be close to markets (port or airport access) and must also attract a skilled labor force, with talent recruited locally or

[401] Some interviewed experts referred to the mussel sector where some producers have struggled due to high license costs

[402] Landsnet

globally. Currently, given the abundance of water and access to electricity, the key limiting factor is likely access to labor.[403]

TABLE 7.12: KEY PARAMETERS TO DETERMINE SUITABLE LOCATIONS FOR MICROALGAE PRODUCTION

Key Parameters	Considerations
Resource availability	
Energy	Grid coverage
Fresh water	Fresh water access (municipalities)
Municipal considerations	
Municipal planning and interest	Skilled labor force, infrastructure, land availability, access to local & export markets

Macroalgae

As macroalgae production is a still a young sector in Europe, there is limited research on large-scale cultivation suitability and environmental impact. That said, as the leading European country in macroalgae aquaculture, Norway can provide learnings for Iceland, particularly given that Norway already has conducted a risk assessment and mapped permitted locations for algae cultivation.[404] The following analysis takes Norway's identified criteria as starting point and has been built upon with expert input from an Icelandic perspective. Although this analysis provides a first view, further biological research is needed to validate suitable locations.

Suitable ocean conditions depend on the species chosen for cultivation and their associated requirements for ocean depth, temperature, current speed tolerance, nutrients, and light exposure. Additionally, factors such as production method, growing season, interaction with native algae ranges, interaction with fish aquaculture, other ocean-based activities, and municipal considerations also need to be taken into consideration.

This exercise will focus mainly on examining potential locations for the two key species identified for ocean-based cultivation in Iceland through the Sustainable Cultivation of Seaweed (SUSCULT) project: Saccharina latissima (beltisþari) and Alaria esculenta (marinkjarni).[405] However, cultivation of other algae species may also be suitable in Iceland pending environmental assessments of impact, such as on native algae ranges.

Table 7.2 presents three key parameters and lists potential considerations to determine suitable locations for macroalgae aquaculture in Iceland.

[403] Expert interviews

[404] Norway Institute of Marine Research

[405] SUSCULT

TABLE 7.23: KEY PARAMETERS TO DETERMINE SUITABLE LOCATIONS FOR MACROALGAE PRODUCTION[406]

Key Parameters	Considerations	
Ocean conditions		
	Saccharina latissima (Beltisþari)	Alaria esculenta (Marinkjarni)
Depth	Seeded lines placed 10-20 m below sea level, anchored at depths of 50-200m	
Temperature	5-15˚C	4-10˚C
Current tolerance	Moderate to heavy currents	
Nutrients	Sufficient availability of salt, carbon, nitrogen, and phosphorous	
Light	Moderate to high light exposure	
Ocean habitats and activities		
Native algae ranges	Interaction with wild populations	
Interaction with existing aquaculture	Distances between production systems	
Other ocean-based activities	Protected areas, naval routes	
Municipal considerations		
Municipal planning and interest	Coastal property rights, public opinion of aquaculture, labor force availability, infrastructure, processing facilities, access to local & export markets	

The following sub-sections will elaborate on the most central parameters from Table 7.2 and cover key considerations.

Ocean Conditions

Ocean conditions suitable for cultivation are similar to those where native algae ranges exist

Native algae range largely possess the optimal growing conditions for species including depth, temperature range, current speed, nutrient levels, and light exposure. Consequently, cultivation in Iceland could follow native species ranges or locations with similar conditions but without established populations. For example, offshore locations may be too deep to support native populations but could employ seeded lines on a buoy system.

[406] Urd 2019, Pedersen, Zacher et al. 2019, Wilkinson 2001, Araujo et al. 2015, Hafskipulag, BCG analysis

Climate change may impact ocean conditions and suitability for algae cultivation

Current wild algae ranges are expected to change in the future. Projected temperature increases and ocean acidification due to climate change could significantly impact native population, likely resulting in population declines and/or possible local extinction for some species.[407] This would in turn impact wild harvest rates and the suitability of aquaculture in certain areas. Cultivation ranges may need to move or shift to species better suited to warmer conditions. To mitigate these risks, planning will benefit from considering adaptation measures such as selective breeding.

Ocean habitats and activities

Areas of cultivation must consider native populations to avoid genetic contamination

Cultivation must examine the risk of genetic contamination, introduction of non-native species and competition with local populations in terms of nutrient and light availability. The spread of pests and disease in the local ecosystem can also be a significant threat. Cultivation installations in deeper offshore locations could potentially reduce the risk of gene contamination, ecosystem alteration, and the presence of predatory species such as sea urchins, snails, and shellfish.[408]

Macroalgae cultivation may benefit from being located close to wild harvest and fish aquaculture

Areas for fish aquaculture have undergone environmental risk assessments to select locations which limit impact of local marine ecosystems. With additional surveys to assess native algae populations and risk of pest and disease spread, algae cultivation could be initiated in fish aquaculture areas. Integrated multitrophic aquaculture (IMTA) systems could be established while considering necessary spacing between operations. For example, in the Faroe Islands, installations must keep 500m distance from the edge of fish aquaculture farms.[409] Additionally, algae cultivation could use existing infrastructure such as processing and drying facilities from wild harvest in Breiðafjörður as well as wellboats and measurement equipment from fish aquaculture.[410]

Municipal considerations

Onshore locations must consult the municipality and individual property owners

In Iceland, around ~80% of the coastline is privately owned.[411] Shore owners manage the land from the coast until 115m into the water.[412] Due to this, some narrow fjords may be almost entirely made up of private waters. It is therefore important that private property owners are involved in future mapping of suitable locations and licensing schemes.

[407] Purcell-Meyerink et al. 2021

[408] Urd 2019

[409] The Fish Site

[410] Expert interviews

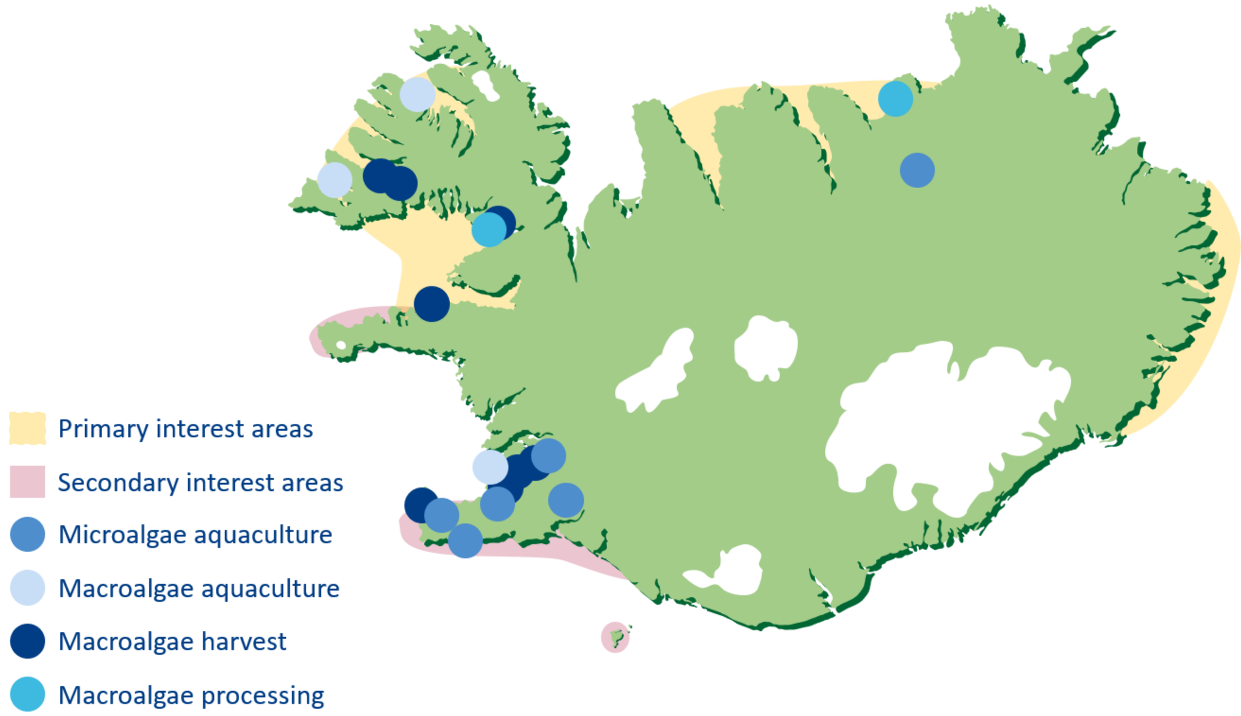
[411] Expert interviews

[412] Skýrsla nefndar forsætisráðherra sem skipuð var samkvæmt III. bráðabirgðaákvæði laga nr. 58/2008

7.3.2 Algae cultivation to be concentrated in certain regions with potential to expand

Figure 7.10 shows existing micro- and macroalgae facilities in Iceland, as well as potential new coastal and ocean-based cultivation areas for macroalgae based on the parameters and considerations. Potential new microalgae and land-based macroalgae regions are not mapped as they are mainly subject to in-land resource availability and municipal considerations.

FIGURE 7.10: MAP OF EXISTING MICRO- AND MACROALGAE FACILITIES, AND POTENTIAL MACROALGAE CULTIVATION AREAS



Existing microalgae and land-based macroalgae operations are concentrated around the Capital and Southern Peninsula regions. This is likely due to their proximity to the capital and export markets, as well as access to skilled labor. Despite this, production has the potential to expand to other regions of the country that offer affordable and accessible freshwater and energy resources. Key limitation will thus remain access to skilled labor.

Existing ocean-based macroalgae cultivation experiments by Nordic Kelp and Eldey Aqua are located in the Westfjords, likely due to ocean and fjord-based condition suitability and proximity to fish aquaculture. From interviews with researchers and companies, the Westfjords, Eastfjords and certain areas of the Northern region were identified as primary interest areas for future macroalgae aquaculture. These areas largely align with key parameters outlined in the previous section (7.3.1) including ocean conditions, ocean habitats and activities, as well as municipal planning and interest. Fjord areas can also provide sheltered locations with generally milder currents, presenting lower risk of seaweed cultivation installations being washed away. Existing wild harvest and seaweed processing areas are also attractive as they can provide infrastructure suitable to aquaculture production.

Secondary interest areas include the coastline around the northern coast of Snæfellsnes, and southern coast of Reykjanes based on native species ranges. However, ocean conditions and biological impact must be further assessed for these areas. For example, the area in Reykjanes has historically experienced extreme storm conditions that could wash algae installations away. Potential future salmon offshore locations may also be of interest due to IMTA compatibility and synergies with infrastructure use.

A thorough biological survey, social and environmental risk assessment as well as consultation with marine planning authorities would be required to validate the suitability of algae cultivation and biomass carrying capacities in these areas and beyond.

7.3.3 Sub-conclusion

Iceland appears to hold considerable potential to expand algae cultivation outside of current areas of operation.

Microalgae and land-based macroalgae facilities are currently concentrated in the Capital region and Reykjanes due to proximity to markets and sufficient access to natural resources, infrastructure, and labor. In the future, operations could expand to other regions where energy and water resources are available and affordable and there is sufficient infrastructure and labor. Thus, the main constraints location-wise relate to labor and infrastructure, given the presence of energy grids and water supply across the majority of Iceland. However, at large scale, energy availability can potentially become a question, given competition from other industries.

Macroalgae cultivation trials onshore are located in the Westfjords due to suitable ocean conditions and proximity to fish aquaculture. Future commercial operations may be established in these regions and/or expand to primary interest regions in the eastern and northern regions where ocean conditions, habitats and activities are suitable and municipal plans and interest align. A thorough biological survey and consultation with the appropriate authorities is necessary to define specific area suitability, carrying capacity and future licensing schemes.

7.4 Key sector opportunities

The combination of global trends and Icelandic conditions create several opportunities in growing algae farming in Iceland. To capture these opportunities, Iceland must leverage its strengths to develop a thriving and sustainable sector.

The following section discusses some of the key insights, building on those previously mentioned in the Chapter, for Iceland in developing its micro- and macroalgae sectors. It first discusses the entire algae sector, followed by considerations for micro- and macroalgae respectively.

7.4.1 Sector insights

Iceland can take advantage of its natural resources and reputation to capture a premium on algae products

Globally, Iceland is known for its pristine nature. In the western world, algae products have been largely associated with superior nutrition and often marketed as a health and natural beauty product. Synergistic qualities thus hold potential to help Icelandic algae producers market their products at premium when exporting their products.

Value adding processes can allow Iceland to increase the profitability of the algae sector

Raw or minimally processed algae products are likely to compete with mass produced algae at competitive commodity prices. Iceland can leverage value-added processing such as generating nutraceutical products, cosmetics, or biofuels to increase margins on algal products. Use of algae as a sustainable biofuel will require further research and development.[413] Additionally, companies could consider certifying their products e.g., as organic or carbon neutral to capture a premium. Yet, competitiveness and scale requirements vary across commodities, meaning further research is needed to conclude Iceland's opportunity to benefit from value added processing.

Icelandic algae can serve as an affordable and sustainable input in fish feed

The Icelandic salmon aquaculture sector is expected to continue growing significantly, requiring increasing quantities of nutritional feed. Currently, imported feed such as grain and fishmeal are amongst the largest costs for fish farmers.[414] Locally grown micro- and macroalgae cultivation at scale could help reduce the share of imported feed, providing a stable source of affordable inputs while reducing the sectors carbon footprint.[415] However, economic impact of using algae as feed as well as scale requirements need to be assessed.

7.4.2 Microalgae opportunities

Microalgae can provide natural alternatives to synthetic fish aquaculture inputs

In addition to nutritional feed supplements, astaxanthin can replace synthetic coloring additives in the salmon sector. Most salmon farms require pigment inputs to ensure that the fish produce bright orange flesh often associated with wild caught salmon. These synthetic pigments can be one of the largest contributors to feed emissions.[416] With consumer trends emphasizing the desire for healthy, natural, and low-carbon products, fish fed with astaxanthin can for example be used in organic farming and marketed at a premium compared to conventionally farmed salmon.[417]

Iceland has an abundance of natural resources

Energy costs can make up around 50% of total production costs and are therefore a key factor in determining operating margins.[418] Iceland has a competitive advantage in terms of accessible and affordable renewable energy. Due to this, individual companies in Iceland spend only around a quarter of the energy costs of competitors outside Iceland, all else equal.[419] Icelandic operators can secure affordable contracts with energy providers that allow for greater cost predictability for powering equipment, regulating temperature, and generating light for optimal algal growth. Iceland additionally features a cool climate which reduces the risk of algal die-off and limits the need for cooling and its associated energy costs. Additionally, the country has an abundance of freshwater and natural CO_2

[413] BCG Emerging technology: Algae as biofuel feedstock

[414] Expert interviews

[415] Nagappan et al. 2021

[416] SINTEF

[417] Fish Farmer, Panaferd

[418] Expert interviews

[419] Expert interviews

resources that needs little processing for use as algal growth substrate. These advantages position Iceland to focus on high-value products requiring more complex processing.

Additional value can be captured from microalgae biproducts

Processing and extracting target nutrients from microalgae create biproducts such as proteins, lipids, and minerals. These biproducts could be further processed for nutrient capture or used as raw material for products such as biofertilizers.

7.4.3 Macroalgae opportunities

Macroalgae could be used in fish aquaculture to reduce environmental impacts

Approximately 10% of all European macroalgae producers use IMTA systems, with systems established in Spain and opportunities being investigated in countries with large fish aquaculture industries such as Norway.[420] Iceland could learn from neighboring countries to trial its own systems. It could collaborate with its growing salmon aquaculture sector to produce macroalgae in proximity to fish pens using appropriate biosecurity measures to reduce disease and pests. It can be used as a bioremediation measure to reduce to the impacts of waste and excess fish feed on the environment.

Macroalgae can be used as a greenhouse gas emissions mitigation measure

Macroalgae has the potential to help mitigate emissions by replacing carbon-intensive inputs in the supply chain. For example, algae can serve as a low-carbon replacement of fishmeal and fish oil in Iceland's fish aquaculture sector. Additionally, Iceland could investigate integrating seaweed into cattle and sheep feed to reduce methane emissions, similar to experiments done my ClimeFeed in the Faroe Islands.[421]

Farmers in coastal areas in Iceland may also have the possibility in the future of receiving income through carbon credit offset programs if they were to plant and maintain permanent macroalgae stands. Seaweed farming has not yet made it into most international carbon credit registries, such as Verra's Verified Carbon Standard offset program. However, there are programs such as that operated by Running Tide which creates offsets using seaweed.[422] While the overall scope of blue-carbon credits is lower than land-based credits, some blue-carbon credits have been sold for more than ~13.35 EUR (15 USD), while land-based carbon credits can go for less than ~0.89 EUR (1 USD) per ton of CO_2 equivalent. This is driven by a higher willingness to pay for projects that also benefit the local people and their surrounding ecosystem.[423]

These key opportunities position Iceland in a favorable position to expand the sector. That said challenges and risks must also be considered to ensure a strong foundation for algae cultivation in the country. These risks be discussed in section 8.5.4.

[420] Araujo et al. 2021

[421] Duarte et al. 2017, Roque et al. 2021

[422] Running Tide

[423] Hakai institute

7.5 Conclusion: Iceland can accelerate algae farming growth

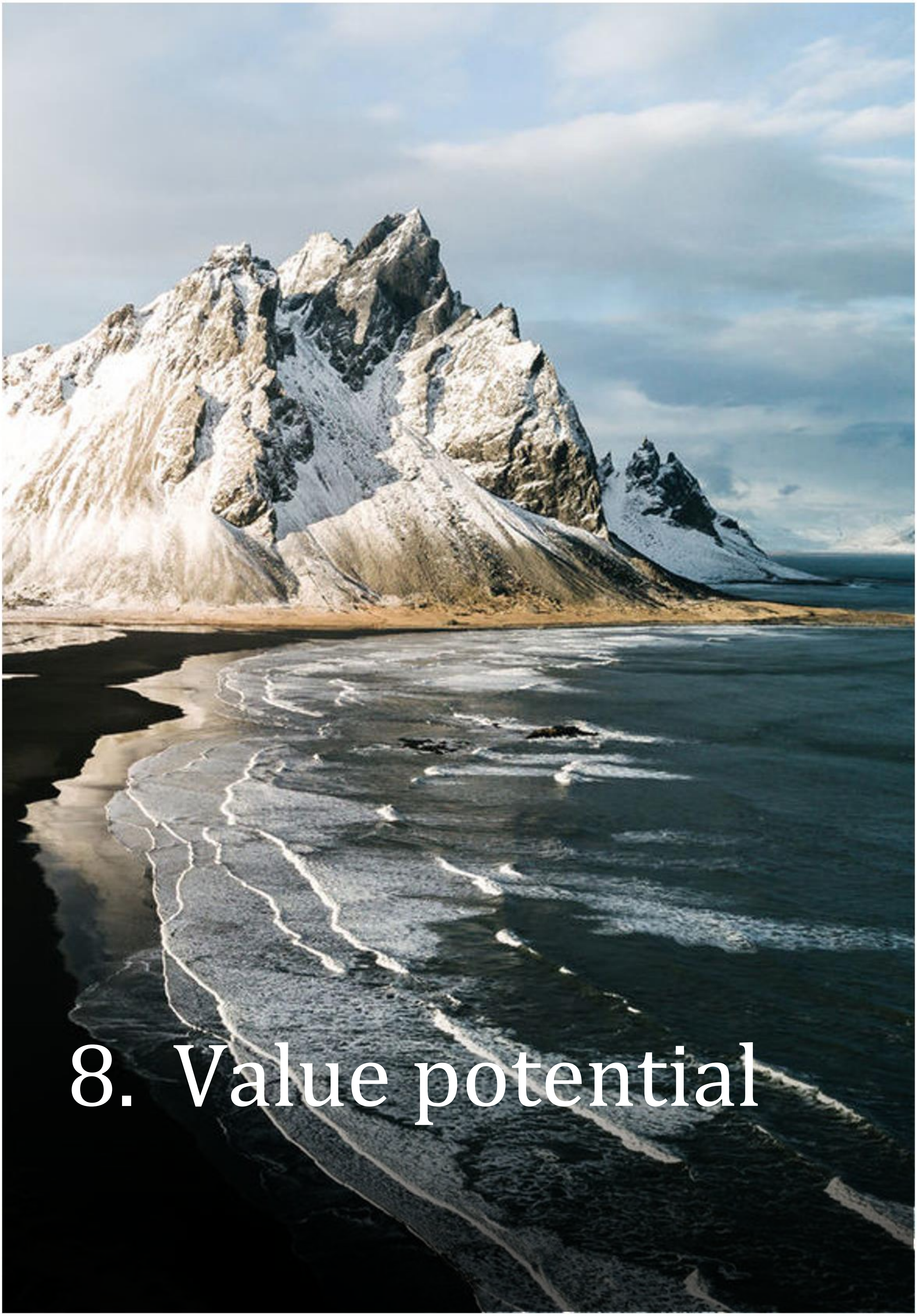
Algae cultivation is a nascent but growing sector in Iceland, with only a handful of players. With growing global demand for algae products in nutraceuticals, animal feed and other uses, Iceland has the potential to expand production. The Icelandic government can play an important role in enabling expansion of the algae sector while minimizing environmental impacts.

