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A Deep Dive Into Offshore Aquaculture

Will Offshore Aquaculture Bring Evolution or Revolution to the Seafood Industry?

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Summary

- Coastal marine aquaculture is reaching growth limitations, so a natural development is to move farming further out to sea. The entry of the salmon industry into the offshore aquaculture sector is supercharging innovation and scale, with many new projects in the pipeline, especially in Norway. A second and parallel epicenter of offshore aquaculture innovation is China, where the space in coastal areas is restrictive while the demand for marine proteins is booming.
- While these two development pathways are related, we expect them to progress in different ways. In Norway and the salmon farming sector, the transition to offshore is a natural evolution of the current business model, whereas in China, an industry transformation is needed for offshore farming to be a reality. But if this can happen anywhere, it is in China.
- The global impact of offshore aquaculture's future success, especially in the longer term, will be a new source of supply growth for healthy and premium marine proteins, as well as a key business opportunity for many in the aquaculture and seafood industry. If executed well, offshore aquaculture also has the potential to greatly improve aquaculture's biosecurity, sustainability, and animal welfare while lowering its environmental footprint.

Aquaculture Has Space Limitations

After decades of rapid growth, many marine aquaculture industries have now occupied the best farm locations globally, with additional growth occurring in increasingly less ideal locations. In many cases, legislation is limiting growth, such as in the salmon industry. In fish farming industries where legislation is not as restrictive, aquaculture operations are reaching the maximum carrying capacity for the local area, with negative impacts on the environment and fish health. Moreover, climate change is warming coastal waters, while pollution in some regions is making once ideal farming locations increasingly difficult to operate in. Lastly, tourism and other human-driven coastal developments compete with aquaculture operations for coastal space. Therefore, moving marine aquaculture offshore is a logical solution.

Offshore Aquaculture: The Next Evolution in Marine Farming

Although there is a not a generally accepted definition for offshore aquaculture, some operational criteria might help to distinguish coastal fish farming from offshore fish farming. While the distance from the coast or the depth of the water can be thresholds, in our view, the degree of exposure to high wave energy environments is what makes the difference. To be able to operate in harsh conditions, resilient farm designs that are largely controlled remotely are needed. Different designs exist for offshore fish farming. Offshore aquaculture farms can be floating,

submersible, or semi-submersible in structure (*see Figure 1*). A submersible design allows farms to be lowered under water to resist strong waves during a current or to reach colder waters if that is needed. Other designs allow farms to be partially lifted above the water to assist with harvesting or cleaning. While some offshore aquaculture farms and projects are already operating, the industry is still searching for the optimal design, and we are far from any standardization.

Figure 1: An offshore aquaculture farm could be a steel construction or a submersible net cage system

Source: Nordlaks, Norway

Source: Gili Ocean, Israel

Source: Salmar, Norway

Source: Ocean Era, Inc.; Photo credit: Jeff Milisen

Source: company websites, Rabobank 2021

The Salmon Industry to Supercharge Innovation in Offshore Farming

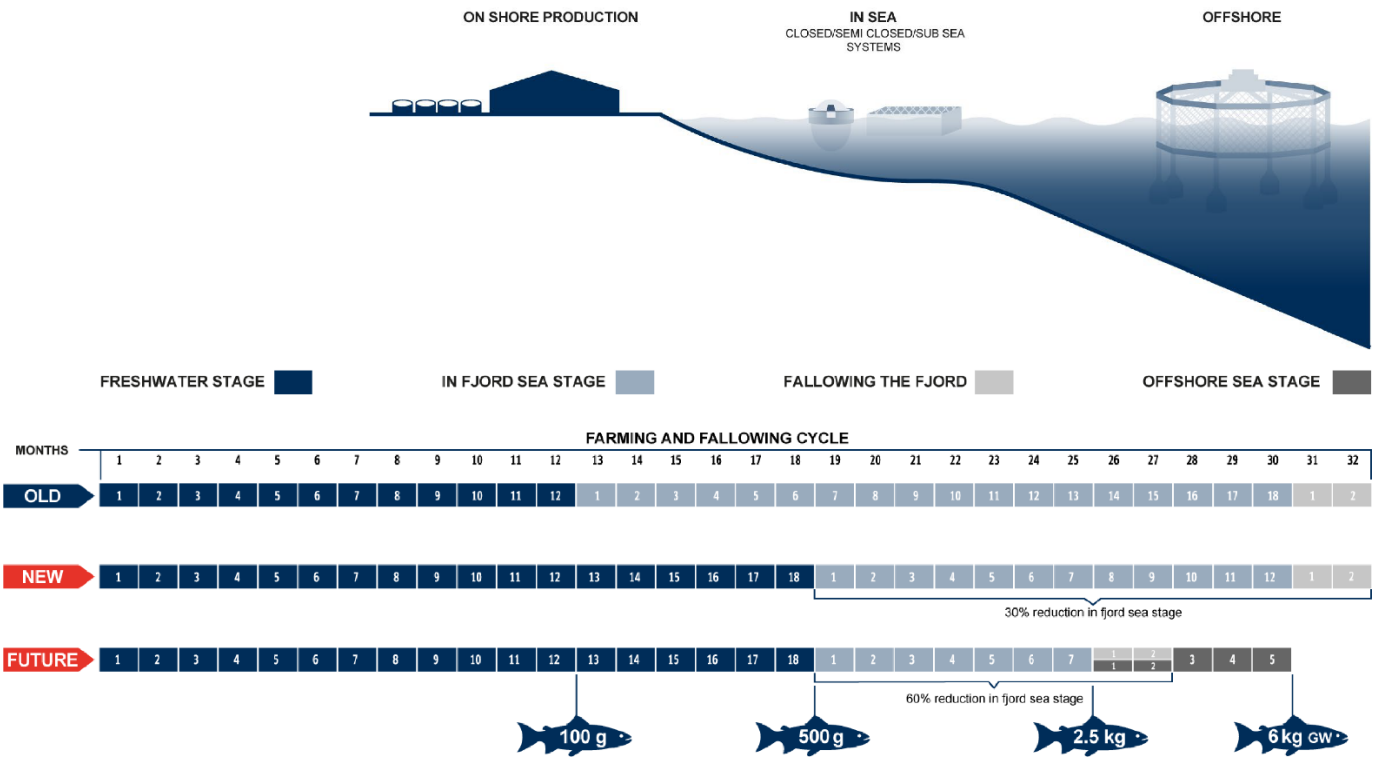
Offshore aquaculture has been around for at least a few decades. Most of the early innovation was in tropical waters, with early projects in places like the US, Mexico, and Central America. The difficulty of getting coastal aquaculture licenses in the US was the key driver for this innovation. However, despite the relentless efforts of many innovators and entrepreneurs, no large-scale offshore aquaculture has emerged so far. The reasons for this are numerous, but most important are: insufficient capital, a lack of supportive legislation and government policies, and a lack of marine fish species that have a large, established market and are suitable for tropical waters. What the innovators in tropical offshore farming needed was a tropical version of salmon.

Salmon Farming Enters Offshore Expansion

Norway is the world's largest salmon producer, accounting for just under 50% of global Atlantic salmon production. It is also a highly regulated industry, with production volume limited by licenses. Scant new licenses can be acquired, and the system is designed to prevent uncontrolled growth, with 6% every two years the theoretical maximum – and only possible provided biosecurity parameters such as lice numbers and medication use are low. A 6% reduction (or even revocation) of the license is also possible if these conditions are not met. To ensure growth while maintaining good biological performance, Norwegian salmon farming companies see offshore production as one of the main solutions. Since 2017, when legislation promoting offshore production was passed, a myriad of creative farm designs have been proposed and tested in Norway, and many more are on the way. The fact that there is already a highly developed industry

cluster with all inputs, skills, and technologies available makes Norway the ideal location for this development. Not only are the large salmon farmers well-capitalized companies that have the funds to execute the costly R&D for offshore farming, it also fits their business model. Offshore farming can be used as the last step in the farming process. For instance, fish weighing 2.5kg to approximately 6kg (harvest weight) can be farmed offshore, with the initial stage remaining in the existing coastal farms. This also combines well with the trend of using large smolt, which also aims to reduce the time salmon spend in coastal farms by moving part of the production on land (*see Figure 2*).