Iceland offers advantages to develop a robust microalgae industry. These include affordability of renewable energy and abundant access to freshwater. Low and stable temperatures also provide an advantage towards specific algae products (e.g., astaxanthin), while relatively high costs of labor imply a focus on high-value species that require complex processes to cultivate.

Macroalgae holds attractive benefits for the environment, given its ability to mitigate carbon emissions as well as remediate local marine ecosystems. As wild harvesting in Iceland can only expand to a limited scale, cultivation could allow for further growth. That said, a lack of specific regulation currently restricts commercial cultivation, and Iceland could learn from countries such as Norway, the Faroe Islands, Denmark, and Scotland in developing a comprehensive regulatory framework.

While being a distinct sector, algae also share potential synergies with Iceland's growing fish aquaculture sector. Further research into the viability of algae for use in local fish feed and to reduce the impacts of fish effluent and excess feed could reveal opportunities for simultaneous growth and development.

While there is potential to grow the sector, there remain uncertainties in the sector surrounding regulation, technology, and biological research on suitable species. The establishment of clear ambitions and a path forward would allow Iceland to support its growing algae sector.



8. Value potential

This chapter builds on the preceding chapters to present the future economic value potential of aquaculture in Iceland, along with considerations for unlocking that potential. After summarizing Iceland's competitive position, the chapter describes three possible future scenarios that have different growth prospects and value potential. The chapter concludes by outlining how Iceland can realize this potential, including the key challenges and risks to address. Beyond economic value, the future of aquaculture in Iceland needs to be considered holistically, including environmental and social value. This chapter serves the purpose of illustrating how the economics of the industry might develop and be influenced by a future policy that also considers environmental and social impacts.

The conclusion is that Icelandic aquaculture holds considerable and can in due course become one of the pillars of the Icelandic economy. If the industry is to grow in harmony with the environment and society, however, considerations other than economic need to be considered. The 2021 Agreement on the Platform for the Coalition Government of Iceland emphasizes the importance of building the industry on sustainability, scientific knowledge, and the protection of wild salmon stock. With a holistic aquaculture strategy for Iceland, that takes environmental, social and economic factors into account, aquaculture has high potential to become a sustainable pillar of the Icelandic economy.

8.1 Iceland's competitive position

As described in previous chapters, Iceland is well-positioned to serve the rising global food demand through aquaculture. This section provides an assessment of the competitive position of each sector. Assumptions for the future scenarios are based on the competitive position analysis.

8.1.1 Traditional aquaculture

Traditional aquaculture is still growing in Iceland. Factors such as geographical position, clean waters, and an international image linked with pure nature offer advantages. Iceland's highly developed seafood industry also creates potential synergies, such as value-adding processing. However, the regulatory framework, resourcing, and research output have not kept up with traditional aquaculture's rapid growth. This has created some areas of disadvantage compared to competitors.

Traditional farming in Iceland employs a proven production method and technology with a track record of delivering economic benefits. Key advantages for Iceland include well-suited fjords for traditional farming, as well as an advantageous geographic location regarding access to key demand markets compared to Norway and Chile.

In terms of challenges, the Icelandic aquaculture industry is still in its early stages, with limited scale and a less mature value chain compared to, for example, Norway and Chile. Iceland currently has a maximum allowed biomass (MAB) utilization in licenses of 0.6x vs. 1.3x in Norway. This is largely driven by high share of new licenses granted in recent years in Iceland, where first generations of salmon have not reached harvestable size. This may also be partially driven by the less flexible regulation around moving biomass between production areas and fjords as is allowed in Norway and smaller smolts.[424] Furthermore, Icelandic waters are colder than in most other markets, with a temperature range that is

[424] MAB utilization in licenses of 1.24x-1.5x in Troms and Finnmark in Norway, which has water temperature conditions similar to Iceland's

less favorable for salmon growth and only allows for smolts be stocked a few months per year. This is however at the same time expected to limit the number of sea lice and disease outbreaks.

From an institutional perspective, the regulatory system has not followed industry growth. This has resulted in potential inefficiencies related to predictability, speed, and transparency of licensing process as well as capacity constraints. Both research facilities and educational output are also below leading peer countries.

Traditional aquaculture is still faced with significant environmental and biological challenges. Compared to land-based methods, traditional carries a higher risk of genetic introgression for the wild salmon population. Traditional aquaculture also produces and releases significant amounts of organic load, and in some cases chemicals, into the ocean.

Currently, fees per kg of harvested salmon are higher in Iceland compared to Norway but lower than in the Faroe Islands. With current plans of changes in fee structures and assuming a price of 6.4 EUR/kg (HOG), fees per kg of harvested salmon in Iceland will have surpassed those in the Faroe Islands in 2026. Norway, however, has proposed a new resource rent tax. Provided the new resource rent tax in Norway is implemented in 2023, Norwegian farmers will be substantially disadvantaged in terms of total levies compared to Icelandic farmers.

8.1.2 Land-based aquaculture

Like the traditional sector, land-based aquaculture benefits from Iceland's natural endowments, while it may face infrastructural challenges as it scales.

As energy requirements are considerably higher for land-based farming than for traditional, Iceland's affordable, renewable energy is a key advantage, lowering operating costs compared to other markets and contributing to the sustainability of production. The use of renewable energy improves the perception of both the local public and end consumers, many of whom are willing to pay a price premium for sustainable products. Icelandic land-based farmers also have access to clean seawater of the optimal temperature for raising salmon, filtered through the volcanic bedrock. This unique feature contributes to a further reduction in energy cost, as less energy is used for temperature control and the porous rock performs the function of a biofilter. With temperature regulation, land-based technology can create optimal growth conditions for its salmon, leading to the expectation that production time can be reduced. Land based fish are also not exposed to sea lice, which reduces operating costs and has a positive impact on fish health. Fish escapes do not pose a threat to wild salmon stocks, from the perspectives of both genetic introgression and the spread of sea lice and diseases. Moreover, waste is collected as a biproduct instead of being released directly into the ocean and can potentially be used to create value as fertilizer.

Land-based technology may run into infrastructure challenges as scale increases, mainly with regards to energy supply, including transmission. Labor challenges are expected to be less than for the traditional sector due to current projects being located close to the highest populated areas in Iceland. These locations also carry the benefit of nearby seaports and international airfreight, allowing for easier access to markets.

8.1.3 Offshore aquaculture

As described in Chapter 6, a preliminary analysis indicates that there are suitable offshore conditions around Iceland. Primarily, the waters in the West and in the South of Iceland appear attractive to further explore. There are, however, significant efforts required to establish a new offshore industry. Foresight around planning and legislation needs to be in place to attract investment. Special development licenses have also proven to be successful in Norway, with several projects launched. Special infrastructure further needs to be developed over time, but many of these services can initially be delivered from other countries with developed offshore industries. Iceland can learn from the early sector experience in Norway and begin to build its own offshore infrastructure and legislation, as described in section 6.4.

8.1.4 Algae

Iceland possesses natural conditions favorable for algae production with its cool climate, abundance of freshwater, and accessible and affordable renewable energy. Microalgae producers can reduce the need for cooling and its associated energy costs in the production of species which thrive in cooler conditions. As freshwater and energy are the largest inputs in microalgae production, Iceland can be cost competitive with its provision of stable renewable energy and abundance of clean water supply. For macroalgae, the cold waters around Iceland create favorable conditions for nutrient-dense species that are ideal for value-added processing.

Harvesting of wild macroalgae has been conducted for many years in Iceland but macroalgae cultivation is a nascent sector in Iceland. There are currently a few players in the market, most operating at an experimental scale with further growth mostly constrained by lack of specific regulation. Research and educational capacity are also limited. Iceland has highly qualified experts in the field, but more are needed to support robust growth.

Due to the nature of the production, microalgae growth is not constrained by regulation in Iceland. Many current producers have ambitious plans to scale their production and access to funding may become a limiting factor.

8.1.5 Sub-conclusion

Iceland has a sustainable competitive advantage due its natural endowments, but it trails other supplier markets in maturity of regulation and infrastructure. Not only do the fjords of Iceland provide the natural conditions for salmon farming, but Iceland is also suitable to land-based production of salmon and microalgae due to its affordable, renewable energy supply and its water resources, both cold freshwater and geothermally heated seawater. Although the cold temperatures of Iceland can be less optimal than the temperatures of some other supplier markets for traditional salmon farming, these cold temperatures are a benefit in algae production. Cold air temperatures save cooling costs for microalgae and the water temperatures are ideal for nutrient-dense macroalgae species. All these advantages are inherent in Iceland's geography and location and thus difficult to replicate.

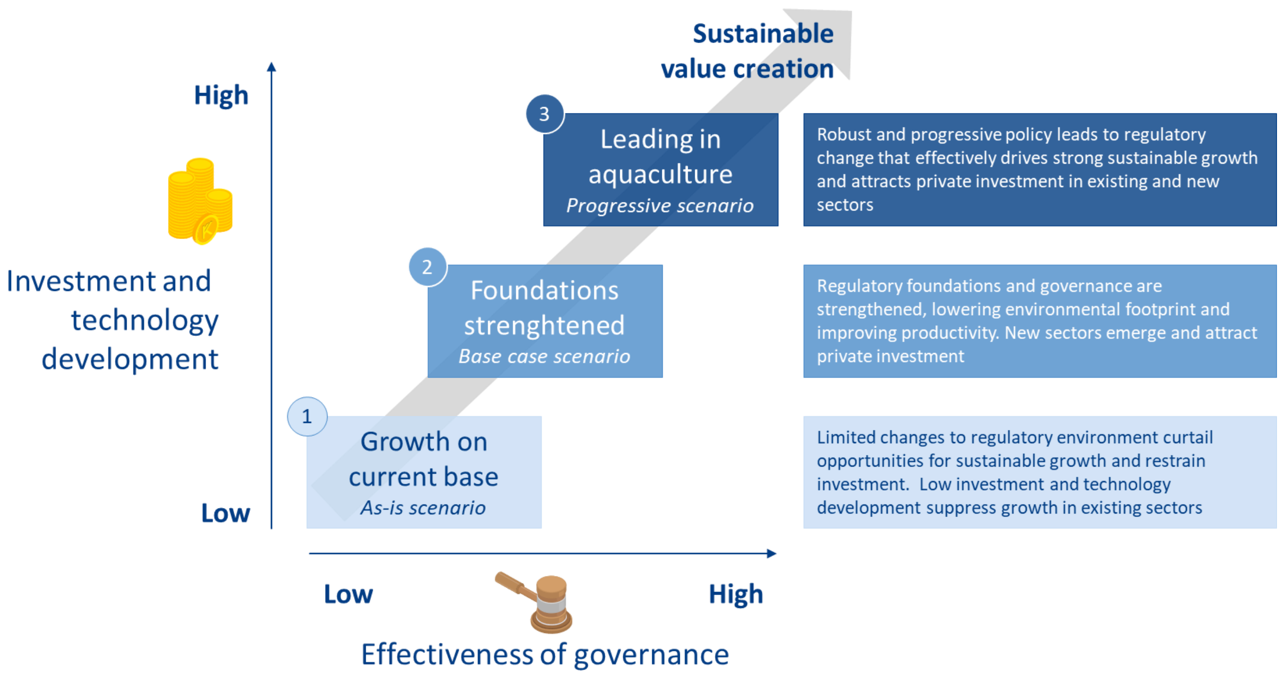
Iceland's disadvantages relative to other supplier markets of aquaculture stem from relatively underdeveloped regulatory capacity and infrastructure. Regulatory capacity has not kept up with the growth of traditional aquaculture, and the emergence of new sectors adds more complexity. Additionally, education and research institutes are less developed than in most other markets.

Ultimately, Iceland holds high potential for aquaculture in all four sectors, which can be reached primarily through regulatory and infrastructural initiatives. Between the three fish farming sectors, the key determinant of relative competitiveness is the pricing of licensing and utilization of capacity. These considerations are used for the modeling of Iceland's future potential, the scenarios of which are described in the next section.

8.2 Future scenarios

As any discussion of the future involves uncertainty, multiple scenarios have been modelled to illustrate the range of possibilities within the expected future potential of aquaculture. Three scenarios have been chosen: *Growth on current base*, *Foundations strengthened* and *Leading in aquaculture*. The three scenarios build on two driving forces, the amount of investment and technology development, and regulatory effectiveness. Generally effective governance supports investment and technology development, therefore scenarios where investment and technology development are low despite effective governance and vice versa are not considered. Figure 8.1 shows an overview of the three scenarios used to assess the future development of aquaculture in Iceland.

FIGURE 8.1: OVERVIEW OF THREE SCENARIOS FOR THE FUTURE OF AQUACULTURE IN ICELAND



8.2.1 Three future scenarios represent the range of possible outcomes

Three future scenarios have been selected to represent a reasonable range of future outcomes, from an as-is scenario, where limited action is taken to drive sustainable growth to a progressive scenario, where private and public actors place significant effort and investment in developing a best-in-class sustainable aquaculture industry. The value created in these scenarios should however not be considered as the industries boundary conditions, but instead, following the assumptions described below, as reasonable outcomes given certain conditions are met. The scenarios do represent the aggregate of low or high case for all four sectors. This means that the as-is scenario models low production for all sectors and similarly, the progressive scenario, high production. While this excludes the possibilities of one sector succeeding irrespective of another, it provides a wider view of the range of possibilities without extending beyond three scenarios. Beyond sector-specific assumptions, each scenario also considers assumptions spanning across sectors, such as supply and demand dynamics, as well as the assumptions required to calculate value, such as the jobs generated per kT of production.

Growth on current base (As-is scenario)

The as-is scenario assumes no significant strengthening of regulatory and surveillance frameworks. This is reflected in no growth in overall traditional aquaculture MAB compared to today and limited changes to MAB utilization. Technological challenges and lack of financing also limits production growth across all sectors. Lastly, neither offshore nor macroalgae farming establish operations on a commercial scale over the next 10 years.

Foundations strengthened (Base case scenario)

The base case scenario assumes that growth is enabled by strengthening regulatory and surveillance frameworks. Furthermore, technological development, improved operations and availability of funding are conducive to growth. During the 10-year timeframe, offshore farming as a sector is established, attracting projects that by the end of the timeframe are operating at a commercial scale. Over all sectors, this is the scenario considered most likely and therefore most indicative of the value potential of aquaculture in Iceland in the next 10 years.

Leading in aquaculture (Progressive scenario)

In the progressive scenario, regulatory, surveillance and strong technological developments boost production in traditional aquaculture. Research and surveillance show that technological developments limit environmental impact, which allows for sustainably increasing licensed MAB. Farmers furthermore increase their utilization of the MAB to amplify overall production. Ample access to funding, technological success, and favorable regulatory conditions enables strong growth in land-based and algae farming. The regulatory conditions to operate offshore farming are quickly established, and investment is attracted that results in several projects succeeding commercially before the decade is over.

8.2.2 Assumptions within sectors

Each sector of aquaculture covered by this report has specific drivers of production volume. This section lists the meta-assumptions made for these drivers for each sector by scenario.

FIGURE 8.2: OUTLINE OF SECTOR SCENARIOS[425]

	Assumptions	As-is	Base case	Progressive
Traditional	New technology application	None	Small/Medium	High
	# of fjords for production	10	12	13
	Max kT (MAB / Risk Ass'mnt)	144 / 115	160 / 140	200 / 180
	MAB harvest per license	0.8x	1.04x	1.3x
	Production 2032 (WFE)	94kT	146kT	234kT
Land-based	Availability of funding	Low	Medium	High
	Technological challenges	High	Medium	Low
	Execution of current plans	Challenged	On track	New phases
	Production 2032 (WFE)	48kT	75kT	149kT
Offshore	Development licenses	No	No	Yes
	Licensed biomass	-	30	50
	MAB harvest per license	-	0.8	0.9
	Production 2032 (WFE)	0kT	24kT	45kT
Total fish farming (WFE)		143kT	245kT	428kT
Algae	Investments in R&D	Low	Medium	High
	Value-added processing	Low	Medium	High
	Macroalgae cultivation license	No	Yes	Yes
	Micro/Macro Output	0.5kT/132kT	1.3 kT/177kT	6.1kT/ 267kT

Traditional scenarios

Icelandic traditional farming is still in a growth state with significant potential to optimize and scale. Four key drivers are used to depict future scenarios:

1) Number of fjords open for traditional fish farming (currently there are licenses in 10 of 14 of the fjords not conserved to protect wild salmon stock)

2) Technology developments and application that leads to lower environmental impact

3) Carrying capacity of fjords currently utilized and total biomass of fertile salmon allowed via risk assessment

4) Utilization rate of licensed MAB. Three benchmark scenarios are used to illustrate the potential impacts of these primary drivers on production:

[425] Menon, Marine policy – Eoin Grealis et al. 2017, Norwegian Seafood Council, Skatturinn, Araujo et al. 2021, Ministry of Industries and Innovation, FAO. Van den Burg et al. 2016, Company websites, Marigot Group Ldt, Singularity Hub, Marine and Freshwater Institute, Seaweed for Europe, Vázquez-Romero et al. 2022, Kepler Cheuvreux, Faroe Islands Statistics, Marine Scotland Science Scottish Fish Farm Production Survey, Directorate of Fisheries in Norway, Hagstofa Íslands, Regional Development Agency and the National Association of Fish Farms, BCG analysis

As-is

Utilization is assumed to continue to be low and only grow due to utilization of licenses already granted, with average smolt weight to remain around 100 grams. There are limited investments in technological development mitigating environmental risks of salmon escapees, resulting in limited increase or decrease of allowed biomass of fertile salmon in fjords. No new fjords are opened for salmon farming due to limitations in farming technology to decrease the risk of escapees. Therefore, growth beyond the cap of ~106.5kT of fertile salmon and ~144.5kT of farmed fish is constrained by legislations and low utilization. The resulting production is assumed to reach ~94kT output by 2032.

Base case

The 2022 production volume of ~45kT, is assumed to roughly double by 2027, provided licenses already granted are fully utilized at 1.0x per license due to higher smolt weight decreasing time in sea and increasing productivity. New technology is introduced reducing environmental impact, including the risk of escapes. This allows for growth in risk assessment and carrying capacity. Location of production areas are moved further away from salmon rivers which leads to an increase in the risk assessment. One or two of the non-utilized fjords that are not conserved will be opened for production. The resulting production is assumed to reach ~146kT by 2032.

Progressive

In addition to the development in the base case, a new license regime is implemented allowing biomass to be moved between fjords, and companies increase the use of post smolt (higher weight smolts). This results in a utilization rate of ~1.3x MAB per license. Large investment in the sector translates to rapid technological progress, significantly reducing or eliminating the risk of escapes. This is reflected positively in carrying capacity and risk assessments and all except for one non-conserved fjords are opened for salmon farming. Increases in government capacity and focus in the sector create streamlined administrative processes and optimized license allocation processes. Strong surveillance regimes established internally within companies and through government measures limit disease and mortality impact on volume. The resulting production is modelled at about ~234kT output by 2032.

Land-based scenarios

Current Icelandic land-based projects have the ambition to produce a total of ~110kT of salmon once they reach full scale operations. Production output depends on regulatory constraints, available funding, and technological success. Additionally, utilization, access to energy, and biological challenges will impact total volume produced. The impact of these primary drivers on production is considered across the three scenarios.

Current production of Arctic char and Rainbow trout are not assumed to vary across the three scenarios, as farmers are already producing at a stable rate. Current production volumes are therefore assumed to stay stable across all three scenarios.

As-is

In the as-is scenario, access to funding and energy supply is assumed to be a challenge, slowing down plans to reach scale. Additionally, technological challenges prevent farms from reaching the anticipated capacity utilization. This results in slower overall progress and lower output compared to current plans and may mean some of the projects never enter the production phase. Licensing also continues to be a lengthy process, resulting in ~48kT total salmonoid production by 2032.

Base case

Due to the current economic outlook, in the base case scenario, access to funding is not ideal, but it is still less of a challenge than in the as-is scenario. Some technological challenges prevent land-based farms from reaching their capacity utilization ambitions, though not to the same extent as in the as-is scenario.[426] The result is that current salmon farming projects are not assumed to reach their full planned potential by the time they had hoped for, but that production is still assumed to grow at a reasonable rate and inspire at least one new entrant by 2032. Regulatory processes are, furthermore, streamlined and tailored to the land-based sector, which helps reduce the time required to obtain licenses. Overall, the combination of these factors results in total land-based salmonoid production of ~75kT by 2032.