Figure 2: Offshore salmon farming fits well with the strategic goals of salmon farmers

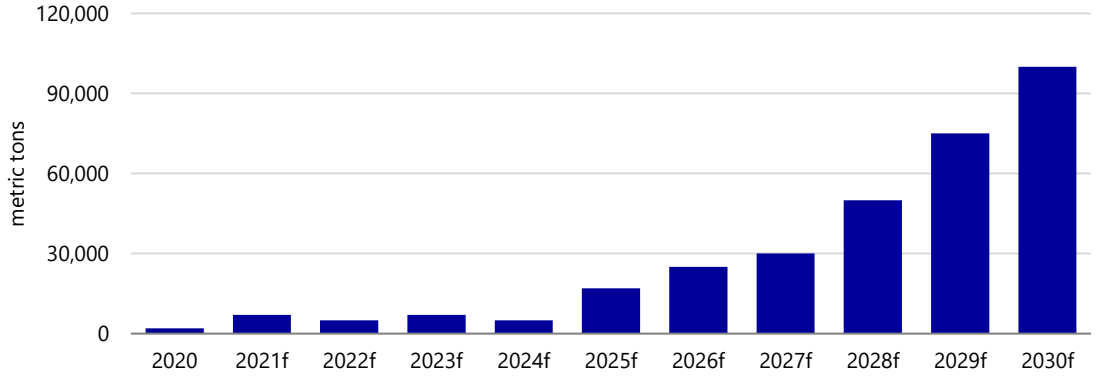


Source: Bakkafrost 2021

Moving fish offshore for the last stage of the farming process means that the capital-intensive offshore structure is used efficiently at close to full capacity while license capacity is freed up on the coast, ensuring more growth potential.

The Norwegian government has been supportive of this industry, granting development licenses to innovative projects. These licenses have the right to be converted to valuable coastal salmon farming licenses, making experimentation with offshore farms less costly if not successful. So far, over 200 projects have been proposed, with over 70 accepted by the government. At the moment, the expectations – based on a few well-known and large projects – are that Norway can potentially produce over 100,000 metric tons of offshore-raised salmon by 2030 (*see Figure 3*). While this will demonstrate scale and viability, it is still a small part of overall global salmon production, which is currently over 2.5m metric tons.

Figure 3: Offshore aquaculture in Norway will deliver the first commercial-scale volumes in the next few years, 2020–2030f

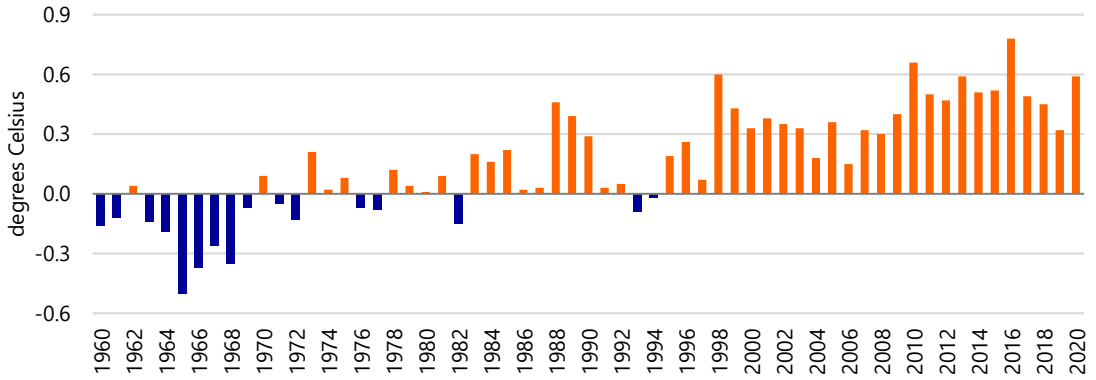


Source: Kepler Cheuvreux, Rabobank 2021

Norway drives innovation and technical development, due to the scale of the industry and government support. However, many of the same drivers apply in other salmon-farming regions where offshore aquaculture is also developing, such as Scotland, Canada, Chile, the Faroe Islands, and Australia. Some smaller regions, such as the Faroe Islands, may in fact move quicker, due to local political will to support the sector, along with increasingly developed legislation on offshore farming.

Australia, which accounts for only 3% of global supply, is another small producer and front-runner in the development of salmon offshore farming, but it has a different approach than Norway. Climate change acts as an additional driver for offshore aquaculture in Australia, where warming coastal waters have shown a marked increase in recent decades (*see Figure 4*).

Figure 4: Australia's surrounding oceans have shown abnormalities since the 1970s



Source: Bureau of Meteorology, Rabobank 2021

The best long-term solution to rising water temperatures is to move salmon farms further out to sea, where the water temperature is lower and more stable. Unlike Norwegian salmon farmers, who use completely new farm designs, Australian salmon farmers have been gradually changing and adapting the existing farm design, and systematically moving to more exposed and open waters.

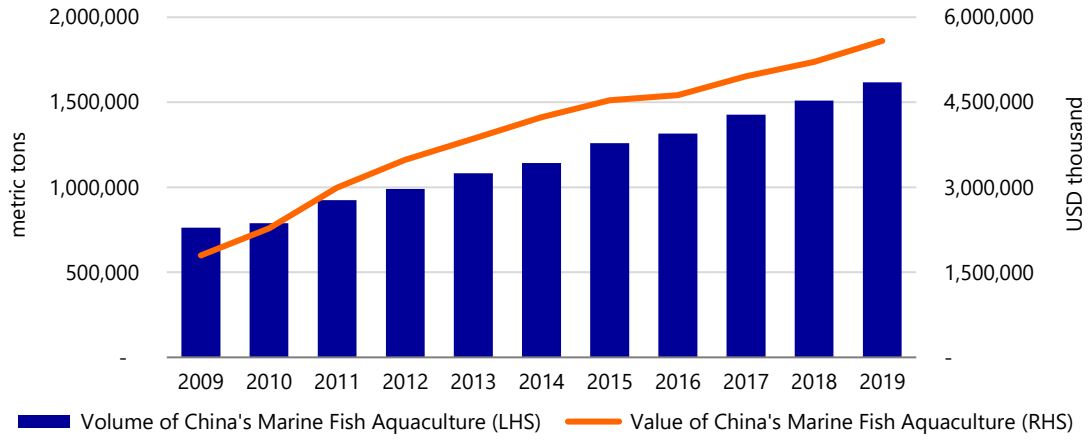
Irrespective of location, it is encouraging that, so far, the results suggest that the move offshore is good for biological conditions and the environment. Salmon raised offshore enjoy strong currents, more stable temperatures, and fewer (or no) parasites such as lice, thus eliminating the need for pesticides or other medications. With the exception of a few issues, nearly all farms demonstrate good growth rates and mortality parameters. The natural conditions of the open sea favor fish welfare, which is an increasingly important criteria for both consumers of salmon and industry investors. Lastly, the farm's environmental impact is low, given that the large body of water easily dissipates any nutrients discharged by the farm. Here too, early evidence from the Norwegian salmon industry, as well as non-salmon farming projects in Hawaiian and Panamanian

offshore farms, suggests very good performance when it comes to the environmental impact on ocean water, benthic ground, and wild fish populations.

China, the Other Epicenter of Offshore Aquaculture

A second epicenter for the development of the offshore aquaculture industry is China. China has, by far, the largest aquaculture industry in the world, accounting for nearly 60% of global farmed seafood production. Even though most of this is fresh water (carp) and mollusk aquaculture (mussels), China's marine finfish aquaculture is a large and rapidly expanding industry, comparable to that of the European Atlantic salmon industry in terms of volumes produced (*see Figure 5*).

Figure 5: Chinse marine aquaculture is a large and growing industry, with farmgate values above USD 5bn in 2019



Source: Food and Agriculture Organization of the United Nations, Rabobank 2021

Space constraints for aquaculture on China's coasts are far greater than those of Norway or any other salmon-farming region. Moreover, there are significant risks for a young industry growing rapidly in environments with high farming density close to the Chinese coast. There are weather-related risks, such as typhoons, and warmer and more extreme weather patterns caused by climate change. Local water pollution can be a challenge for farms close to industrial clusters and cities. Lastly, with farms in close proximity to each other, disease can easily spread from one farm to the next. Offshore aquaculture is a logical solution for all of these issues.

From a demand perspective, the need in China for marine protein supply growth is among the highest globally. China is not only the largest seafood-consuming nation in the world; it is also where most incremental seafood demand growth is expected to be, due to the rising middle class and broad appreciation for seafood.