Progressive

Early successes in the industry attract more funding, speeding up development and helping to overcome technological challenges. This also results in investors backing new entrants. Access to energy is not a constraint, and regulatory processes are both tailored to the land-based sector and designed to encourage development. Benefitting from regulatory changes and industry knowledge, new entrants are faster to reach the production phase. At the same time, current projects can reach their ambitions according to their planned timeline and continue to grow at the same rate. All in all, this results in overall production of ~149kT output by 2032.

Offshore scenarios

Offshore farming is not established nor has been trialed in Iceland. However, developments in Norway and investor interest suggest that Iceland could see offshore introduced within the next ten years. Production output of offshore aquaculture depends largely on technological developments as well as regulatory constraints and available funding. Like the other fish farming sectors, total production also relies on utilization and potential biological challenges. The impact of these primary drivers on production is considered across the three scenarios.

As-is

The as-is scenario assumes that no offshore aquaculture is established in Iceland. The government decides to prioritize the improvement and development of traditional and land-based systems and defer development in offshore. It can also turn out that investors choose to focus on Norway or other locations before entering Iceland. Naturally, this results in 0kT output by 2032.

Base case

In the base case scenario, Iceland decides to pursue an opportunity in offshore farming and initiates a planning process in the next two years. Research including risk assessments are funded, leading to the identification of potential production areas. No development licenses are created. However, a new licensing and auctioning system are established, incentivizing offshore investment. This results in

[426] Even in the base case, some challenges are expected with new technologies, and even if these do not directly cause mortality, they may force an early harvest of immature fish; see for example Atlantic Sapphire's latest operating challenges: Salmon Business, 17 Oct. 2022

several projects being launched that grow to a total licensed biomass of 30kT by 2032. Average harvest per license is 0.8x, resulting in ~24kT output by 2032.

Progressive

As in the base case scenario, processes and research are initiated in 2023 to establish offshore. Development licenses are created in 2024, creating ideal conditions to do further research, including risk assessment. Technology is adapted to Icelandic conditions in these pilot projects and knowledge is shared, preparing for a faster scaling of the sector. Piloting projects deliver first supply of salmon in 2027 and production ramps up in 2030 when a commercial licensing framework is developed. Overall, by 2032, this results in the issuance of total licensed biomass of ~50kT by 2032. Average harvest per license is 0.9x, resulting in total output of ~45kT by 2032.

Algae scenarios

Algae is a developing sector in Iceland and has the potential to utilize Iceland's natural endowments for competitive advantage. Both micro- and macroalgae scenarios assume the cultivation of multiple algae species. In the macroalgae scenarios, wild harvest has been included in the output volumes and values as industry projections have often been tied. It is expected that existing wild harvest companies may invest in new cultivation practices and leverage synergies between the practices. Production output and value capture depend primarily on regulatory constraints, technological advancements, knowledge building, and investment. Based on these primary drivers, the three scenarios for algae production are assumed to play out as follows.

As-is

Microalgae: In the as-is case, current projects and expansion plans are not all expected to be realized. Sales value assumptions are determined by factoring the volume output and a weighted average price per ton based on current volume and price mix[427]. A conservative view is taken on prices, and they are assumed to remain constant over the next 10 years. The overall result is ~530 tons dry weight of microalgae with total sales of ~60m EUR.

Macroalgae: The as-is scenario assumes no special regulation is formed for the cultivation of macroalgae and only wild harvest continues at industrial scale. This means production is capped at current wild harvest licenses. Values and prices are determined by sales prices per ton in 2021 and with reference to external sources.[428] This results in ~130kT wet weight of macroalgae with total sales of ~20m EUR.

Base case

Microalgae: In the base case scenario current expansion plans are realized and production continues to grow for all players. Like in the as-is scenario prices are assumed to remain constant as demand is met with greater supply. The result is about ~1.3kT dry weight of microalgae with total sales of ~110m EUR.

Macroalgae: Base case scenario assumes ~30% growth in wild harvest licenses over the next 10 years. Special regulation for the cultivation of macroalgae is formed. Cultivation starts at a steady space and a

[427] Araujo et al., 2021

[428] Van den Burg et al. 2016

few projects go beyond developmental scale in 2032 but still relatively low in comparison to the wild harvest. Overall, this results in around ~180kT wet weight of macroalgae. Prices are assumed to be fixed, with total sales amounting to ~30m EUR.

Progressive

Microalgae: The progressive case assumes that increased investment in expansion, technology advancement and value-added processing spurs high growth. Resulting in ~6kT of dry weight of microalgae. Conservatively, prices are still assumed to remain stable resulting in a total sales value of ~250m EUR.

Macroalgae: Fueled by investment, increased research and development, the sector grows significantly. Wild harvest licenses grow like in the base case scenario, and cultivation reaches a similar scale to wild harvest. This results in total output of ~270kT wet weight of macroalgae and assuming fixed prices, total sales of ~40m EUR.

8.2.3 Assumptions across sectors and scenarios

Across scenarios and sectors, increases in volume output and value are reliant on assumptions for how salmonoid and algae prices are expected to develop. Additionally, the required jobs and corresponding tax revenues likewise create additional value within the Icelandic society. Figure 8.3 provides an overview of assumptions across sectors. More details are available in the report's appendix.

FIGURE 8.3: ASSUMPTIONS ACROSS SCENARIOS

1 Salmonoid prices

- Price forecasts applied to Atlantic salmon, Arctic char and Rainbow trout
- In recent years, Atlantic salmon has sold at ~5% discount to Arctic char and at ~40% premium to Rainbow trout this prices relation is assumed to remain
- Salmon prices stay in the range of 66 and 73 NOK/kg until 2028 and then grow at +1.9% CAGR

2 Employment impact

- Employment impact modelled using metrics for jobs/kT output, balancing numbers from Iceland and Norway – the latter used to reflect development of labor requirements
- The base case data assumes ~13 direct and ~12 indirect jobs/kT in 2032
- Direct jobs/kT are split across farming (~6 jobs/kT) and supporting jobs (~7 jobs/kT)
- For jobs related to algae production, ratios vary considerably depending on product type (e.g., micro vs. macro) and species

3 Taxes & fees

- Three drivers of tax revenue: i) Labor income tax, ii) Industry fees and iii) Corporate taxes

i) Calculated assuming avg. salary of 9.2m ISK/year, 3% yearly wage growth and 35.9% effective tax rate

ii) Production fee of 5% to be implemented towards 2026. Environmental fee of 20 SDR per allowed kT biomass. Harbor fee of 0.7%. Fees are tax deductible

iii) Corporate tax rate of 20%. Corporate profits assumed 0 until '25 due to current levels and tax-deductible losses. After '25 EBIT climbs to ~30% by 2030 (excl. fees). Due to high investments, land-based and offshore is not assumed to pay corporate taxes within the projected period

4 Export share

- Currently Iceland's export share for Salmon is ~80% (2021), domestic consumption assumed to stays fixed as output increases, export share will go towards ~96% in 2032
- Algae export share assumed at 99%

5 Processing composition

- Amount of processing assumed to stay at 2021 absolute terms (1.4 kT salmonoids)
- Conservatively not accounted for is upside potential in increased processing incl. with monetization of offcuts, lower transport costs, additional employment and higher taxes

8.2.4 Sub-conclusion

Many factors combined determine the overall value generated from aquaculture in Iceland over the next ten years. Informed by the findings in this report, assumptions have been made, leading to three future scenarios (as-is-, base case- and progressive scenarios) that provide a range of possible outcomes. The following section discusses the value creation potential for Iceland based on these scenarios.

8.3 Production

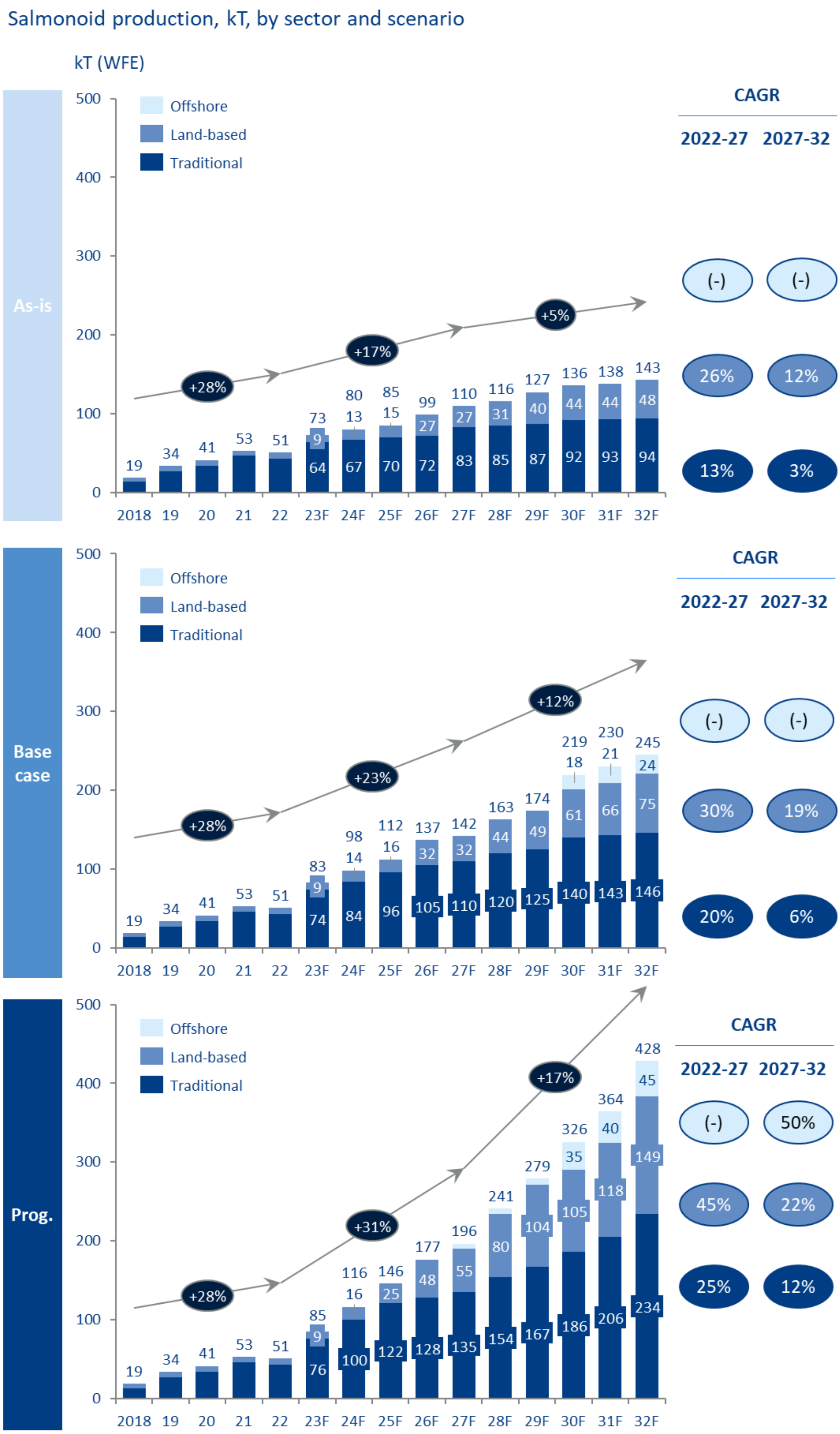
The key driver of economic value is production volume. Growth Based on the competitive positioning of Iceland, informing three future scenarios, the following section presents the projected production volume (kT) expected for each sector and scenario. The production output of each sector will then form the bases for calculating aquaculture's potential for value creation.

8.3.1 Production volume

Salmonoid volume

Figure 8.4 shows the projected production output for each salmonoid farming sector, across the three scenarios until 2032.

FIGURE 8.4: SALMON PRODUCTION BY SECTOR AND SCENARIO (KT)



As Figure 8.4 illustrates, Icelandic aquaculture is expected to grow in all scenarios. This is natural given that traditional aquaculture has not yet reached the maximum capacity available today, and land-based farms have ambitious plans with construction in several instances already underway. In the base case scenario, production volume is expected to grow towards ~245kT by 2032.

Traditional aquaculture drives the growth in volume over the first ~5 years in the base case scenario with a 30% CAGR; this growth begins to flatten to a CAGR of 6% in 2026-2032 as utilization reaches steady state and all available licenses are allocated. Land based grows, from a low base, rapidly until 2026 or by ~30% after which growth slows to ~19% until 2032. The final few years are then bolstered by the entrance of offshore, where production starts in 2030 and makes up ~10% of total volume in 2032.

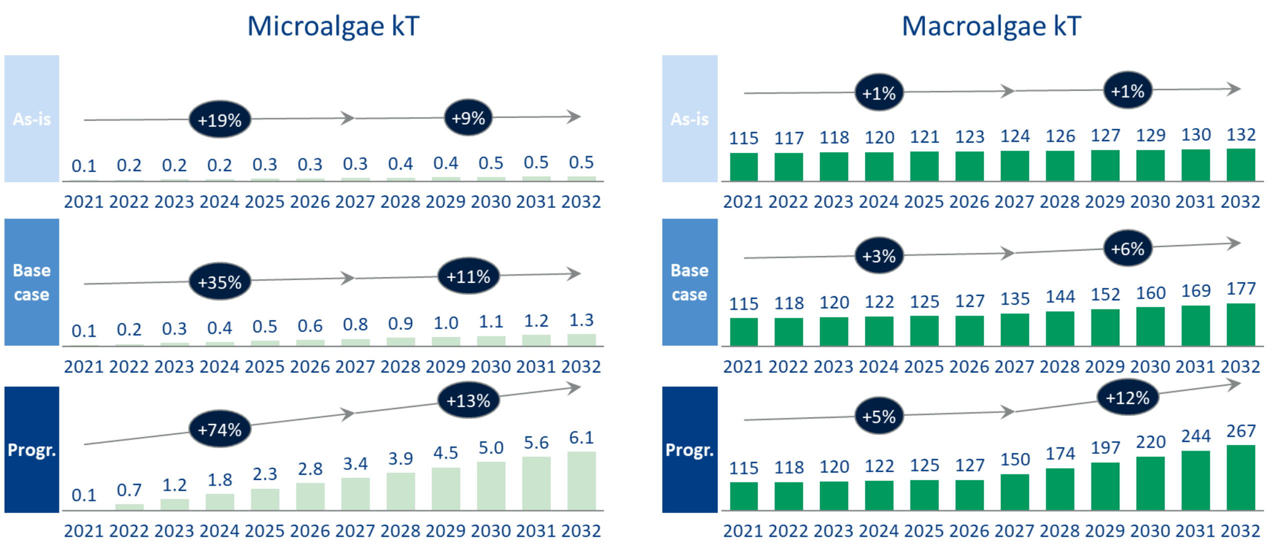
The growth pattern seen in the base case scenario is also reflected in the progressive scenario, where the initial growth is driven by traditional, with a CAGR of 25% in the first five years, whereas the second half of the decade it is driven by a 22% CAGR in land-based, as current projects reach their ambitions and more investment is attracted into the sector. In the latter half of the decade, offshore also starts to grow significantly or by 50% CAGR, driven by the early introduction of development licenses. The scale of growth is naturally higher for this case, with a final output of ~430kT. While this is still less than half of the production of Chile and one third of that of Norway, it reflects an almost eightfold growth from 2021.

In contrast, the as-is scenario shows a steadier CAGR of ~10% for the next decade due to a slowdown in both land-based and offshore financing and technology development as well as offshore not being established in Iceland by 2032. By the end of the decade, the as-is scenario projects a production output ~140kT, of which traditional aquaculture makes up two-thirds of the volume. Even so, the as-is scenario almost triples Iceland's output from 2021.

Algae volume

Figure 8.5 shows production output for micro- and macroalgae across the three scenarios until 2032.

FIGURE 8.5: ALGAE PRODUCTION, MICROALGAE (KT) AND MACROALGAE (KT) BY SCENARIO



In all scenarios in the algae sector, both micro- and macro expect growth in volume. Like the salmonoid sector, increase in volume is somewhat natural, given low current scale and ongoing developments. Overall, microalgae see greater growth, especially in the initial years, as the segment is more established and many of the larger companies have plans for large scale expansions. The segment is also less restricted than macroalgae, by regulation, natural conditions and a lack of local knowledge and experience surrounding cultivation. In the base case scenario, microalgae increase ~10x to 1.3kT by 2032, mostly driven by the large outputs of Spirulina. Spirulina is often produced in significantly larger quantities compared to higher-value products such as astaxanthin which undergo more complicated processing. The as-is scenario sees limited growth, mostly due to a lack of funding of expansion plans. The progressive scenario sees significant investment, technological improvements, and local talent development spurring growth in multiple algal varieties.

For macroalgae, the as-is scenario demonstrates wild harvests reaching their maximum potential ~130kT. In the base case and progressive scenarios, growth is slow at first and ramps up in the second half of the period to 2032. Regulation is passed for ocean-based cultivation, with development licenses initially granted, followed by commercial licenses in 2026 after which growth accelerates. The base case scenario sees existing experimental cultivators going beyond experimental scale to become profitable in their operations, overall resulting in total combined macroalgae production of 180kT by 2032. The progressive scenario expects cultivation to be a success due to Iceland's natural advantages, attracting new entrants and significant improvements in operations. This results in cultivation making up nearly half the total output of 270kT in 2032.

8.3.2 Sub-conclusion

The competitive position of Iceland implies a likelihood of growth across all scenarios. The base case scenario, if realized, would make Iceland amongst the largest salmonoid producer in the world. The algae sector also shows potential to scale existing microalgae facilities and start macroalgae cultivation, with the driver being macroalgae specific regulation and licensing. The following sections build upon these volume projections to estimate the future value potential for Iceland.

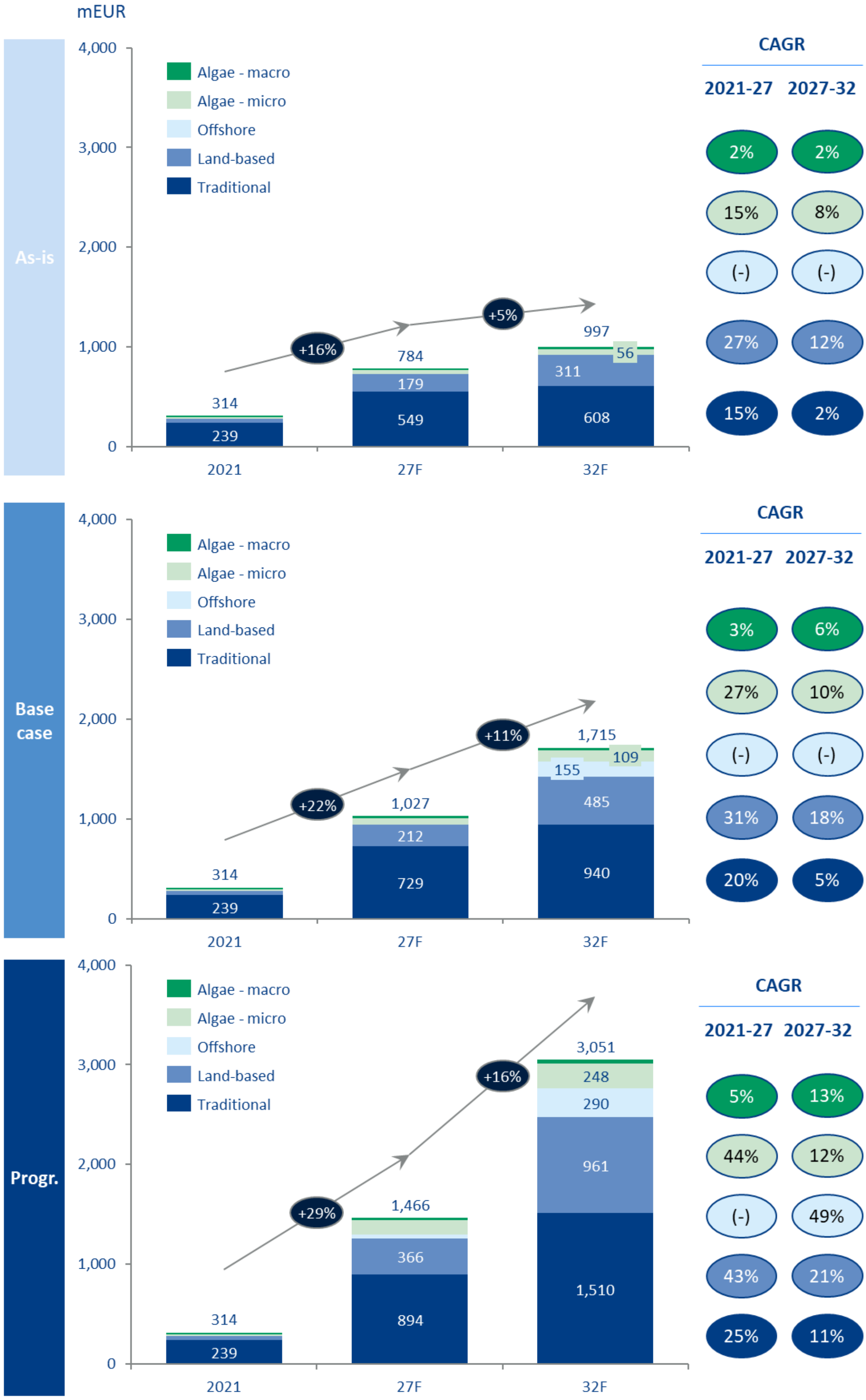
8.4 Value creation

Based on the future production potential, the following section presents the value potential for Iceland across sales and export value, jobs created, and tax revenue. Additionally, the section also considers non-economic factors to provide a holistic view of the impact on Iceland.