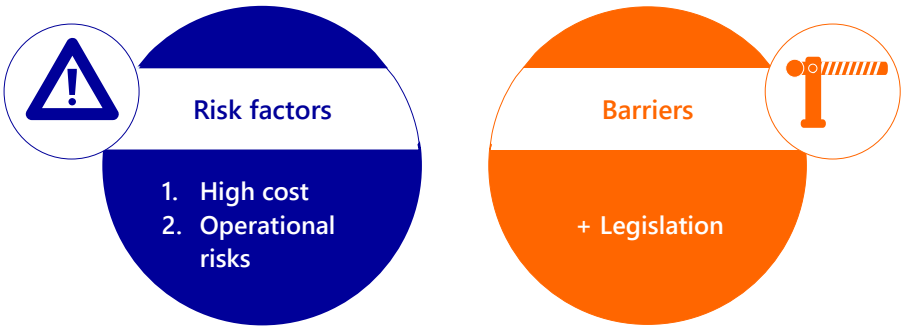
China's wild-catch fleet, the world's largest globally operated fleet, produced 9.9m metric tons of marine fish in 2016, its peak year. But production has been contracting ever since, declining to 8.5m metric tons in 2019 – and this trend is expected to continue, as the fleet needs to scale down even further to be sustainable. So far, the fleet's supply drop is much higher than the growth in marine aquaculture, resulting in a decline in domestically produced marine proteins. China's large freshwater aquaculture industry – which mostly focuses on carp, but also produces tilapia, catfish, crayfish, and many more species – can still expand. However, this growth potential is incremental, due to competition with other economic activities. In recent years, Chinese freshwater aquaculture expanded by only by 1% to 2% per year, down from 4% to 6% in the past (2010 to 2016). Moreover, it is marine species that have the highest income elasticity of demand in China. In the current situation, as consumer wealth increases, imports of marine seafood grow, with salmon and shrimp being the key species, as they are the most traded globally and can increase supply. However, with self-sufficiency being a key political priority, offshore aquaculture will likely be an area of focus for the Chinese government.

Lastly, China manufactures nearly all of the offshore farms destined for Norway and Europe, due to its cost-competitiveness in steel production and welding, and its technical expertise in building large custom-made steel structures. Arguably, there is some technological spillover from the European salmon industry to China that is triggering growth in the offshore farming sector. There are also farm designs that are similar to those in Europe, but adapted to the species and conditions for the Yellow Sea and the East China Sea. Clearly, the recent availability of farming technology, combined with Chinese government involvement, is creating fertile ground for offshore aquaculture.

Success Is Not Guaranteed

In both Europe and China, offshore farming must still overcome considerable obstacles in order to become a reality. We see three factors that currently limit the growth of offshore aquaculture: high capital expenditure (capex), operational risks, and legislation. Capital expenditure and operational risks are related challenges based on the technology deployed. In contrast, legislation is more government-driven and less in the control of the industry.

Figure 6: Limiting factors of offshore aquaculture



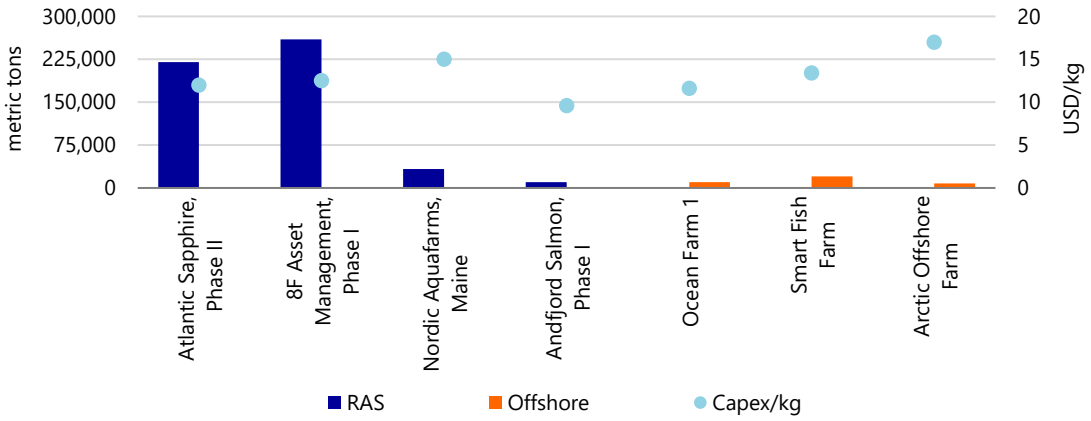
Source: Rabobank 2021

Offshore Aquaculture Is a High Capex Industry

Offshore aquaculture comes in many shapes and sizes. Consequently, the capex varies considerably. Projects in tropical waters and in the Mediterranean tend to have relatively lower capital needs, but, as mentioned, they are not currently driving the industry. When looking at projects in the salmon industry, structures need to be substantial, due to the need to have scale, and to withstand very harsh environments and wave energy. So far, based on data from publicly disclosed projects, capex is in the range of USD 11/kg to USD 17/kg (*see Figure 7*). That is in the same range as the main publicly announced, land-based recirculating aquaculture systems (RAS) salmon projects.[1] The land-based projects have the advantage of being close to the customer and having a lower transport cost – although this needs to be balanced with higher operational costs (e.g. electricity, oxygen). Arguably, if there are no differences in variable cost, mortality, and quality, it will probably be RAS, not offshore systems, that drive incremental growth in salmon.

[1] For more on RAS, please see our report *Aquaculture 2.0: RAS Is Driving Change – Land-Based Farming Is Set to Disrupt Salmon*

Figure 7: Capex per kg of salmon from offshore and land-based aquaculture systems are within the same range



Source: Kepler Cheuvreux, Rabobank 2021

Offshore capex will decline in the future, but it needs to decline considerably, as it is likely that RAS technology will also improve. On paper, offshore farms should have a lower capex than land-based facilities, as expensive water-treatment systems are not needed. Also, the current designs have all been deliberately oversized, as they are experimental and take a precautionary approach. Just as an example, if capex eventually drops to USD 10/kg, which is arguably a realistic possibility, USD 10bn of capital investment would be needed to make an additional 1m metric tons of salmon (current production is 2.5m metric tons). There are, however, projects that can lower this capex by utilizing existing wind energy, or oil and gas infrastructure, which could be used to moor the aquaculture cages and partially reduce the capex below the USD 10/kg mark.

There is anecdotal evidence that the capex is considerably lower in China – perhaps half the cost or less for the large structures in the salmon sector. Submersible systems can avoid typhoons, and under normal conditions, the Yellow Sea and East China Sea are much less harsh environments than the North Atlantic, which has some of the highest waves ever recorded. Also, with offshore aquaculture's strategic relevance to China, the initial capex may not be the main consideration.

Operational Risks

Offshore aquaculture is an emerging technology, and many innovations are needed. The salmon industry has the relative advantage of being highly developed. It is well understood that there will be a market for additional salmon volumes with a good price point, given the expected supply tightness. Many of the technological innovations needed for offshore farming are fairly incremental. For instance, remote feeding already exists in salmon farming and is improving every year. Infrastructure such as wellboats can be fairly easily adjusted to service offshore farms. The main challenge where innovation is needed is in designing farms that can withstand harsh environments, especially high wave energy. Most importantly, the companies that are spearheading the offshore sector are the existing large-scale corporate salmon farmers, with all the needed husbandry, feeding, harvesting, marketing, and other skills already in-house.

In China, where the marine aquaculture industry is less developed and far more fragmented, the operational risks are greater. The industry is fragmented in terms of species, as dozens of species are farmed in marine environments, with various groupers, yellow croaker, Japanese seabass, pompano, and barramundi the largest in volume, but there are many others. More importantly, the sector is fragmented and immature in terms of company structure and technology. Farming is done by small farms, which are not able to transition to the offshore sector. The development of feed, genetics, and husbandry skills for these relatively recently domesticated species is decades behind salmon. The government-backed companies that manage offshore projects will have a steep learning curve in many different aspects. Consequently, the leap forward in China is not only

toward offshore farming, but also toward large-scale professional marine aquaculture farming. In light of the many boom-and-bust cycles the salmon industry has experienced to get to where it is today, it is clear that the operational and market risks are considerable. Nevertheless, given offshore farming's high strategic importance, we believe the industry will continue to experiment as long as there is government support. Many new projects will emerge in the coming years, but we also expect challenges on the operational side.

Legislation: A Key Limitation in Many Regions

As many offshore aquaculture pioneers in the US have experienced – and still do – unclear regulations and ever-changing legislation can impede the path to scale. When aquaculture farming moves beyond the coastal waters, it becomes a mix of local and federal jurisdiction, with many approvals needed. To be able to move forward with offshore aquaculture, departments regulating marine transportation, tourism, fishing, and offshore energy, as well as the military or coast guard, and environmental impact analysis all need to be supportive. There are also diverging political interests. For large, highly diverse democratic regions such as the US or the EU, this has meant that offshore aquaculture on a commercial scale is not yet possible. Norway is a relatively small country and highly dependent on aquaculture, and while Norway's legislation is not yet complete, there is clearly good political will to make it possible and even actively promote it. The Faroe Islands, a country with a population under 50,000 people, probably has the highest relative dependence on salmon aquaculture of any country in the world. Consequently, it has the strongest political will to enable offshore farming and, at the moment, arguably the most developed legislation for offshore aquaculture.