8.4.1 Sales value

Following the estimates of production output, estimates of sales value can be derived based on price projections described in 8.2.3. Figure 8.6 shows the expected sales value of products from the Icelandic aquaculture industry over the next ten years.

FIGURE 8.6: SALES VALUE BY SECTOR AND SCENARIO (MEUR)



The sales value of products from the aquaculture industry in 2032 ranges from ~1bn to ~3bn EUR (~140-420bn ISK) in the three scenarios, with the base case scenario sales value of ~1.7bn (~240bn ISK). This could amount to as much as ~6% of GDP, delivering a significant contribution to the Icelandic economy and establishing itself as an economic pillar.

For the base case scenario, as seen in Figure 8.6, throughout the forecast period of 2022-2032, algae sales make up 8-10% of total aquaculture sales, with sales totaling ~135m EUR (~19bn ISK) in 2032. While this is a relatively small contribution to the total sales value, microalgae, under the assumptions, exhibit higher growth rates than traditional aquaculture. Inherently less constrained by natural conditions, it has the potential to grow as a share of the total industry beyond 2032.

While volume drivers were discussed in the last section, sales value is also contingent on price, which is dependent on the global salmon market. It should therefore be expected that the actual values will show more volatility as they are realized in the next decade. Here, the split between salmonoids and algae also plays a role, as prices for products in these sectors are not expected to be tightly linked. Therefore, diversifying the aquaculture industry with algae production can potentially serve as a risk hedge, should salmon prices develop unfavorably from the producer perspective.

8.4.2 Export value

While the previous section examined the total market value of aquaculture, the next sub-section narrows this figure down to export value, illustrating the share of total sales outside of Iceland.

FIGURE 8.7: GROSS EXPORTS BY SECTOR AND SCENARIO (MEUR)

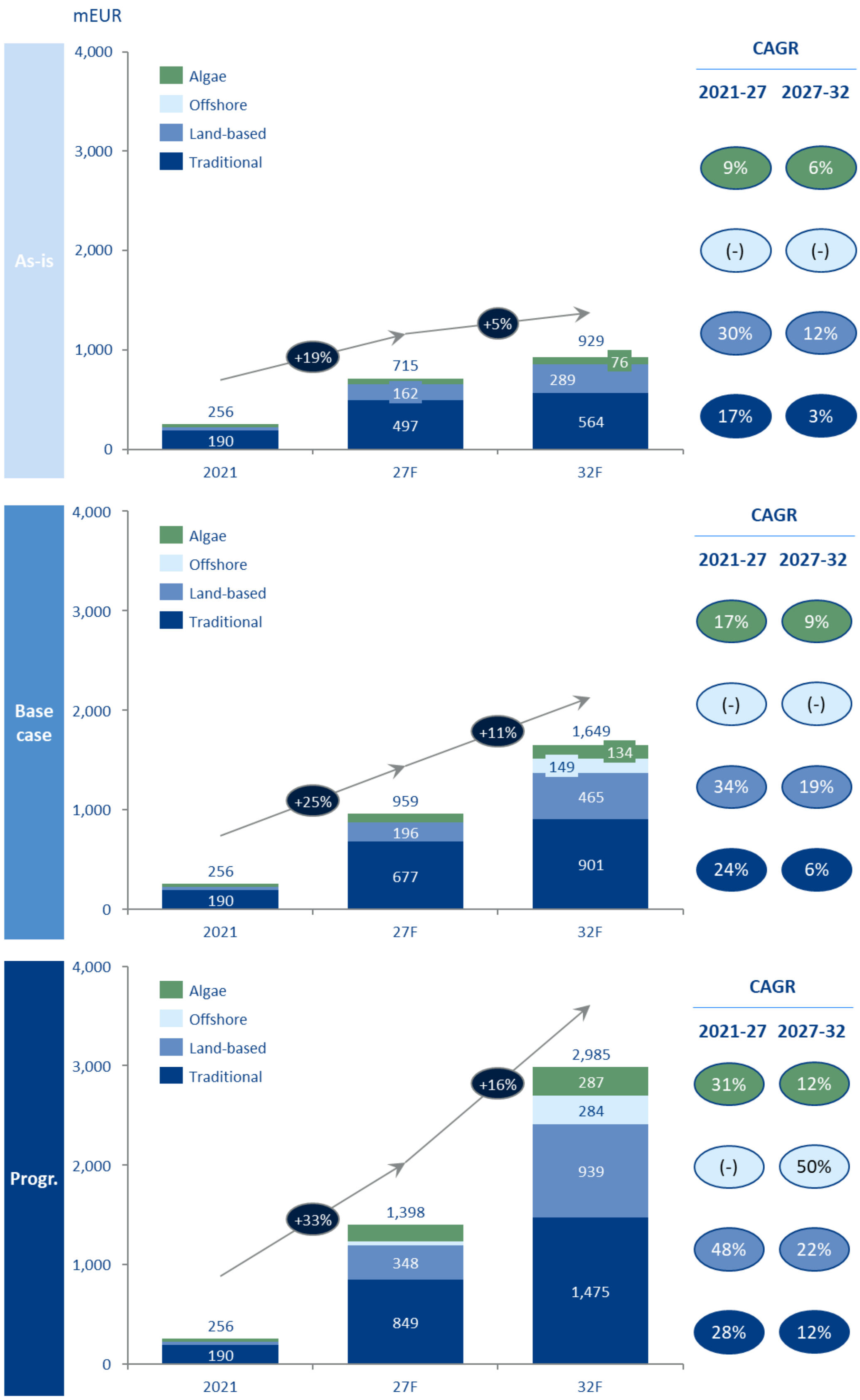


Figure 8.7 shows the gross aquaculture exports of Iceland in each of the three scenarios. Comparing the export value to total sales value, the share of total sales value exported increases from ~80% in 2021 to between 93% and 98%, depending on scenario, in 2032. This is because the Icelandic population is assumed to consume aquaculture products at a relatively constant rate, meaning that the share of production exported increases with scale.

8.4.3 Jobs

Significant growth in production brings the potential to create several thousands of jobs. The following section estimates the direct and indirect jobs created by the salmonoid and algae sectors in each scenario, based on the assumptions for job creation outlined in 8.2.3.

Figure 8.8 shows the additional jobs expected in 2032 compared to 2021, while Figure 8.9 shows job development over time.

FIGURE 8.8: PROJECTED ADDITIONAL JOBS BY 2032 – BASE CASE SCENARIO (FULL-TIME EQUIVALENT)

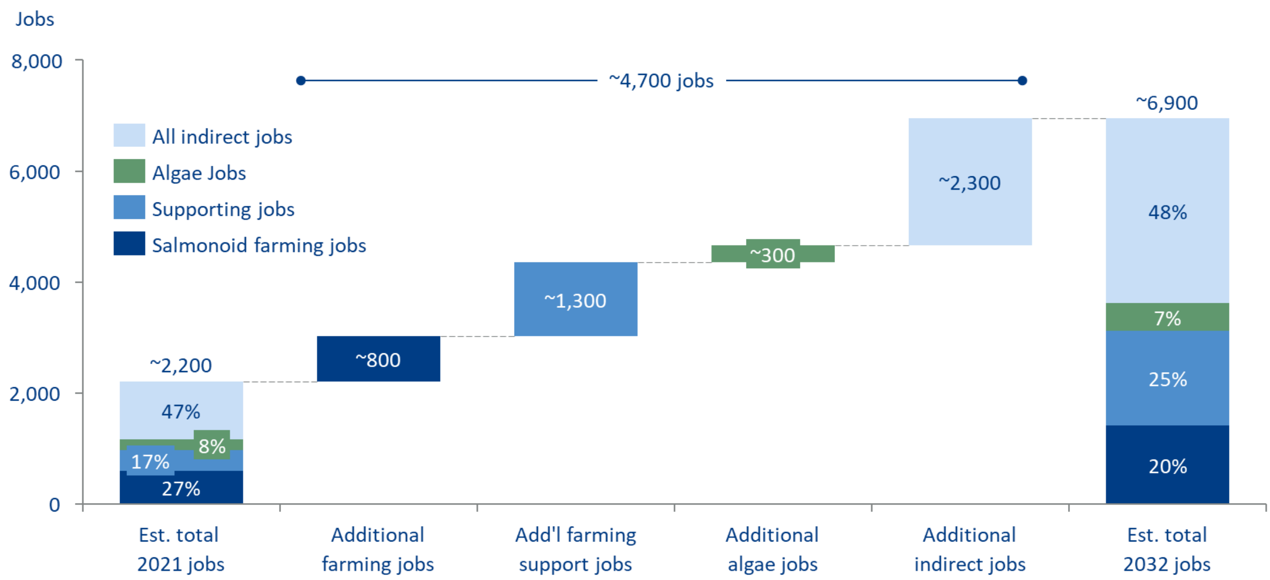
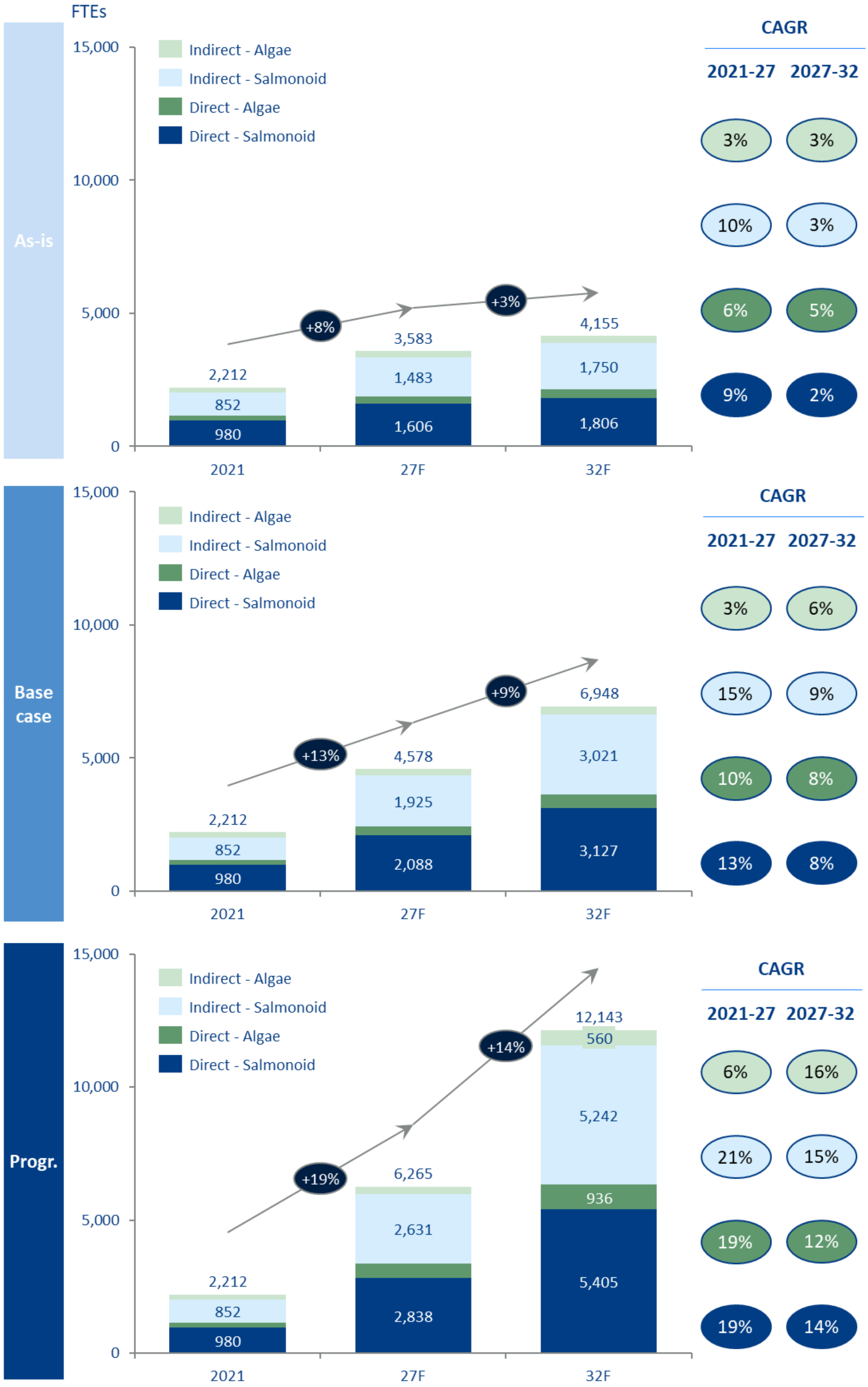


FIGURE 8.9: DIRECT AND INDIRECT JOBS CREATED BY SECTOR AND SCENARIO (FULL-TIME EQUIVALENT)



As seen in Figure 8.9, the Icelandic aquaculture industry has the potential to provide between ~4k and ~12k full-time jobs in the next ten years, an increase from just over 2k today. The base case scenario estimate adds ~2.6k direct jobs and ~2.3k indirect jobs by 2032, which in total account for 3% of the current workforce (direct accounting for ~1.7%). The progressive scenario pushes the total job creation up to nearly 6% of the total Icelandic workforce, and even in the as-is scenario, aquaculture is projected to account for 2% of Icelandic jobs.

While the growth and distribution are directionally the same as seen for the production and sales value projections, the growth rates of jobs are proportionately lower. For example, in the base case scenario, the CAGRs for job creation in the two half-decades are +13% and +9%, respectively, compared to the +22% and +11% projected for production volume. This is due to the assumption that workforce productivity increases with scale, so that the number of FTEs needed per kT is inversely related to total production volume. At the same time, however, indirect and supporting jobs increase as the industry matures, since industry services that are currently done elsewhere can be attracted to the Icelandic market. Compared to salmonoid farming, algae farming is generally less labor intensive.

It is important to keep in mind that some of these jobs may be filled by foreign labor, or that the creation of these jobs may happen alongside a reduction in jobs in another industry. However, this view provides guidance on a reasonable range of FTEs needed for the projected aquaculture production and thus the potential employment benefit to Iceland. However, it does not necessarily illustrate the incremental effect on employment, which in turn depends on where this additional employment comes from (e.g., imported labor, labor market entrants, labor from other industries)

8.4.4 Tax revenue

Having estimated the sales and jobs generated by the projected aquaculture production in Iceland, it is now possible to estimate the direct benefit to the Icelandic government through taxes. These come in the form of income taxes, corporate taxes, and fees associated with aquaculture.

Figure 8.10 shows the additional tax revenue expected in 2032 compared to 2021, while Figure 8.11 shows the projected tax revenue development over time for each of the scenarios, where the assumed delay in corporate tax revenue can be seen.

Figure 8.10: Projected additional tax and fees revenue in 2032 – Base case scenario (mEUR)

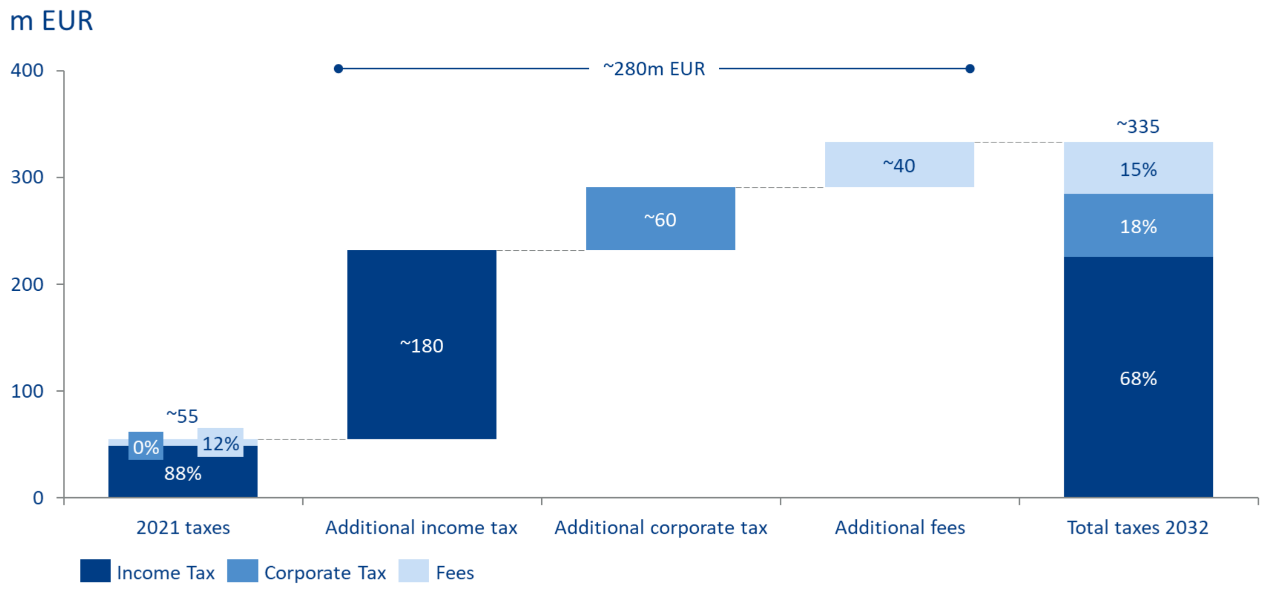
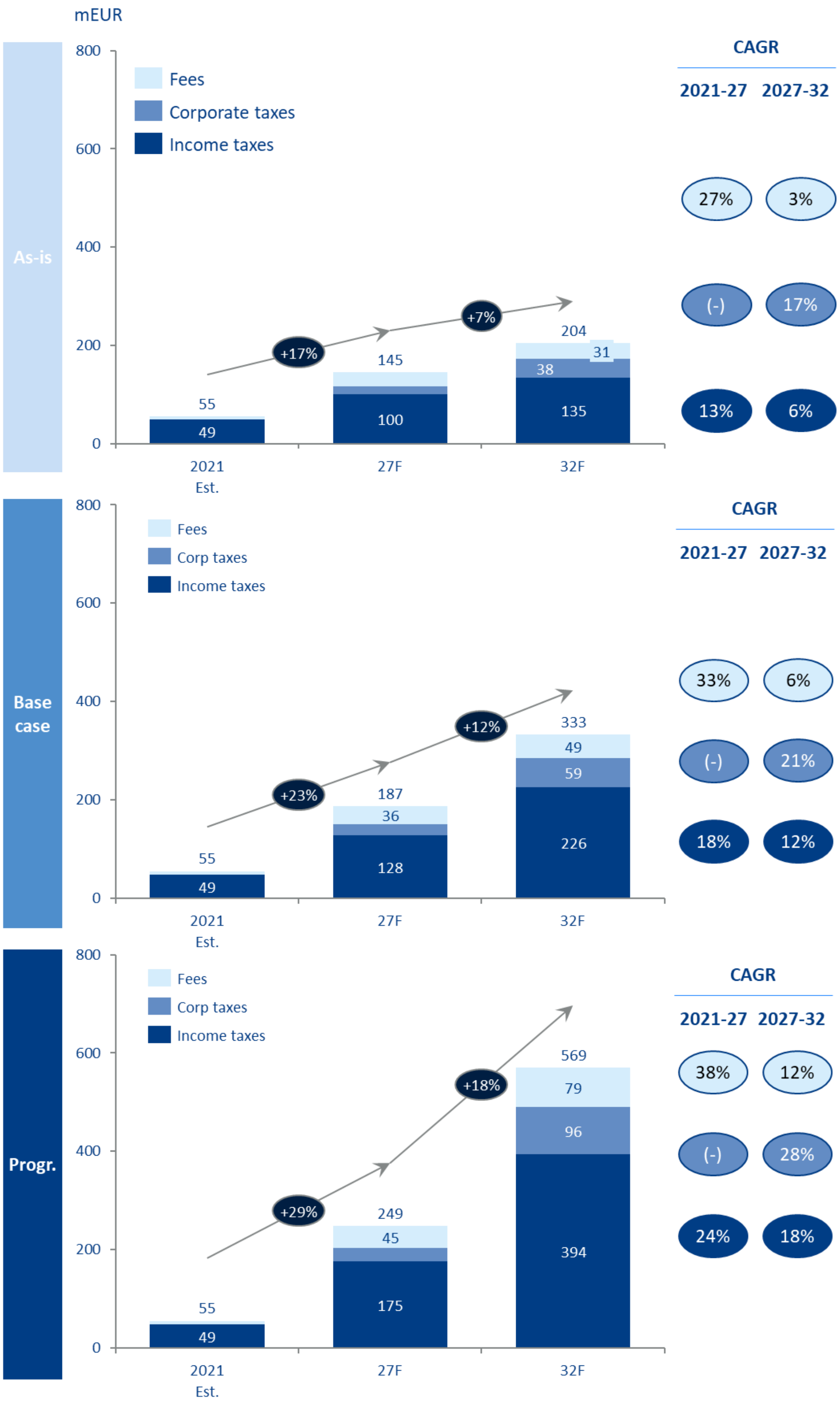


FIGURE 8.11: PROJECTED TAX REVENUE BY SCENARIO (MEUR)



As Figure 8.11 shows, the three scenarios estimate tax revenue from ~205m to ~570m EUR (~29-80bn ISK), with the base case scenario generating a tax revenue of ~335m EUR (~47bn ISK), which could be as much as ~3% share of total tax revenue for Iceland. This demonstrates that the aquaculture industry could significantly contribute to state income.