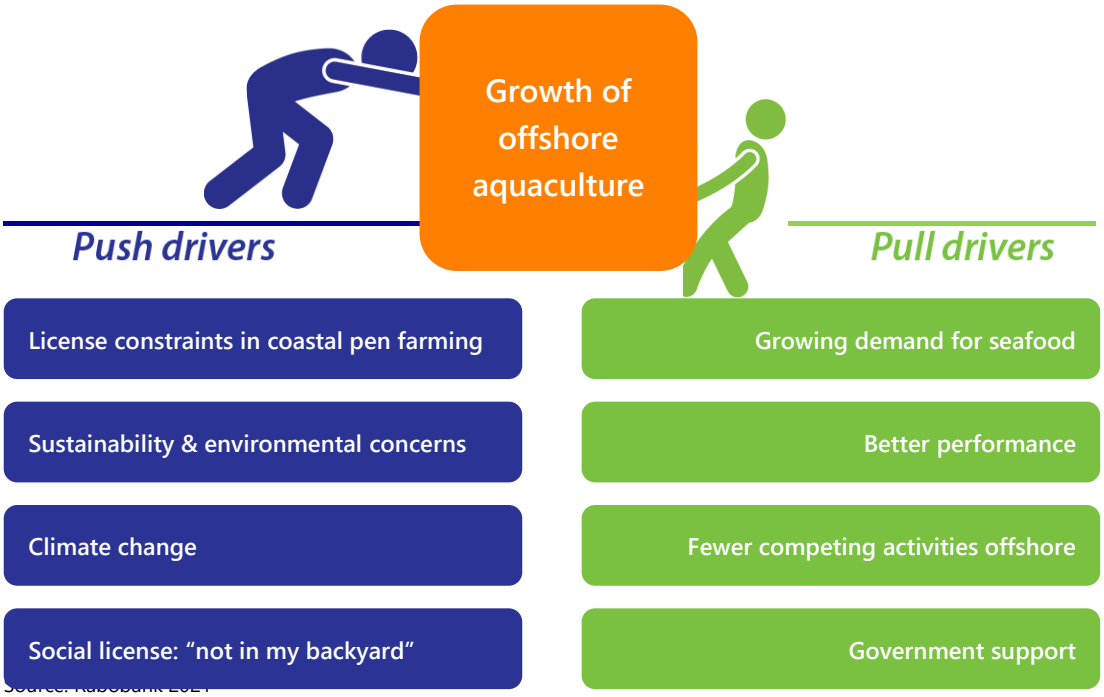
In China, given the close government support and the strategic relevance of offshore farming, we do not expect the same legislative barriers that exist in the West. However, if farms are far enough from the coast, there could be tensions with neighboring countries, as China has disputes with most of its neighbors on the demarcation of its economic exclusive zone (EEZ). Unlike fishing vessels, farms are seen as more permanent structures in the water and will create more political resistance if placed in disputed waters.

Lastly, it is worth mentioning that offshore aquaculture can also theoretically take place in international waters. It is not yet clear what convention will govern this or how it will be supervised. The Convention on Biological Diversity is moving forward to include "areas beyond national jurisdiction" (ABNJ) and could require projects to undertake an environmental assessment (EA) and an environmental impact statement (EIS). Hypothetically speaking, if a Chinese company wanted to build an offshore salmon farm in international waters where farming temperatures are ideal, but just outside of Norwegian, Chilean, or Australian EEZ, an EA/EIS is the only documentation that would be needed. However, this would need to be obtained from the nearest coastal states.

Assuming Offshore Aquaculture Does Flourish

The global demand for seafood continues to increase. Wild catch is stagnant or even declining in some regions. Growth of marine fish aquaculture supply in coastal waters is slowing, mainly due to licensing constraints and biological challenges. The scarce availability of space for farming and increasing sea water temperatures due to climate change are pushing fish farmers to move their farms further offshore in search of lower water temperatures. Achieving a lower environmental footprint for farmed seafood is an increasingly important consideration for both consumers and investors. All of these factors combine to make the case for offshore aquaculture as the logical evolution of coastal aquaculture *(see Figure 8)*. But the leap forward is not the same for everyone.