Income taxes of direct and indirect aquaculture labor are the largest driver of tax revenue, accounting for more than half of total tax income throughout. Corporate taxes and fees increase their share of total tax revenue over time. The increase in fees is driven by the production fee introduced in 2020, which is still in the process of being phased in, and thus will not take full effect until 2026 (3.5%). In the budget proposal for 2023, it was proposed to increase the production fee rate to 5% but was not approved. It is important to note that industry fees are supposed to fund the governance of the industry, and that many of the payments made by these fees are again taxable. On the corporate income side, the increase in taxes paid towards the end of the period is due to companies reaching a point of operational maturity where positive net income that can be taxed.

This graph demonstrates how, while aquaculture can generate a healthy tax revenue stream through income taxes, the full tax revenue potential will only be realized as the industry matures and becomes profitable. This emphasizes the benefits of encouraging this sector to gain a strong foothold in Iceland and creating conditions where it can grow to reach a profitable scale.

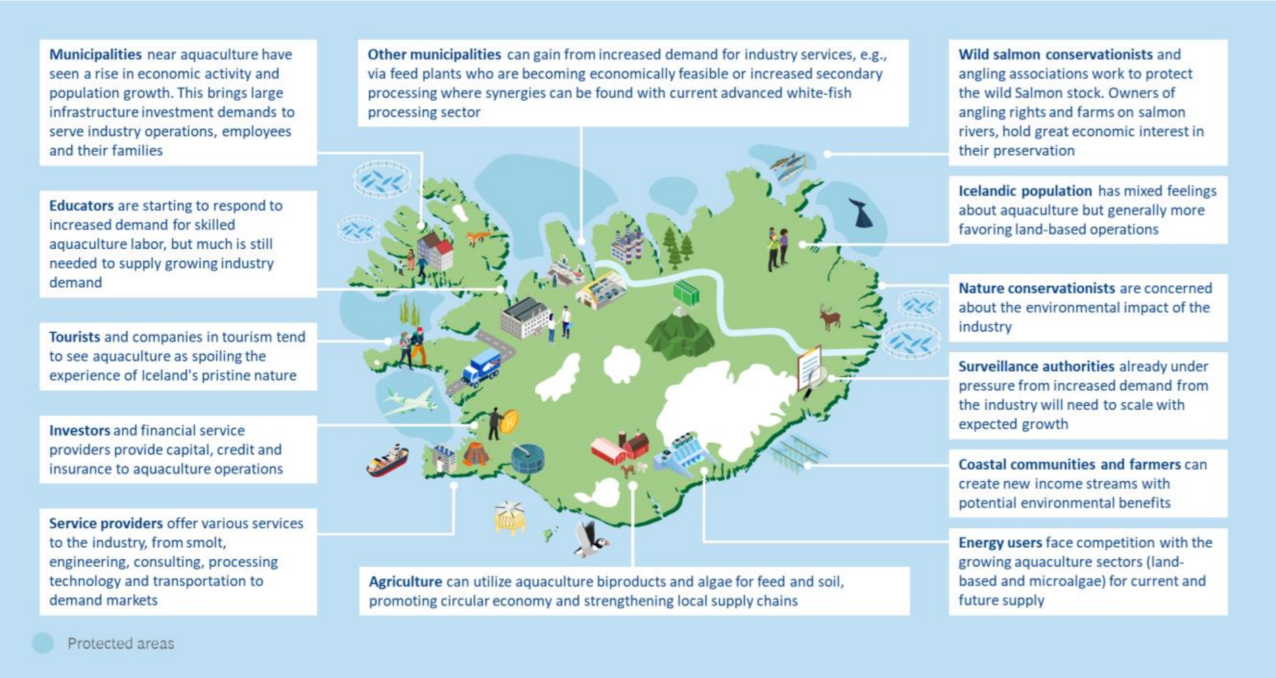
8.4.5 Non-economic impacts

Aquaculture, like most other types of farming on an industrial scale, has complex and wide-ranging societal impacts beyond the economic measures discussed in the preceding section. Like many commercial endeavors, it creates economic interest from which many benefit but also causes friction with or risks to the commercial interests of others. Moreover, most aquaculture sectors rely on the use of common resources with opportunity costs for alternative use, including environmental preservation. As the aquaculture industry grows, it is likely that greenhouse gas emissions will also increase. However, as technology advances and sustainability becomes a more pressing consideration in the industry, emission intensity per unit of output is likely to fall.[429] Other environmental impacts have been discussed in sector-specific chapters, and the potential for aquaculture to change or have a negative impact on common natural resources has been a topic of public debate.[430] As the potential impact varies for each aquaculture venture (based on sector, location, technology, and so forth), the non-economic impacts are not specified in detail here. Instead, Figure 8.12 (repeated from Chapter 3) illustrates the myriad of stakeholders related to Icelandic aquaculture, all of whom should be considered as the industry grows.

[429] Ziegler & Hilborn (2022)

[430] See 3.9.4.3 for details

FIGURE 8.12: SELECT STAKEHOLDER GROUPS RELATED TO ICELANDIC AQUACULTURE



8.4.6 Sub-conclusion

Based on Iceland's competitive position outlined in 8.1 and the scenarios outlined in 8.2, the preceding section shows that the Icelandic aquaculture industry can have a significant positive economic impact. Production is estimated to grow in all scenarios, with the base case scenario reaching ~245kT of salmonoids and ~180kT of algae by 2032. This results in a total sales value of 1.7bn EUR (~240bn ISK) in the base case scenario, accounting for as much as ~6% of GDP. This production is expected to be carried out by ~7k direct and indirect full-time employees, located in Iceland, amounting to ~3% of the current Icelandic workforce. Additionally, the base case scenario projects that aquaculture will contribute ~335m EUR (~47bn ISK) to tax revenue by 2032. Tax revenue builds up more slowly than sales value, as it correlates with the maturity and profitability of producers.

This growth is driven by several factors. Among the salmonoid sectors, traditional aquaculture drives early increases, while land-based and offshore gain foothold. In the base case scenario, land-based, begins to scale up quickly ~2026, when the first phases from large projects are harvested. Offshore follows, contributing to growth starting in 2030. Finally, algae's growth is assumed to be relatively steady, meaning its contribution to the total sales value holds at ~8-10% over the ten years considered.

There is growth projected in all scenarios, partly due to licenses that have been granted but not yet yielded harvest. However, to support aquaculture in growth beyond the as-is scenario (with substantially lower impact than the base case scenario), Iceland needs to offer suitable conditions for aquaculture to flourish. The following section describes how Iceland can concretely take action to achieve the projected potential.

8.5 Unlocking Iceland's potential

The following section describes the enablers needed to achieve the aquaculture industry's potential, as well as concrete actions that the ministry can take. While some aspects of the scenarios modelled are outside of the Ministry's control, such as funding availability, technological success and internal monitoring of diseases, there are several actions the Ministry can take to encourage the industry's development and to mitigate the effects of these influences. These actions are described below.

8.5.1 Traditional

The traditional sector's growth is first and foremost reliant on growth in the MAB. Currently, volumes are restricted by the risk assessments determining maximum biomass of fertile salmon to limit impact on wildlife, and maximum carrying capacity in fjords to limit impact on seabed, sea conditions and other marine life. Changes to the current MAB for traditional aquaculture require research and thorough environmental assessments, especially with regards to the impact on wild salmon stocks. Prior to such research taking place, many of the following enablers, should not be read as recommendations but levers to be considered and analyzed for potential application. A prerequisite for which is a scientific and political process with the aim to optimize the sector's sustainable value generation.

G. **Increase transparency around the auction process** to provide producers with greater clarity surrounding requirements and decision process. This could entail publishing a list prior to the auction process with details on assessed parameters and their associated weights.

H. Consider establishing **one-time green licenses** to incentivize the development of technology. Improved technology could lead to lower impact from escapes, sea lice and organic waste, resulting in higher biomass over time of fertile salmon and higher carrying capacities in fjords.

I. Holistically **revisit license allocation with the aim to maximize the MAB** under the constraints of the risk assessment and offer operators the possibility of relocating sites (see further in 4.6.3).

J. **Assess changing the licensing regime to allow for moving biomass between defined regions within defined MAB limits**. Norway currently uses a flexible licensing system, allowing producers to move biomass between fjords, which is a large driver for the average harvest volume of 1.3x per license and 86% biomass utilization rate compared to Iceland at 0.6x per license and 38% utilization respectively. That said, these rates are expected to increase in Iceland when recently stocked salmon is harvested. A prerequisite for doing this is to assess the carrying capacity of each production area and estimate total carrying capacities on a larger geographic region than just fjord based (e.g., South Eastfjords). Considerations also need to be made on how a new system would impact existing licenses and situations where there is more than one farmer in the same fjord. Environmental and practical considerations must also be factored in, such as how this would impact the risk assessment.

K. **Lowering risk thresholds, increasing internal monitoring requirements and government surveillance** to monitor compliance, and more tightly follow changing sector dynamics. This could be done with lower thresholds e.g., include seasonal lowering of sea lice thresholds to enable earlier activation of contingency plans (e.g., 0.5 to 0.2 during warmer months), decreasing pen densities to limit disease risk (e.g., 25 kg/m^3 to 20 kg/m^3), consider screening for the ISAV HPR0 strain, and greater surveillance of smolt facilities and wellboat transport. This would require more government capacity (up to 40 FTEs when volume reaches ~100kT). Further details are provided in section 4.5.8.

L. Consider **streamlining the medicine approval process** and pre-approving select sea lice treatments to allow for faster responses to limit impact from outbreaks.

M. **Review the distribution fees** to support the capacity of municipalities to invest in infrastructure to support the industry and its workers. This could also be done with a temporary arrangement.

N. **Increase resourcing for industry regulation and surveillance**. Regulatory capacity has not grown in line with the industry and is increasingly challenged in supporting and monitoring it. Increased government capacity can support producers in optimizing their production and lead to better monitoring of fish welfare and environmental impact.

O. **Increase transparency and accessibility of industry surveillance information**, clarify consequences for non-compliance to regulation, and enforce actions when they occur.

8.5.2 Land-based

Key to achieving the land-based sector's full potential lies in streamlining the regulatory framework to cater for its specific needs. As the land-based sector in Iceland is already well underway, the role of the government is one of clarification and optimization rather than attracting industry players from elsewhere. The following considerations should be taken to support the sustainable growth of land-based aquaculture in Iceland:

A. Create an **independent licensing and surveillance system** optimized for land-based aquaculture. The system would license and survey the land-based sector in accordance with its special technical and operational standards, as well as fish welfare requirements. As land-based facilities do not draw to the same extent on public resources, license fees can primarily cover surveillance, and the cost should be balanced to incentivize sustainable development and competitiveness across all three fish farming sectors. This independent licensing structure can help boost efficiency in application processing and Iceland's global competitiveness within the industry. A robust surveillance program can mitigate the uncertainty associated with new technologies and potential environmental impacts (e.g., monitoring of quality of filtered run-off water).

B. Consider how to optimally **enable land-based growth**. This can be achieved through innovation support, such as contributing to research for land-based technologies. It can also take the form of marketing assistance, the possibilities of which are further discussed in 8.5.4. To balance out this support, a plan should be in place for how tax and fee structures will over time source income from a well operating, successful industry.

C. Assess the **potential future energy requirements** of the sector to help energy providers better plan for the sectors energy needs, including potential prioritization (see section 8.5.5). This will grant land-based farmers greater certainty in securing stable energy contracts and plan for potential future expansions.

While this is a high-potential opportunity, the sector is still nascent, and thus the government plays an important role in monitoring technological developments, potential environmental and animal welfare challenges, and the long-term impact on Iceland's energy resources. Enriched by Iceland's natural endowments, this sector has sustained competitive advantages compared to other global players. With the right policy and regulation in place, it can take a leading role globally.

8.5.3 Offshore

The offshore sector is not yet present in Iceland. Globally there is increasing interest in the sector which holds the promise to be the new frontier of creating capacity. Other nations have started taking steps towards attracting industry players. If Iceland wants to establish an offshore sector, its first consideration should be how it can create feasible conditions for companies to start operations. Planning, regulation, and infrastructure are the first steps to provide clarity and predictability for investors considering making the high investments required for offshore aquaculture. Key considerations for the Icelandic government are described below:

A. Attract **interest and develop capabilities** through early regulation and developmental licenses. Offshore aquaculture should be explicitly included in Iceland's aquaculture policy, providing visibility of the government's intentions to the market. To accelerate capacity building, Iceland can follow Norway's example by offering developmental licenses and secure MAB in predefined areas. This will allow investors to commence work on preparations to establish developmental farms. Like in Norway, development sites can accelerate the adaptation of technology to Icelandic conditions, with information publicly shared with the market, and serve as a proof of concept for successful commercial operations. Further research and experience gained from the development sites should be applied to create models for MAB allocation and risk assessments. The development sites will also require infrastructure and services which will then naturally start to form in Iceland.

B. **Identify suitable locations** for offshore farming in Iceland. Thorough research and surveying need to be conducted to confirm the feasibility of offshore operations in Icelandic waters. Preliminary analysis performed for this report suggests that there should be no major constraints. Once feasibility is validated, an open consultation process can prove beneficial to identify the most suitable areas for farming. To minimize conflicts with other commercial interests at sea e.g., offshore wind farms, offshore planning should be done holistically. The planning should also include further research into the environmental impact profile of offshore, with special focus on risks associated with escapes and where local species such as coral need to be protected. This preliminary work to identify locations will accelerate the licensing process and provide more certainty to potential investors.

C. Assess creating an **independent licensing and auctioning process** optimized for offshore aquaculture. Clear licensing frameworks and auctioning processes are critical to investors. The earlier these can be established; the faster Iceland can expect production to commence. A separate licensing system for offshore farms, allows for flexibility with regards to pricing, to cater for higher investment needs.

D. Identify and **establish infrastructure and surveillance** needs. Similarly, to land-based, offshore aquaculture requires new governance capabilities. These need to be established and resourced to facilitate and monitor the sustainable growth of the industry. In addition to governance, special service infrastructure may need to be built to support new capabilities. For example, harbor facilities may need to be adapted or expanded to account for increased and different operations. Norway's offshore aquaculture has benefitted from synergies with capabilities already existing in its offshore energy sector. While Norwegian and other service providers can service an Icelandic offshore sector, in the medium to long term, Iceland would likely benefit from building these locally.

Like for the land-based sector, the government's role in monitoring developments and challenges is highly important for a developing offshore sector. However, by explicitly addressing offshore in its aquaculture strategy and attracting local development early on, Iceland can maximize the chance of successfully creating a robust offshore aquaculture sector.

8.5.4 Algae

Algae is a developing sector in Iceland. However, ambitions for the sector have not yet been defined, challenging certainty in investment and further development. Micro- and macroalgae segments share both similar and discrete challenges, creating the following key takeaways for Iceland:

A. Define a **comprehensive regulatory framework for algae** to provide clear guidelines for sector development. Algae should be explicitly included in Iceland's aquaculture strategy, with a specific framework outlining the value potential for algae as well as clear guidance for best practices in production and supply chains. This will give investors greater clarity on the future potential of the sector and allow them to develop without regulatory obstacles.

B. Support **local knowledge and talent development** for algae aquaculture. Iceland's algae sector can learn from other countries with established algae sectors. However, Iceland faces many specific local challenges which require local solutions. For example, local climate and environmental conditions will likely place Iceland at an advantage to produce specific species. In addition to increasing access to education specific for algae farming, the algae sector may also benefit from common or shared resources and infrastructure such as, processing facilities, and research labs to innovate on production processes and develop new value-added algae products.

C. Assess **algae-specific research and development incentives** (building on already existing innovation grants[431]) could encourage more rapid sector expansion. As the sector is in development, government leverage, for example through research and development can strengthen the sector's position.

Microalgae

D. Creating **standardization in output tracking and data sharing** could allow for greater understanding of sector dynamics and enable the government to better support sector development. Currently, data availability in the sector is lacking which creates challenges in monitoring which species are produced and in what quantities.

E. Assess the **potential future energy requirements** of the sector to help energy providers better plan for the sectors energy needs, including potential prioritization (see section 8.4.5). This will grant microalgae producers greater certainty in securing stable energy contracts and plan for potential future expansions.

Macroalgae

F. **Identify suitable locations** for macroalgae cultivation through a comprehensive biological assessment of ocean and coastal conditions. Research on suitable species, and associated biomass carrying capacities will inform the development of a licensing scheme for algae cultivation in Iceland. Preliminary analysis in this report suggests areas of primary and secondary interest to be further analyzed. A sector in development could benefit from existing wild harvest macroalgae processing infrastructure and find synergies with current salmon infrastructure.

[431] Examples include the tax incentives for green investments (5% discount on sustainable movable assets) and the innovation tax credit of 25%-35% of R&D costs

G. As current legislation does not license commercial cultivation, a **two-pronged seaweed-specific licensing process** could spur innovation and growth in the sector.

- **Temporary development licenses** at low or no cost could be granted to businesses to conduct research and trial the economic viability of their operations. Environmental assessments and surveillance should ensure that risks to surrounding ecosystems and marine activities are minimized.
- A **comprehensive streamlined licensing system**, created in consultation with relevant authorities, would give operators greater clarity to establish and invest in their businesses in the long-term. The design of this regulation/licensing system should start while development licenses are in operation, to not delay commercial scaling of operations.
- License and fee structure should consider limited margins and the need for a developmental period before financial viability is achieved, e.g., by having **low fixed license costs for production under specific volume**. This will enable smaller experimental projects as well as seaside farmers to establish operations.

8.5.5 Enablers

While the sector-specific considerations described earlier are important to unlock the potential of Iceland's aquaculture industry, there are several enablers that will be essential to supporting the industry overall. These include ensuring the governmental capacity to execute the suggestions presented in 8.1-4, facilitating and strengthening the value chain, maturing supporting infrastructure, and considering a central marketing role. These enablers are described in more detailed below, followed by some additional considerations that stretch beyond aquaculture.

Governmental capacity

The regulatory and governance changes proposed above ultimately require more from governmental agencies than current resourcing allows for, especially as this report suggests that each sector will benefit from its own licensing and partly tailored surveillance framework. Thus, the final suggestion for regulation is to ensure sufficient capacity to manage new regulatory and surveillance work. Here, some synergies with traditional aquaculture should be sought where tasks align, such as surveillance of fish health. However, separate standards are still expected to increase the total work involved for governing bodies, and different capabilities are needed across the sectors.

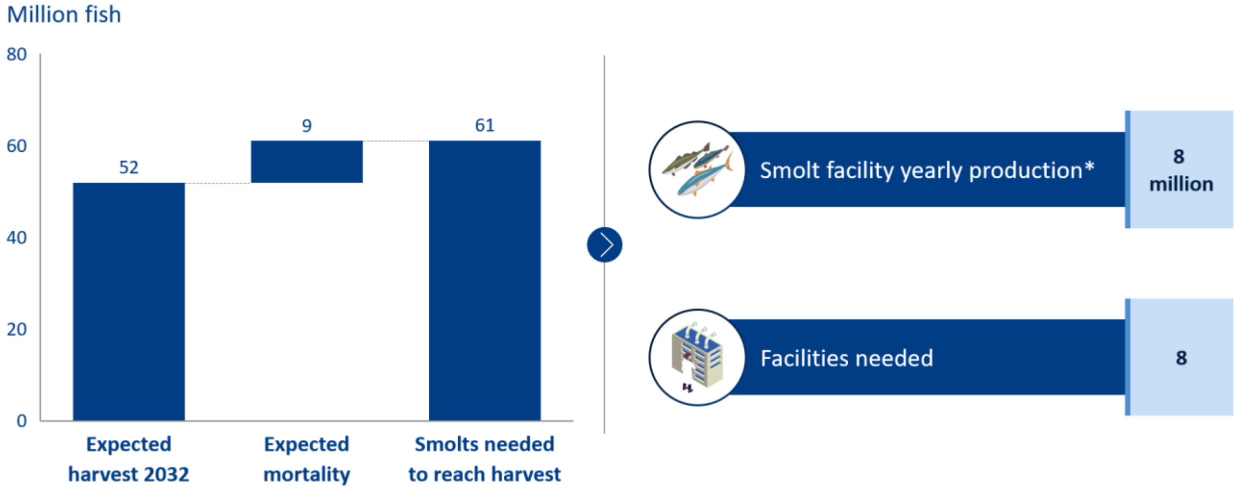
Value chain

Strengthening the value chain will be important to reach planned volume outputs of salmon by 2032. The local input sector also has the potential to grow, making the industry more sustainable, resilient, and creating more economic value.

Smolts

Smolts are an essential component of the fish aquaculture value chain. Figure 8.13 shows the estimated smolt facility requirements to accommodate the production volume assumed in the base case scenario.

FIGURE 8.13: REQUIRED SMOLT FACILITIES IN THE BASE CASE SCENARIO FOR 2032



Assumptions

15% mortality rate at sea; average harvest weight 4.5kg (WFE); smolt size of 250 grams
*Based on size of the smolt facility Sævareid Fiskeanlegg in Sævareid, Norway

Iceland will need to increase smolt production capacity to accommodate the large increase in farmed salmonoids. Smolts cannot be imported, therefore accommodating the projected total production in the base case scenario in 2032, means total smolt production capacity will need to be ~60 million fish by 2030. This equals 8 smolt facilities with a yearly production rate of ~8 million. Most farmers are however vertically integrated and produce smolts in-house to cater for their specific volume and secure own supply. Total production in 2021 was supported by these facilities, assuming they continue operations. Iceland will need to build 6 new smolt facilities with annual production capacity of ~8 million.

Municipalities can furthermore support the establishment of new facilities by ensuring effective processing of site applications. Government and municipal support therefore will likely take the form of streamlining processes and prioritizing the processing of smolt facility applications.

Feed

In the base case scenario, ~320kT of feed is needed to deliver on projected 2032 salmon output. While feed currently is imported from Norway, Iceland can invest in the production of local fish feed to internalize costs and produce locally, thus increasing value added in the Icelandic economy as well as reducing GHG emissions from transport from Norway. Scale is a key driver for financial competitiveness of a fish feed mill, with financial viability achieved with a yearly output of ~100kT. Such a factory can support annual salmon output of ~75kT. Based on volume projections in the base case and progressive scenarios, facilities could thus start operating from 2024 and scale up to reach up to 320kT and 560kT tons feed per year, respectively by 2032. At that scale, depending on feed mill size, Iceland will require 1-3 facilities to cover all salmon output.

Currently, plans to build a feed mill in Iceland are underway: Danish aquaculture feed company Biomar has announced plans to create a fish feed production site in Iceland in 2024 with Icelandic fishing and processing company Síldarvinnslan. Current offcuts from Síldarvinnslan's farming and processing activities will be used to produce fish meal and fish oil for aquaculture feed. Additionally, some Icelandic microalgae producers have expressed interest in producing feed inputs and could potentially benefit from synergies. This local feed capacity would lead to the creation of local jobs,[432] value contribution to GDP and potentially offering a lower-carbon input[433] compared to conventionally imported feed.

Infrastructure

Strong infrastructure can enable development and growth in the aquaculture industry. The future potential of the industry can be enabled with three key infrastructure considerations:

- Consider **aquaculture in the prioritization of energy**. Sustainable food production with green energy is an essential part of addressing major world challenges. Predictability around the access to energy will facilitate investment in the industry. It moreover creates a highly valued product that is likely to fetch premium prices, helping Icelandic aquaculture companies grow and prosper.
- Create a **single point of entry in terms of managing regulatory affairs related to aquaculture**. This can increase oversight, drive the speed of decision making as well as make processes smoother and easier to navigate for private players
- **Funding research facilities**, such as basins for growing fish and algae, in conjunction with a university, as well as laboratories and equipment. Publicly available research facilities accelerate the development of know-how and expertise that can both directly assist Icelandic companies in their development efforts and help attract investors searching for feasible locations for their businesses.
- **Increasing educational capacity** and building practical education pathways to cater for student interest and meet future labor demand from the industry. Plan long-term to cater for increased technical requirements for industry workers and focus on enabling scientists and research scholars to conduct research to advance knowledge. Look at opportunities in combining current centers of educational excellence across the Iceland from secondary to tertiary education to harness current capabilities.

Enabled by access to resources, best in class governance structure, strong research and education, Iceland can facilitate effective industry planning and lead in expertise and innovation within the sector.

Marketing

In other competing supply markets, common marketing efforts have proven to increase the value of aquaculture products. This an area where Iceland has experience from fisheries that can be leverage for aquaculture as well e.g., the 2020 “Seafood from Iceland” campaign in the UK.

Norway is one of the countries viewed as the most well-developed in this area, having invested heavily in marketing. The Ministry of Trade, Industry and Fisheries in Norway has established the Norwegian Seafood Council (NSC), which aims to increase the value of Norwegian seafood resources compared to other countries through market insights, market development and risk management. The council represents companies in the Norwegian seafood industry and is funded through fees levied on exports

[432] It is assumed that Biomar’s plant will use 30 jobs in 2024 and growing towards 50 over the following 2 years

[433] Through reducing transport emissions and incorporating algal-based inputs

of Norwegian seafood. By representing Norwegian seafood as a single entity, the creation of the NSC has encouraged Norwegian companies to work together to increase the value of their production.

Although there are several potential benefits to establishing a unified marketing organization for Icelandic salmon, the variation between aquaculture sectors can make this more challenging. For example, many land-based farmers in Iceland focus on the difference between their product and traditionally farmed salmon, aiming to earn a premium for features specifically tied to land-based products, such as assumed lower environmental footprint. Thus, while there is some level of internal competition between Icelandic aquaculture sectors, it can be difficult to establish a single umbrella organization for the industry. Still, there are many Icelandic-specific advantages that benefit all sectors, as discussed in section 8.1 and preceding chapters, and thus it is likely that there is still value to be gained by marketing the unique value of Icelandic salmon in the global market.

Beyond country-specific marketing, the salmon farming industry has also established several certifications that can attract a value premium. The Aquaculture Stewardship Council (ASC) and Global Aquaculture Alliance (GAA) manage the international salmon aquaculture sustainability standards. The GAA further certifies the Best Aquaculture Practices (BAP), which is a certification program that encompasses compliance with the Global Food Safety Initiative and the Global Sustainable Seafood Initiative.

In addition to these aquaculture certifications, some farmers aim for an even higher premium through organic certification, which in some markets has been estimated to achieve a premium of up to 20%.[434] As a global standard recognized by consumers, and with sustainable consumer choices on the rise, this can provide an opportunity for Icelandic salmon farmers to seek an additional premium. Additionally, with Iceland's growing algae sector, local organic inputs such as astaxanthin and algal omega-3 oils could supply the organic segment.

However, the role of the government could vary. Subject to competition authority approval, the government could initiate independent bodies, either to perform marketing and/or certifications, with operations funded by the private players. Another alternative, equally subject to competition authority approval, is private players initiating such bodies, potentially sector specific.

Additional considerations beyond the scope of this report

While this report centers on aquaculture, there are several considerations beyond the scope of this report that can have an important impact on the growth of the Icelandic aquaculture industry. Among these, two elements stand out for further consideration to maximize the value of Icelandic aquaculture:

- **Role of foreign labor and experts:** As described in this report, Iceland does not have the scale of expertise and labor as other aquaculture supplier markets. With a decisive effort to grow educational and research capacity, this will change over the next few years. In the meantime, it is however a significant risk that labor and expert shortages will become a constraint for growth.

[434] Department of Food and Resource Economics (IFRO), Copenhagen University (2016)

To grow the industry towards becoming an economic pillar for Iceland, it is therefore important to consider the role of foreign labor and experts.

- **Role of foreign direct investment:** The potential of aquaculture production in Iceland is high, but this will require a significant amount of investment. Some of this will likely need to come from outside of Iceland. Thus, Iceland must consider both the role of foreign direct investment especially when businesses consume common resources, if there is desire to and how to attract it.

These considerations require further analysis beyond the scope of this report but can be important factors in solidifying aquaculture's place as a key economic pillar of Iceland.

8.5.6 Sub-conclusion

Reaching Iceland's potential in aquaculture is contingent on targeted action to drive sustainable growth. These actions should be considered both at the sector level to optimize for specific regulatory needs, and holistically to enable the aquaculture industry to thrive within the ecosystem of Iceland. Collectively, regulatory changes should be formulated with a view on how they fit into Iceland's future aquaculture ambition as a whole and with the aim to balance environmental, societal, and economic impact.

8.6 Key challenges, risks and mitigators

While this report has identified a high value potential for aquaculture in Iceland, there are risks which must be considered to enable its success. In this section, these risks and potential mitigating actions are considered.

8.6.1 Traditional production

Traditional aquaculture is scaling and becoming more mature with higher production volumes. Risks are therefore primarily related to regulatory and environmental impacts, as well as Iceland specific limitations in licenses discussed in section 8.1. The main environmental, commercial, operational, and regulatory risks are described below:

- **Environmental risks** for traditional aquaculture center around the sea pens' interaction with the local environment. Biological challenges such as diseases can lead to mass mortality, impacting production and potentially wild stocks. Traditional aquaculture is still challenged with escapes that can lead to genetic introgression. Organic load and chemical substances from sea pens can also cause excessive pressure on the seabed if production areas are too concentrated. Finally, climate change can increase sea temperatures, which in turn can increase the presence of sea lice and diseases.
- **Commercial risks** can be driven by license costs in auctions as capacity reaches its maximum, provided farmers will compete for licenses and drive costs to unsustainably high levels, causing financial risk in case of a market downturn, e.g., if salmon prices fall.
- **Operational risks** stem mainly from human error, labor, and supply chain risks. Not following best practice procedures can lead to disease outbreaks or cause damage to pens resulting in escapes. Many farms are located away from population-dense areas risking access to labor with the right capabilities. Disruptions to supply chains can moreover lead to significant operational issues, e.g., access to feed, smolts and eggs.

- **Regulatory risks** are not only local, but also impacted by the dynamics of regulation in all supplier markets. The recent information of a potential resource rent tax in Norway may, as an example, increase Iceland's competitiveness, and similarly legislations benefitting farmers in other markets may have the opposite impact on Iceland. Additionally, regulatory amendments negatively impacting on traditional aquaculture can have a positive impact on growth of other sectors governed by different regulations.

There are several actions that can be taken to mitigate these risks. To limit the risk of disease outbreaks, Iceland can enhance biosecurity by increasing requirements on farmer's internal monitoring, contingency plans, and government surveillance. Additionally, outbreaks can be contained more quickly with an increase in sampling or screening for diseases, a streamlined process for sea lice treatments, and clear reaction guidance in case of diseases. Preventative measures such as vaccination have the potential to mitigate ISA. To protect the seabed and limit biological challenges, Iceland can further implement incentives e.g., with lower taxes, fees or license cost provided companies apply current or develop new technology with less impact on the environment.

8.6.2 Land-based production

Compared to traditional aquaculture, land-based aquaculture's biggest risks to production stem from the relatively nascent stage of the industry, without proven experience at a large (+10kT scale). At this stage, with several companies working to develop their own technologies and best practices forming, technological failure is a large risk driver. Technology is therefore the root of many environmental, commercial, and operational risks.

- **Environmental risks** mainly stem from failures in equipment and technology, as well as the associated failures involving human error (which can be exacerbated by unfamiliar technology). The primary risks center around water and energy consumption. While seawater is available in vast quantities, the expansion of land-based aquaculture according to current plans involve drilling and pumping up vast quantities of seawater, thus it is not possible to rule out unknown consequences to the water supply or the structure of the volcanic bedrock. Once the saltwater has served its purpose, filtration and wastewater disposal might carry risks until the technology has been proven. Energy consumption in Iceland has limited environmental impact due to the availability of renewable energy, but poses a supply risk, as discussed below.
- **Commercial risks** are driven by funding and demand for premium products, as well as being impacted by technological challenges. If the technology does not work as expected, this threatens the commercial viability of land-based ventures. Furthermore, funding is a key resource when developing new technologies, and so a lack of funding slows down technological progress. In addition, there is a risk that land-based farms will not realize the premium they aspire to, due to growth in land-based supply. Land-based farms situated closer to or in key end consumer markets (such as the USA) may also have a competitive edge due to lower transportation fees.
- **Operational risks** center around supply chain, technology, and labor inputs, which all are essential for production. While many land-based farms are vertically integrated through the smolt or hatchery phase, a lack of long-term supply contracts for inputs such as energy and feed could limit the scaling of operations. Increased capacity in the energy transmission infrastructure is needed in some locations, however it is not expected to constrain growth in the short term. Transmission infrastructure needs should be mapped, and investments made to fulfil

those needs. Labor and expertise, as the other key inputs, poses a risk. Although Iceland is in many ways a leading nation in land-based aquaculture, the expected growth will require scaling of that expertise. Given the nascent nature of much of the technology applied, it is likely that expertise will largely need to grow organically within the land-based operators. However there are naturally similarities with other sectors where due to the size of the current industry Iceland does not have the same scale as other nations. Lack of access to the number of people required can leave Icelandic farms at a disadvantage if they are unable to develop and attract the right expertise. Finally, technology again plays a role as technological challenges can create operational bottlenecks.

- **Regulatory risks** for land-based aquaculture can come both from targeted government action and lack thereof. If regulation for land-based aquaculture remains tied to that of traditional, Iceland risks its attractiveness as a land-based farming location, falling behind other markets where these processes are optimized. At the same time, if in the process of creating a land-based-specific licensing framework, Iceland's regulation becomes much more restrictive than other markets, this can have the same effect.

There are several actions that can be taken to mitigate these risks. To ensure high environmental standards in land-based aquaculture, technical standards can be enforced. These might include, for example, a requirement to follow certain technical specifications, to have a maintenance plan approved, to have key equipment such as filters regularly tested, to perform regular risk assessments and ensure clear and actionable contingency plans for any operational disruptions. Similarly, surveillance and monitoring of fish health and organic discharge can help mitigate risk to fish welfare and the environment. At the same time, to support commercial success, Iceland can ensure that conditions are attractive for investment (including foreign) and developmental research. Marketing assistance, as described in section 8.5.3, can also help in developing a green premium on price. The governance of energy can mitigate some supply risk, although each supply input should be considered and evaluated. Finally, with regards to regulatory risk, Iceland should find a balance between over- and under-regulation by reviewing the land-based licensing process with both the environment and competitiveness in mind.

8.6.3 Offshore production

Like the land-based sector, offshore aquaculture's biggest risks stem from the nascent stage of the industry. As such, these risks center around technology and regulation, both of which impact appetite for funding.

- **Environmental risks** for offshore are similar to those for traditional farming, though expected to be less severe as potential fish escapes occur farther from salmon rivers and waste is more quickly dispersed and diluted. However, the larger sites planned for offshore farming can cause higher volume escapes, especially as they are typically exposed to a harsher environment.
- **Commercial risks** center around funding, which is impacted by technology and regulation. If technology does not work as expected, this threatens the commercial viability of an offshore venture. Additionally, the lack of planning and regulatory frameworks around the nascent industries can make investors hesitant to invest at the levels required to set up offshore farms.
- **Operational risks** center around the availability of infrastructure and labor, as well as functioning technology. Special infrastructure is required to service offshore, e.g., offshore support vessels and labor with new capabilities. Here, offshore has the capability to overlap with

the offshore energy sector. However, this sector is also not currently established in Iceland. Technology is again an underlying risk to operations, as the technological requirements are different than in traditional aquaculture to sustain exposure to the open seas. As structures have not yet been built for offshore farming beyond near-shore facilities, it is possible that it will take time until designs will be able to withstand the more extreme weather conditions.

- **Regulatory risks** for offshore farming mainly stem from inaction on the government's part. As made clear in Chapter 6 and section 8.4.3, clear regulation of the offshore industry, including expected fees required for licenses, can provide more certainty to investors considering the high investment needed of offshore. Thus, in the absence of regulatory certainty, the risk of investing in offshore in Iceland may be considered too high.

There are several actions that can be taken to mitigate these risks. Similarly to land-based aquaculture, governments can mitigate some of the technological and environmental risk by instituting high technical standards and regular monitoring. Additionally, the cost of a license can be used to offset the significant investment needs compared to traditional farming. This can help mitigate funding needs and enable the technology development required for operations to reach a commercial scale. An example of a promising technology, being tested at scale to prevent escapes are double-nets. Additionally, early introduction of regulatory frameworks and development licenses (as discussed in section 8.4) can create certainty and predictability among private players and investors. Given complementarity of assets and capabilities, fish farmers can seek partnerships with offshore solution providers to mitigate the risk of Icelandic offshore infrastructure not being developed in time. Finally, the primary regulatory risk is that of inaction, this can be mitigated with focused attention to the regulation and planning of offshore aqucalutre and clear, public statements on government intentions to establish the sector in Iceland.

8.5.4 Algae production

Algae production in Iceland faces many unknowns due to the developing state of the sector. Like both land-based and offshore salmon production, this is reflected in challenges that must be addressed to seize the opportunities outlined in section 7.4.

- **Environmental risks** of algae production differ between micro- and macroalgae. Microalgae production requires primary inputs such as energy and freshwater. Despite Iceland having advantages from renewable geothermal and hydropower, competition with other industries for access to these resources can pose a risk as discussed further below. Large scale consumption of freshwater may also impact local reserves. For macroalgae cultivation, one of the greatest risks is potential genetic contamination of wild stocks and alteration of local ecosystems dynamics.
- **Commercial risks** center around the limited demonstration of large-scale commercial viability in Iceland to date. The sector is limited by the collection of reliable and accessible data on different algal strains, processing methods, and their potential. This may result in investor risk and companies being challenged in attracting funding. The sector for both micro- and macroalgae is a highly competitive space putting Iceland at a scale disadvantage when competing with mass market producers. Macroalgae markets are dominated by Asian producers typically operating at low margins, creating questions about Iceland's ability to compete with high labor costs. Icelandic producers will therefore need to identify niche target markets which play to its advantages. In macroalgae, the absence of regulation for commercial cultivation has created uncertainty and halted developments beyond the experimental level.

- **Operational risks** center around labor and technology. Historically, Iceland has not had established research bodies for knowledge sharing on algae farming. This has resulted in pockets of, rather than widespread local knowledge and skill in the field, creating demand for imported labor and skills. As an example, some producers have hoped to develop operations focusing on creating biofuels from algae, however further research is still required to understand its practical potential. In macroalgae, local species populations and their associated ocean-based cultivation structures will likely differ from neighboring algae producing countries as Iceland faces harsher ocean conditions, calling for local knowledge and expertise to be established.
- **Regulatory risks** of algae production differ between micro- and macroalgae. For microalgae, current regulation governing production is not seen as a barrier to expansion. For macroalgae, the creation of a two-pronged license process may interfere with the wild harvesting segment or its processes if not thoroughly considered. Finally, high license costs and fees for a developing industry might render it unable to scale as projects do not have the means to be self-sufficient.

There are several actions that can be taken to mitigate these risks. Consultation with the relevant authorities, municipalities, producers, and research bodies could minimize environmental and regulatory risks. Strengthening of centralized platforms along with well design regulatory frameworks can help establish clear best practices for the sector, help build market intelligence and reduce commercial uncertainty. For macroalgae, the initial development licensing scheme for macroalgae could allow for further knowledge and skills to be developed ahead of large-scale investments. Algae could leverage and build upon existing synergies with the fish aquaculture sector in terms of infrastructure and inputs support parallel growth in the sectors.

8.6.4 Macro risks

In addition to the risks within the industry, there are several risks on a macro level that can have a significant impact on the industry. These are numerous, but the key risks center around demand, which can be affected by alternatives to traditional protein, as well as supply, of which feed and egg supply may become constrained while climate change may change growing conditions. Finally unfavorable economic conditions may simultaneously affect both supply and demand.