Figure 8: Offshore aquaculture could be a solution to some of the challenges the industry faces



Source: Rabobank 2021

Evolution in the West

In Norway and other salmon-producing regions, offshore aquaculture is a natural step forward for the industry that provides the opportunity to generate a gradual, longer-term increase in supply. Today's leading players, especially the large Nordic salmon farmers, will be the key drivers of offshore farming – in contrast to RAS, which so far has seen little involvement from the incumbent industry. The largest players will become larger, further increasing consolidation and barriers to entry in the sector. Although offshore salmon farming has the potential to reduce barriers to entry and open the market to those that do not have licenses in the very long term, at present, it seems unlikely that non-producer regions will have an offshore industry. The necessary expertise, existing infrastructure, and legislation are key success factors not present outside of the existing producers. Consequently, offshore farming is not a near- or even a medium-term opportunity for regions such as Alaska, Argentina, the Russian Far East, or South Africa, where water temperatures allow for salmon farming, but no farms currently exist. The gradual progression to offshore farming is a benefit to the industry, the consumer, the environment, and the welfare of the farmed salmon.

Revolution in China

The implications of the development of a large Chinese marine finfish offshore aquaculture industry are more considerable. Firstly, China could, in a relatively short period, develop a sector that has a corporate scale to rival that of the European salmon farming sector. This would support China's self-sufficiency as a seafood and protein producer, and ensure that China remains the leading seafood exporter – not based on low-cost reprocessing of Russian and Western wild catch (as is the case now), but based on high-quality marine proteins farmed domestically, which is a far longer-lasting and more profitable competitive position. There will be implications for the value chain and inputs of this industry. High-quality feed, genetics, and service vessels such as wellboats will be needed for marine species farmed offshore in China. From a Western aqua-technology suppliers' perspective, this is the main opportunity.

Moreover, with a large domestic marine fish industry, not only are import requirements reduced, but the need to have a large, offshore, long-distance wild catch fleet is also potentially diminished. Reducing this fleet further has benefits for the ocean environment globally and for Africa especially, as questions regarding the sustainability of Chinese international fleet operations persist.

The need for fish meal and perhaps also fish oil – especially from Peru, the world's leading exporter – will increase. China already accounts for over 85% of Peruvian exports, so there is virtually no possibility to increase this further. Fish meal is a scarce commodity, with production limited by fishing quotas for small pelagic species. With the current marine fish feed formulations in China, it will be hard to ensure quality feed for a sector potentially entering a phase of rapid expansion. Novel feed ingredients will be needed, such as insect and microbial proteins, as well as high-purity vegetable protein concentrates, as virtually all marine fish are carnivores and need a high level of protein in their feed. Novel aqua feed ingredients are another opportunity for Western producers who are driving innovation in this field.

Norway and China Are Just the Start

As offshore aquaculture technology proliferates, it will be only a matter of time before farming proliferates in other regions. It may also become a reality in international waters, especially if legislation elsewhere is slow to develop or impedes growth. If done well, this could be an environmentally beneficial way to supply seafood to the world's growing population. However, currently there is no international convention governing the sector. Clear global agreements and standards are needed to ensure the industry grows in an environmentally sustainable way. Given that there are fewer supply constraints in international waters (legal and biological), we can expect that offshore aquaculture in the long run will become one of the key disruptive technologies in the seafood industry.

How Significant Can Offshore Aquaculture Farming Become?

Oceans provide near limitless space, and there are many factors that encourage the development of offshore aquaculture, but there are also technological, market, and legislative constraints. As this is a question of technology, adaptation, and proliferation, it is a notoriously difficult prediction to make. Our estimate is that, by 2030, up to 10% of salmon supply (100,000 metric tons to 300,000 metric tons) could be harvested from offshore farms globally. This production could also involve partial use of coastal farming. How offshore technology proliferates among other species will depend on how capital-intensive the farms are and the development of Chinese offshore farming. As a reference point, we estimate the current market for marine and diadromous species (excluding salmonids) that could potentially be farmed offshore at approximately 4m to 4.5m metric tons as of 2019. A fraction of this could be farmed offshore by 2030.

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