Demand

- Although global demand for protein is rising, and salmon provides an attractive source as discussed in Chapter 3, it is possible that **alternative proteins** can over time **substitute** fish protein. These include products such as plant-based proteins, as well as artificial meat, which however needs to become competitive in price and nutritional quality as well as adopted by consumers at scale.[435]

Supply

- In the current market, where growth in supply from traditional aquaculture is relatively constraint by natural conditions, industry players are looking towards new production methods, i.e., land-based, and offshore aquaculture. This is also the case for Icelandic players who seek to

[435] SingularityHub (2020); This startup is growing sushi grade salmon from cells in a lab

benefit natural conditions. It is possible that certain breakthroughs in technology may reduce the competitive advantage based on those conditions and lead to significant growth in production in other parts of the world. This will inevitably put pressure on current market prices that may constrain value creation from Icelandic aquaculture.

Inputs

- Salmon farming relies on the supply of **salmon eggs**, and all Icelandic salmon farmers source these eggs from the Benchmark Genetics located in Iceland. Thus, there is an inherent supply risk in case this company **cannot supply fast enough** to match the projected growth of the industry. In addition, any event that impacts Benchmark Genetics (from natural to commercial) and reduces their production output will have a direct impact on their buyers and the industry's growth. Moreover, Iceland cannot readily import eggs from other geographies such as Norway due to legislative restrictions.
- Growing salmon requires significant feedstuff, and **salmon require high protein feed** of which most of its content are plant-based (see Chapter 3). However **globally, competition for protein-sources for feed is significant,**[436] which may risk the supply certainty of salmonoid feed as well as the price of it.
- **Climate change may change the natural environments of which salmon farming depend**, including potential changes to temperature, storm strength and prevalence as well as other indirect effects on fish health and growth.

Economic

- Unfavorable economic conditions can result in a **lack of financing**, which would particularly hurt the **high-investment** sectors including **land-based** and **offshore** aquaculture, as well as macroalgae requiring medium to long term startup capital prior to reaching commercial scale. Negative developments in the global economy can impact **interest rates** and **salmon prices** which will threaten highly levered operations.
- The **Icelandic Króna**, due to its size is exposed to volatility against larger currencies relevant to both inputs and sales (e.g., EUR, USD). This effect is however to a large extent naturally hedged as most of the production is exported.

Mitigating macro-risks are inherently challenging, farmers can hedge some of these risks, e.g., against currency exchange risks and by carefully monitoring the leverage of their balance sheets. Natural and consumer driven risks are however harder to mitigate. In terms of supply risk, inventory strategy can be used as a tool to avoid short-term disruptions yet cannot solve medium to long-term structural challenges. Iceland can however and should consider, partly hedging its industry wide risk by balancing exposure across the aquaculture sectors.

8.6.5 Sub-conclusion

Like with any ambition, the growth of the aquaculture industry in Iceland carries risks. Key risks include environmental risks, such as excessive environmental impact and climate change. There are also

[436] FAO (2022)

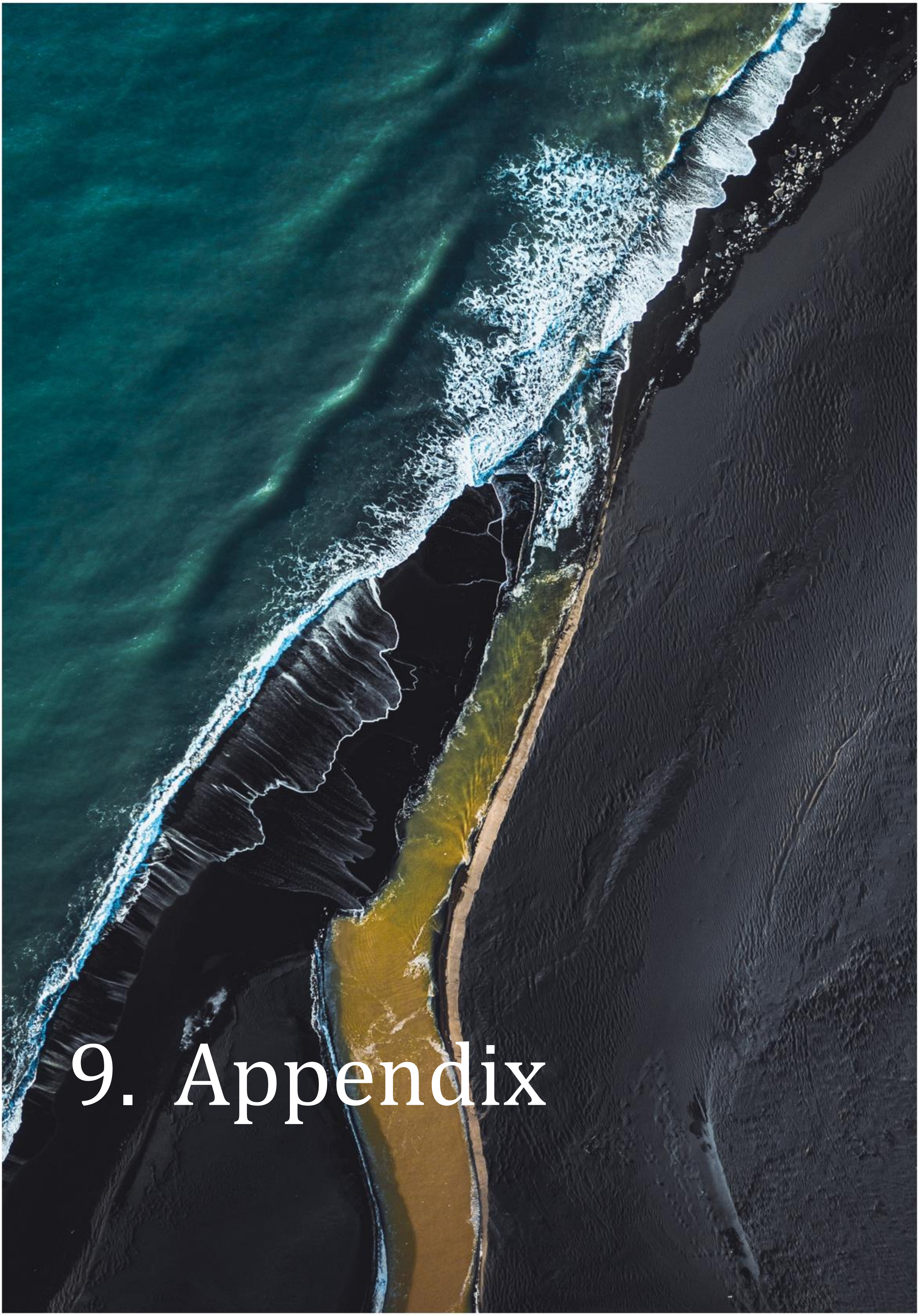
commercial risks, which again are impacted by macro conditions such as economic downturns and the level of industry competition. Operational risks are e.g., around supply, and for the newer sectors, also related to technology and infrastructure. Finally, regulatory dynamics are complex in an evolving industry, changes, both within and outside of Iceland, impact the aquaculture industry has a whole. By keeping these risks in mind, Iceland can take proactive action mitigate their likelihood and limit their effects.

8.7 Conclusion: Aquaculture can become a new economic pillar in Iceland

This chapter has covered one of the key objectives of this report, to provide a perspective on the future economic value potential of aquaculture in Iceland. This analysis has demonstrated that aquaculture holds the potential to become an additional economic pillar of Iceland, with an estimated sales value of ~1-3bn EUR and tax revenues of ~205–570m EUR in 2032. In the base case scenario, with a total production volume of ~245kT salmonoids and ~180kT algae, the economic value generated amounts to ~1.7bn EUR sales value (~240bn ISK), which can amount to as much as ~6% of GDP and deliver ~335m EUR (~47bn ISK) in taxes and fees.

The details of the preceding chapters have provided insights related to the status and outlook for each sector. These insights inform and contextualize the economic value projected in this final chapter. Altogether, this report thus provides a holistic view and illustrates how each sector of aquaculture has the potential to grow in Iceland.

For that potential to be realized, this chapter furthermore brings forward considerations for regulators. Building upon these considerations, environmental, social, and economic factors need to be carefully evaluated and political decisions made based on priorities. This includes balancing key factors such as environmental protection, direct economic output, societal impact, and value distribution. Prior to such analysis and prioritization, clear recommendations cannot be brought forward. Consequently, this report has focused on creating an option space, bringing forward considerations and levers to provide a foundation for developing a comprehensive policy that promotes a sustainable future for Icelandic aquaculture.



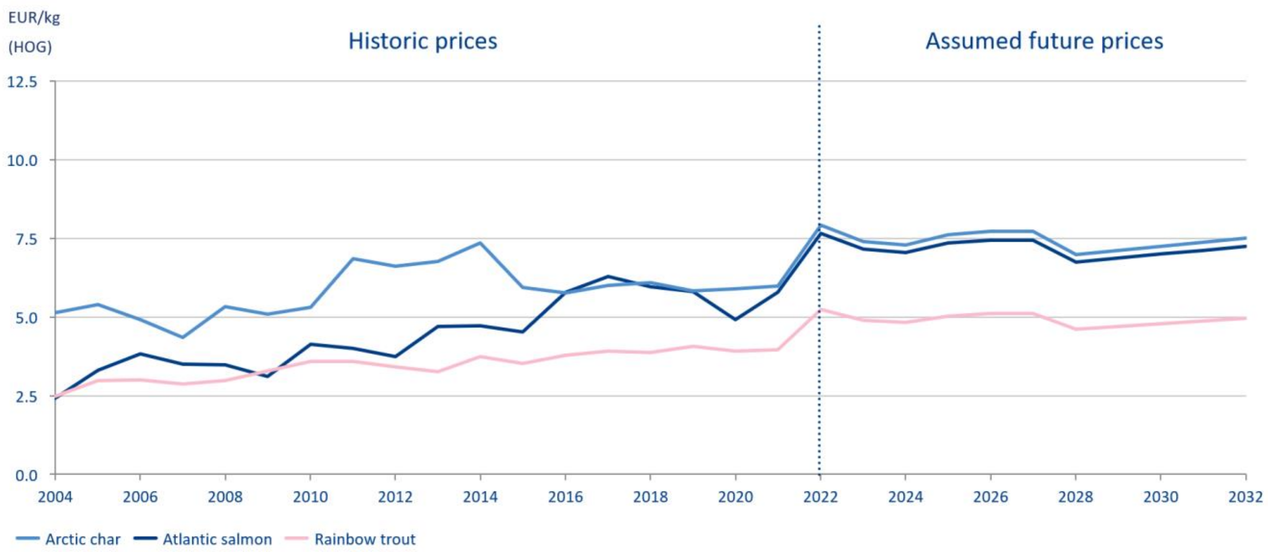
9. Appendix

9.1 Price development

Salmonoid prices (Nasdaq spot prices) are assumed be in the range of 66 to 73 between 2023 and 2028 after which they are assumed to increase at a constant rate of 1.9%, which is close to average historical inflation.[437] The difference between the spot price and the export price (FOB) is assumed to be 1.4 NOK/kg (2019-2021 average). A fixed NOK/EUR exchange rate of 9.99 is assumed.

Compared to salmon, Arctic char has in recent years attracted a price premium of 4%, while salmon has attracted a price premium to Rainbow Trout of around 40%. These ratios are assumed to persist through to 2032.

FIGURE 9.1: HISTORICAL AND PROJECTED SALMONOID PRICE DEVELOPMENT[438]



For the **algae sector, constant prices** over the scenarios and period were conservatively assumed due to historical data on price trends being limited. Prices used were inferred by dividing total current sales values by output sold. For microalgae prices range from ~16k EUR/ton for lower-value species such as Spirulina to ~7m EUR/ton for high value products such as astaxanthin. For macroalgae, prices fall between ~120-700 EUR/ton depending on species. Prices are benchmarked against external sources to ensure they fall in line with the typical price ranges for different species. [439]

[437] Kepler Cheuvreux

[438] FAO; BCG analysis

[439] Skatturinn; Araujo et al. 2021; FAO; Van den Burg et al. 2016

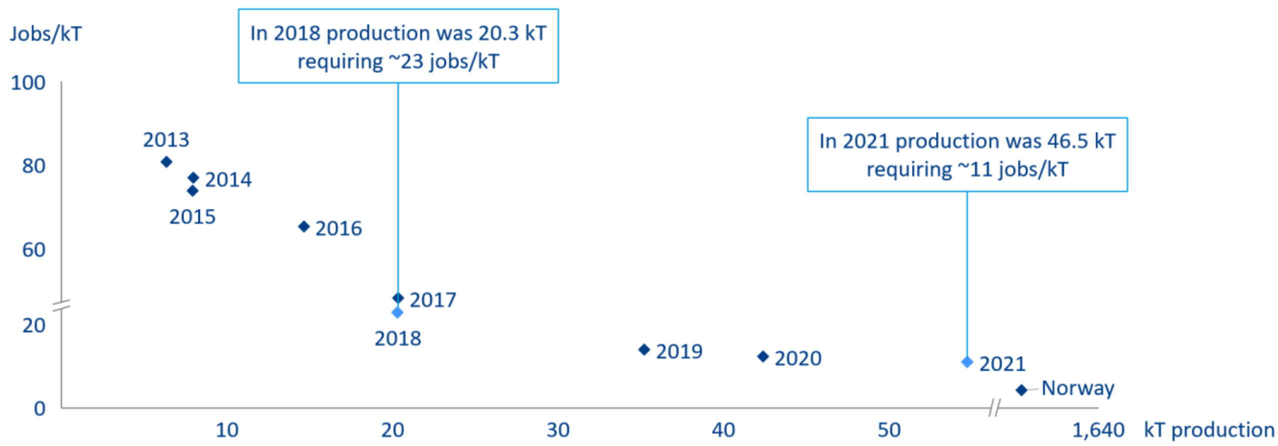
9.2 Jobs per kT

9.2.1 Direct jobs - salmonoids

Farming jobs

New industry jobs will be created with growth in volume. As Icelandic aquaculture is relatively nascent and scale of production is low compared to countries like Norway, Chile and Scotland, labor productivity is assumed to increase with production. This growth in productivity is already starting to materialize, in 2018, Iceland had 464 people who received salaries directly from activities associated with traditional fish farming which amounted to ~23 employees per kT production, in 2021 that number had decreased to ~11 employees per kT.[440] This highlights a substantial increase in labor productivity, in line with what has been experienced in other countries. The historical trend for Iceland is depicted in Figure 9.2. Naturally there are more jobs as the first few generations of salmon or being grown out and harvested due to fixed overhead and development work. As production reaches industrial scale the productivity growth tapers off but continues to some extent.

FIGURE 9.2: PRODUCTIVITY CURVE OF FARMING JOBS CREATED BY SALMONOID OUTPUT[441]



In line with this logic, it is assumed that employees directly receiving salaries from traditional salmonoid farmers will reach **~6.8 jobs/kT in 2032**. As highlighted in chapter 5, land-based farming will develop in similar fashion but is assumed to be have higher levels of automation, and the number of farming jobs in relation to kT is assumed to be half of those for traditional farming or **~3.4 jobs/kT in 2032**. Offshore aquaculture is assumed to have the same labor productivity as traditional farming.

Supporting jobs

Growth in aquaculture production has been shown to lead to the creation of new servicing jobs, e.g., equipment operation and maintenance, transportation, site construction, marketing etc. Based on

[440] Iceland statistics; FAO; BCG analysis

[441] Iceland statistics; Norwegian Sea Council; BCG analysis

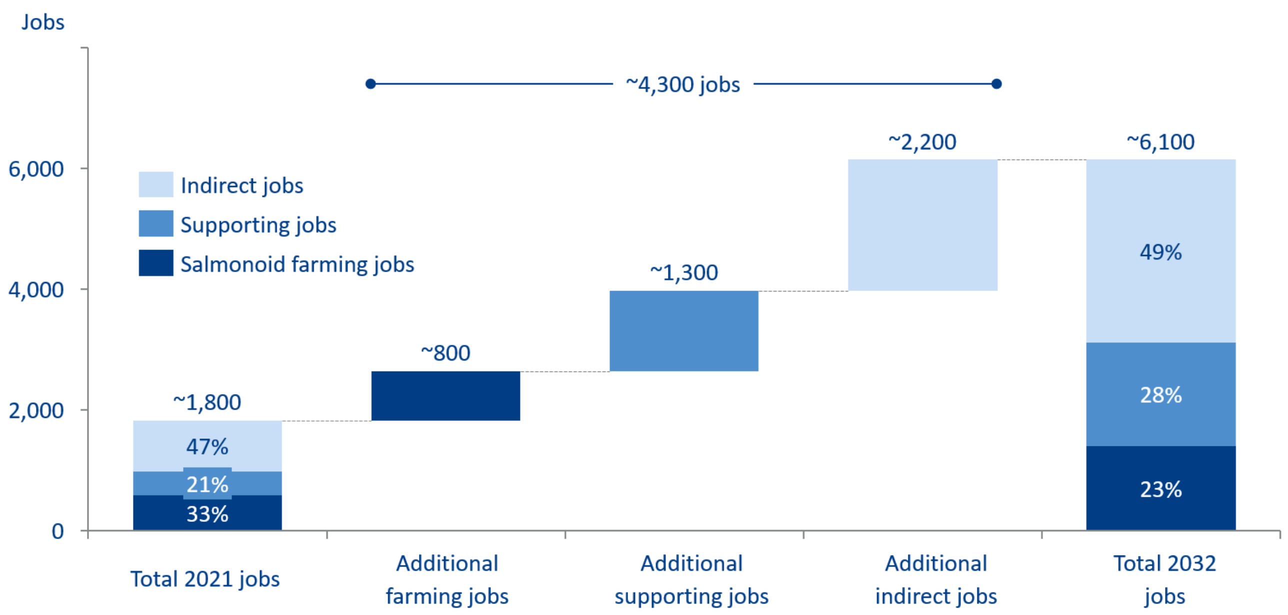
industry research from Norway,[442] it is assumed that **~7.0 jobs/kT** are created. This ratio is held constant across the fish farming sectors (traditional, land-based, and offshore). This number is higher in Norway because Norway e.g., produces much of the fish feed used by Norwegian farmers and has more processing jobs related to aquaculture. Plans have been made to produce feed in Iceland which could amount to as much as 50 jobs by 2026 and it assumed over time that more parts of the value chain will be carried out locally as the industry matures. The ratio of supporting jobs per kT production is due to this not assumed to decay with kT growth, in contrast to farming jobs.

9.2.2 Indirect jobs – salmonoids

Besides supporting jobs, the aquaculture industry also creates **indirect jobs**, such as public administration and service, legal and accounting services, financial intermediation etc. The number of indirect jobs is assumed to scale with direct jobs and reach **~12 jobs/kT** by 2032.

The new salmonid farming jobs (both direct and indirect) are gross figures and may not represent net new jobs as workers filling these roles may leave other industries. The total number of jobs created by salmonoid production in the base case scenario can be seen in Figure 9.2.

FIGURE 9.3: JOB CREATION BETWEEN 2021 AND 2032 IN SALMONOID PRODUCTION (BASE CASE SCENARIO) [443]



9.2.3 Algae jobs

Due to the different nature of micro- and macroalgae, job creation in the different sectors is considered separately.

[442] Menon

[443] Menon; Marine policy – Eoin Grealis et al. 2017; Directorate of Fisheries in Norway; Hagstofa Íslands; SFS; Regional Development Agency and the National Association of Fish Farms; Iceland Statistics; BCG analysis

Microalgae

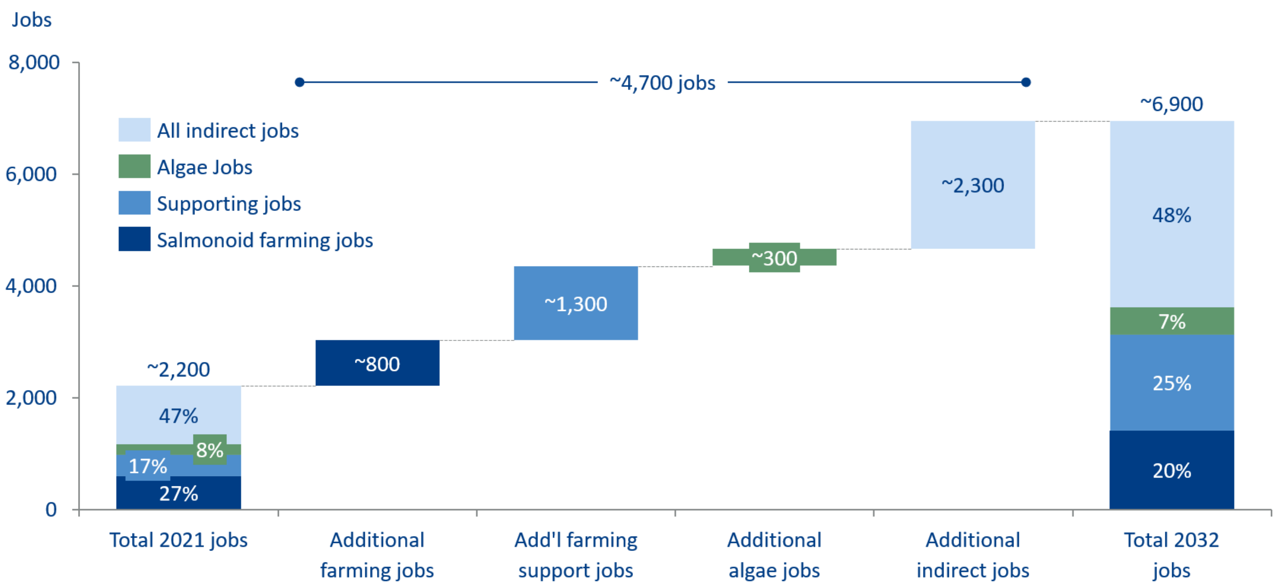
Employment within algae production in Iceland is mainly driven by the production of astaxanthin and Spirulina and employment is assumed to increase according to the job/ton ratio experienced by the two largest producers. The jobs per ton of produced microalgae in Iceland depend on the split between these two species as it generally takes more labor to produce astaxanthin which is a higher value product. In 2021, there were ~0.6 jobs/ton of produced microalgae. This is assumed to decrease towards **~0.1-0.3 jobs/ton** depending on scenario due to assumed labor productivity increases with production growth. Conservatively, no indirect jobs are assumed as the segment is largely vertically integrated.

Macroalgae

For macroalgae, as limited information is available on job trends in the European algae sector, labor productivity is assumed to be constant at **~1 direct job/kT** throughout the period, based on a weighted average of direct jobs required to produce different species. The assumption is based on information from the largest producer in Iceland and sector standards for brown and red algae.[444] The number of **indirect jobs is ~1.75 jobs/kT** following segment standards.[445]

Figure 9.4 includes the number of algae farming jobs created and shows the split of ~4,700 jobs added to the aquaculture industry by 2032 in the base case scenario.

FIGURE 9.4: COMPOSITION OF INCREMENTAL JOB GROWTH BETWEEN 2021 AND 2032 (BASE CASE SCENARIO)[446]



[444] The number of direct jobs is ~0.35 jobs/kT for red calcareous and ~2.7 jobs/kT for brown and red algae

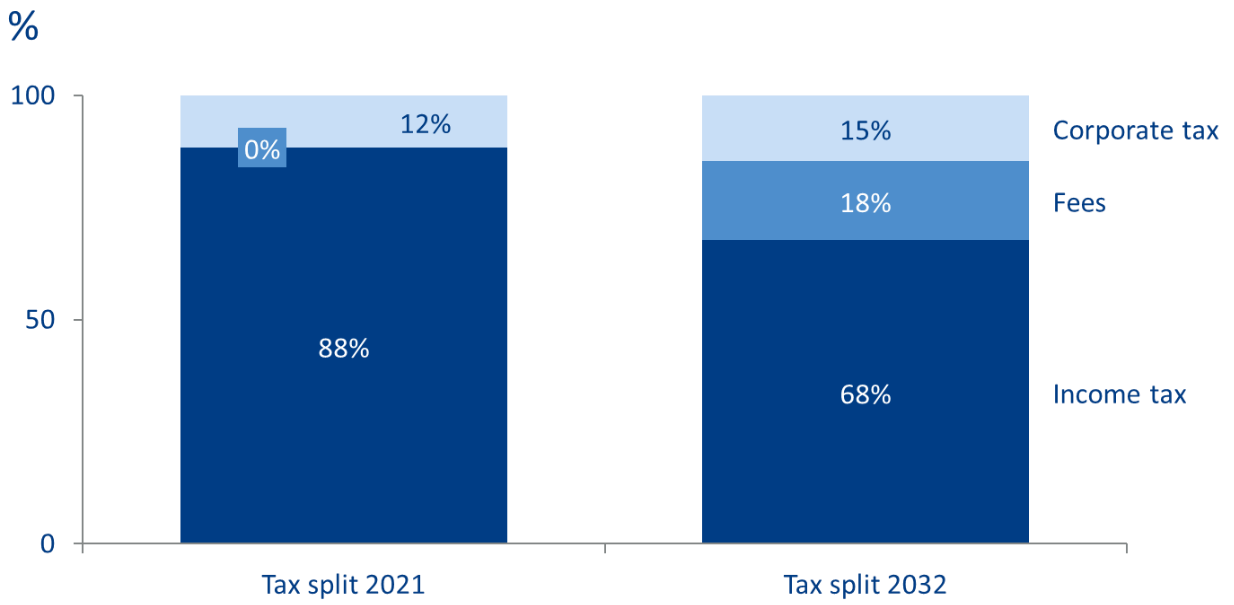
[445] Seaweed for Europe; Orbis; Skatturinn; Marine and Freshwater Institute; company websites

[446] Menon; Marine policy – Eoin Grealis et al. 2017; Norwegian Seafood Council; Skatturinn; Araujo et al. 2021; Ministry of Industries and Innovation; FAO; Van den Burg et al. 2016; Company websites; Marigot Group Ldt.; Singularity Hub; Marine and Freshwater Institute; Seaweed for Europe; Vázquez-Romero et al. 2022; Directorate of Fisheries in Norway; Hagstofa Íslands; Regional Development Agency and the National Association of Fish Farms; Iceland Statistics; BCG analysis

9.3 Tax revenue

Growth in the industry will create taxes and fees through new jobs and profitable corporate growth. Figure 9.5 demonstrates how taxes are assumed to be split between income tax, industry fees and corporate tax.

FIGURE 9.5: COMPOSITION OF TAX REVENUE 2021 AND 2032 (BASE CASE SCENARIO)



9.3.1 Income tax

Tax revenue is based on the **current aquaculture industry average salary** of 9.21m ISK a year,[447] assuming salaries will increase by 3% per year due to inflation and GDP.[448] An effective tax rate of 35.9% was applied, following current Icelandic income tax rates.

9.3.2 Corporate tax

Salmon farmers have only once in the period 2014 – 2020 filed positive taxable net income.[449] It is conservatively assumed that corporate tax income will remain close to zero until 2025. Thereafter, positive reported earnings are expected to gradually increase to industry average of ~30% EBIT (before fees) towards 2032.[450] Fees are tax deductible and are subtracted before corporate tax is calculated. Corporate tax is assumed to stay constant at 20% throughout the period.

[447] Not including pension and insurance; Source: Radarinn

[448] Assuming labor share of GDP to be constant throughout the period. 3% is based on 1,5% inflation plus 1,5% GDP growth

[449] Hagstofa Íslands

[450] BCG analysis

9.3.3 Fees

As described in section 4.4, salmon farmers are subject to pay several fees. Fees are charged either based on harvested weight, average market prices and maximum biomass allowed in licenses. The production fee is the largest share of total fees paid. It is assumed that the price of salmon will be higher than 4.8 EUR/kg throughout the period and the production fee increases in even steps from currently 1% in 2021 to 3.5% in 2026. Included in the calculations is the fee rebate of 50% for Rainbow trout and production fee exemption for Arctic char. The rebate of environmental fee applicable to production in closed cages are not accounted for.

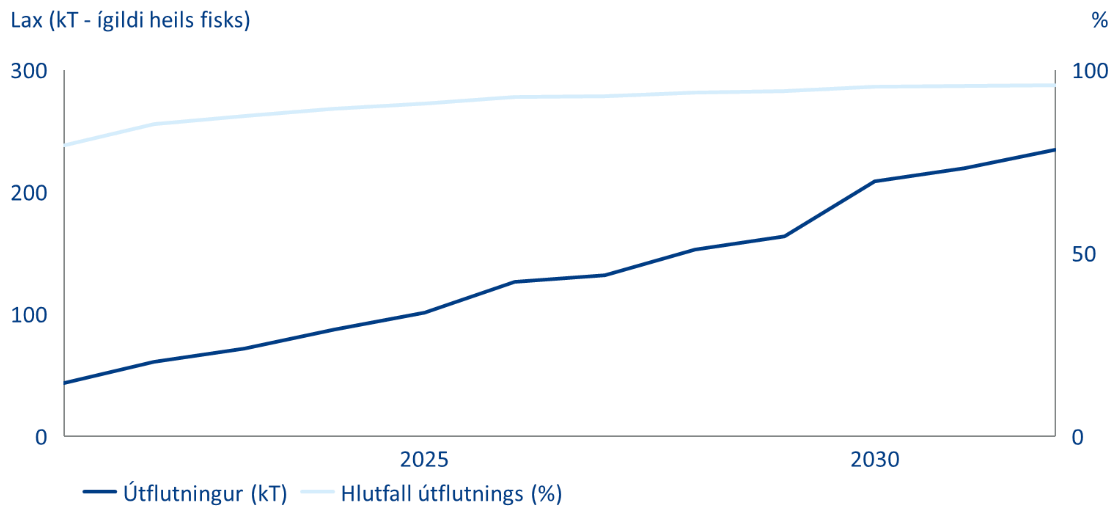
Besides the production fee, Iceland also charges a harbor fee (on all species) and an environmental fee based on the maximum allowed biomass. The rate of the harbor fee is 0.7% while the environmental fee is set at 20 SDR multiplied by the total biomass of each license. The SDR exchange rate is assumed to be 1,235 EUR per SDR (see section 4.4 for further details regarding Icelandic salmonoid fees).

9.4 Export share

Today a total of 9.6kT of fish farmed fish is consumed in Iceland (production minus export).[451] It is assumed that the absolute domestic consumption of farmed fish per person stays constant over the period.

As domestic consumption is assumed to stay constant, the export share will gradually increase with production growth. In 2021, ~80% of farmed salmonoids were exported, by 2032, in the base case scenario, the export ratio is assumed to be ~95%. Algae export share is assumed to be 99%. Figure 9.6 shows the amount of salmonoid exported in kT and export share for the base case scenario.

FIGURE 9.6: EXPORT AND EXPORT SHARE OF TOTAL PRODUCTION BETWEEN 2021 AND 2032 (BASE CASE SCENARIO)



[451] FAO, Iceland statistics, BCG analysis

9.5 Processing composition

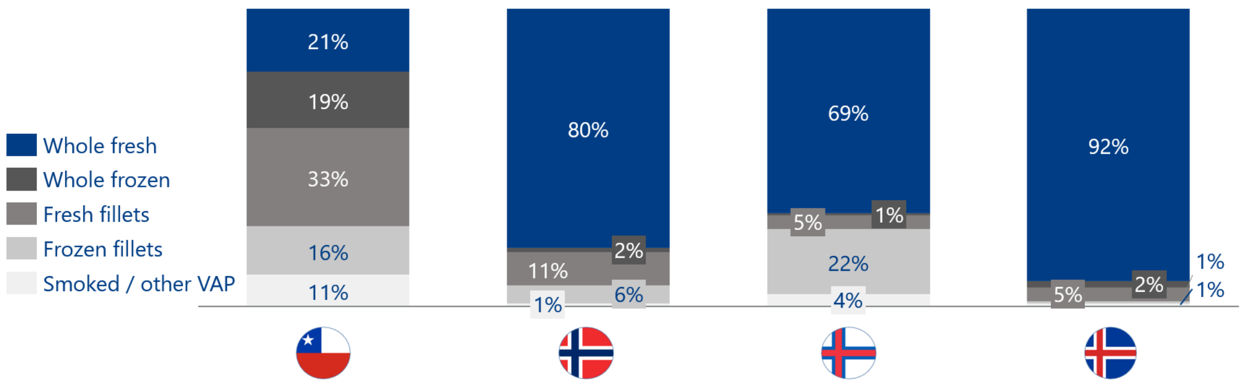
Today, Iceland lags other markets in terms of the proportion of processed salmon exported. Chile currently has the highest proportion of secondary processing. To extract the highest amount of value from local production the industry must weigh pricing dynamics on fresh, frozen, and processed salmon. The amount of processing in Iceland has been close to constant at ~1.4kT from 2016-2020.[452] It is assumed that this amount stays constant throughout the projected period. Icelandic farmers should however consider the option of doing more processing in Iceland as this is likely to create more value and increase the sustainability of production.

Fish are generally exported after having undergone five different processing options. These are:

- Fresh whole (only gutting)
- Frozen whole (only gutting)
- Fresh fileted
- Frozen fileted
- Smoked/other value-added processing

As seen in Figure 9.7, the 1.4kT of processed salmon corresponds to ~6% of Icelandic exported salmonoids in 2019 and 2020 and the bulk are sold as cooled fresh whole salmon.

FIGURE 9.7: PROCESSING OF FARMED ATLANTIC SALMON EXPORTS IN SELECT MARKETS (2019-2020 AVG.)[453]



With Icelandic most end consumers being on both sides of the Atlantic, exports require relatively high transport time. This imposes limitations to the possibilities of processing in Iceland. Fresh salmon have a shelf life of ~11 days, meaning that the product must be transported relatively quickly to the end destination.[454] Furthermore, salmon enters a rigor mortis state within 20 hours, in which the salmon becomes stiff and is more difficult to handle. Salmon can stay in this state for several days before it

[452] Statistics Iceland; BCG analysis

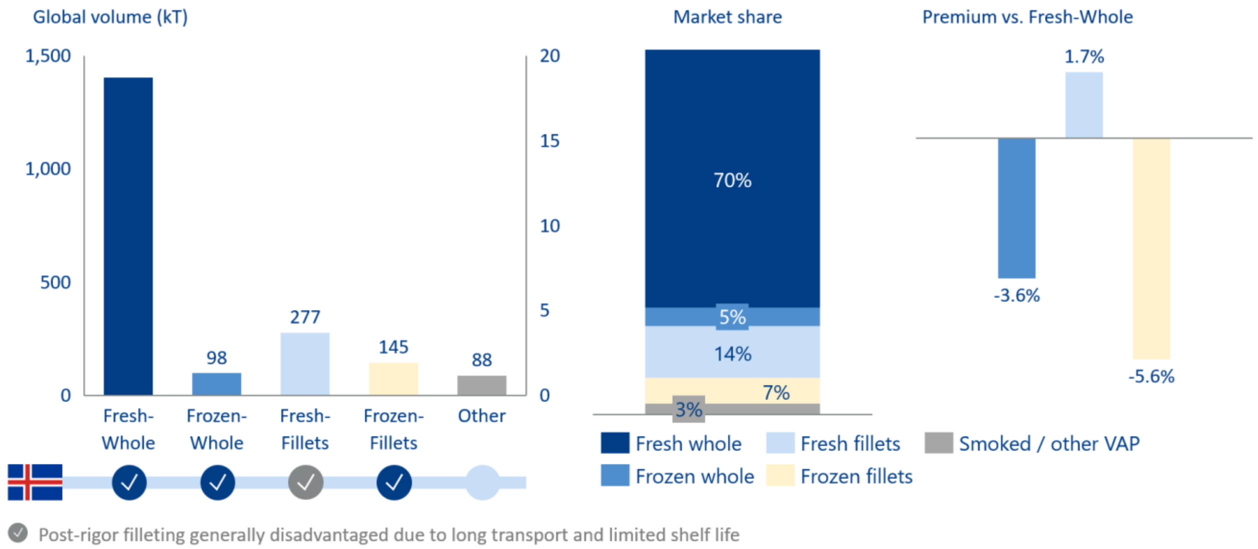
[453] Kontali, Norwegian Statistics, BCG analysis

[454] J. Taveres et al. 2021

returns to its limp state.[455] It is therefore optimal to transport the salmon during the rigor state to maximize time at the end-destination.

Despite these constraints, Icelandic salmon farmers can do pre-rigor filleting of fresh salmon or pursue other value adding processing for the frozen segment. Nevertheless, current export prices show that the price of fresh salmon and other fresh products is generally on par when accounting for differences in product weight, while frozen products are generally associated with a price discount as seen in Figure 9.8. This implies that the advantage of doing more processing in Iceland is mostly driven by lower transport costs due to processed fish having lower product weight and offcuts that can be sold for other uses e.g., the production of oil and gelatin.[456] Frozen salmon, although generally seen as an inferior product, that can be used for effective supply management i.e., the salmon is frozen when prices are low, and sold when prices are high.[457]

FIGURE 9.8: GLOBAL PRODUCTION AND PRICE PREMIUMS[458]



Although there might be a case for doing more processing in Iceland e.g., pre-rigor filleting, the benefits of doing so (such as lower transport costs and the sale of off-cuts) and the investment costs must be weighed against investment opportunities in other parts of the supply-chain. In other aquaculture countries, large players are more vertically integrated, and carry do more processing themselves, while smaller players rely on external service providers.[459] As the aquaculture industry grows in Iceland it is likely that a larger portion of the exports is processed.

455 Stead & Laird 2002

456 The price of offcuts is around 2.5 EUR/kg. Source: Expert interview

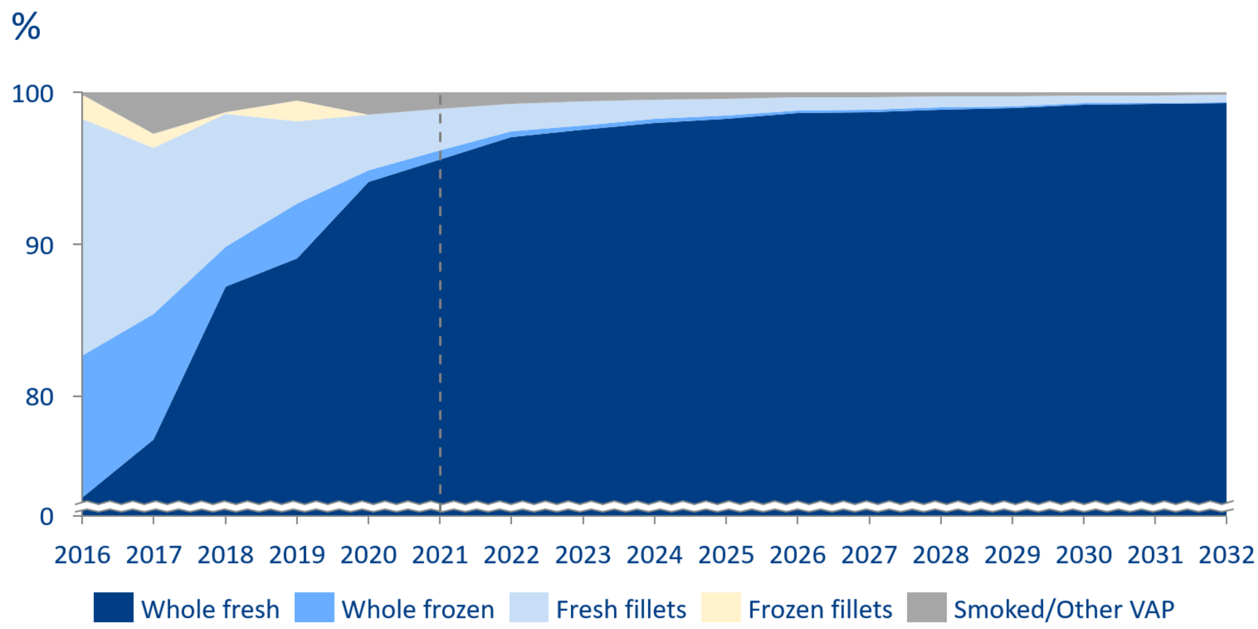
457 Expert interview

458 Norwegian Seafood Council; Kontali; BCG analysis; Note: price premiums are based on product weight of 61% for fresh fillets and 50% for frozen fillets on average Norwegian export prices to EU countries from 2018-2022 (2022 numbers based on prices from week 1 to 32)

459 EAS Aquaculture Europe September 2019; Expert interview

If Icelandic companies were to do more processing it would result in more jobs and income tax revenue. The sales value of salmonoids would likely stay the same due to the price parity of products when accounting for product weight. Corporate taxes could increase as the sale of biproduct should have a positive impact on margins. These considerations may pose an untapped opportunity for Iceland, not covered in this analysis. As described before, it is assumed that the volume of processed fish for export is constant throughout the period. Naturally this results in a lower export ratio of processed fish as production rams up. The assumed processing distribution of salmonoids in the base case scenario can be seen in Figure 9.9.

FIGURE 9.9: SHARE OF PROCESSED EXPORTS FROM ICELAND BETWEEN 2016 AND 2032 (BASE CASE SCENARIO)



Government of Iceland
Ministry of Food, Agriculture and Fisheries