ELBE

EUROPEAN LEADERS OF BLUE ENERGY

MARINE AQUACULTURE

ANALYSIS OF POTENTIAL NICHE MARKETS TO OVERCOME VALLEY OF DEATH IN WAVE ENERGY DEVELOPMENT

Co-funded by the COSME programme of the European Union

ESCPoi ELBE Partnership

ELBE - European Strategic Cluster Partnership in Blue Energy

Cluster Energía BASQUE ENERGY CLUSTER

areG Aberdeen Renewable Energy Group

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OFFSHORE VÄST

PÔLE MER MÉDITERRANÉE

TABLE OF CONTENT

1. Introduction
2. Overview of the niche market
3. Analysis of the marine aquaculture
    I. Main geographical markets
    II. Power requirements
    III. Opportunities for wave energy
4. Main conclusions

1. **Introduction**
2. Overview of the niche market
3. Analysis of the marine aquaculture
   I. Main geographical markets
   II. Power requirements
   III. Opportunities for wave energy
4. Main conclusions

Purpose of the project

- The world is living a transition to a cleaner and more eco-friendly energy. Different renewable energies like wind or solar, are already competing with the rest of conventional energies in the electric market. Their technology maturity allow them to have competitive prices and so, supply electricity into the main grid. However, this is not the case for other renewables energies, such as wave energy, with a lower level of maturity.

- This project aims to support wave energy development by contributing to identify potential market niches which may be a suitable target for early commercial development of wave energy converters. All these potential niches have in common that they are applications not served by the main electrical grid, and therefore prices for electricity are significantly higher, making wave energy converters to potentially become a competitive contester.

- This project has been developed as the Final Thesis of Master REM (https://www.master-rem.eu/) of Nerea Guinea in collaboration with the Basque Energy Cluster and the ELBE alliance (http://www.elbeproject.eu/), which gathers seven European clusters joining efforts for development of Blue Energy.

Two phases to identify the niches with a higher potential

The analysis carried out in the project is structured in two phases:

- **Phase 1** consisted on a first study of all possible niches with potential interest.
  - 14 niches were identified. Each niche was analysed in order to give information regarding two independent prioritization criteria:
    - Market potential, which tries to quantify the size of the potential market
    - Competitiveness, which analyses main advantages and disadvantages that wave energy presents versus other potential alternatives
  - A survey was sent to key stakeholders so that they prioritized which niches they deemed more relevant based on the information provided

- **Phase 2 (this report)** is a more in-depth analysis of the three niches that were considered more interesting based on the feedback gathered from the survey. The selected three market niches are:
  1. Isolated Power Systems
  2. Electric Supply of O&G Platforms
  3. Offshore Marine Aquaculture

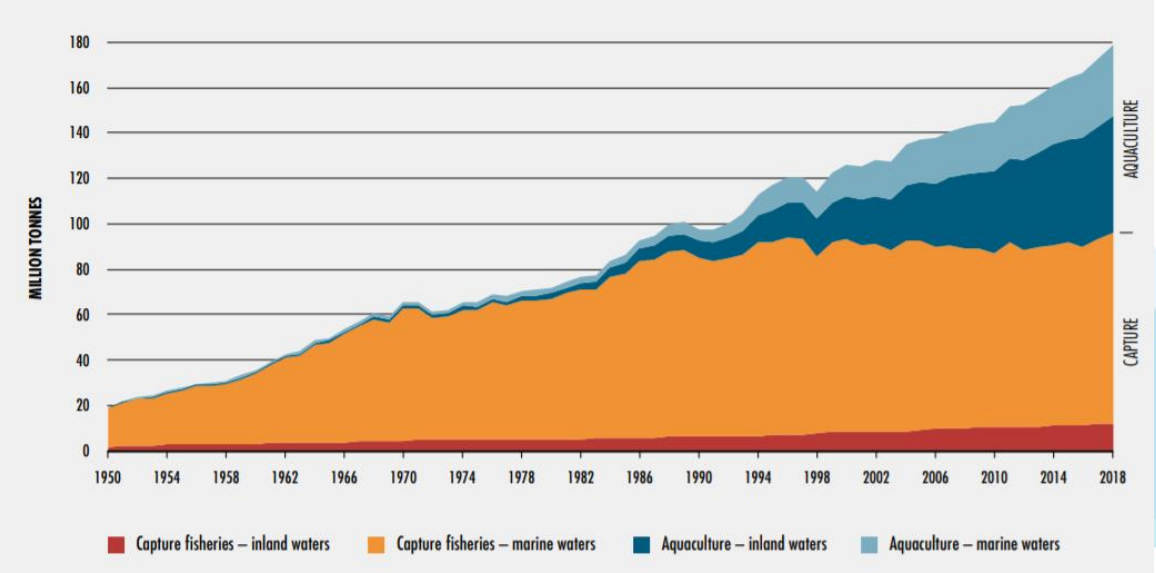
  These niches has been analysed following the most suitable structure for each case depending on the available information.

1. Introduction
2. **Overview of the niche market**
3. Analysis of the marine aquaculture
   - I. Main geographical markets
   - II. Power requirements
   - III. Opportunities for wave energy
4. Main conclusions

Marine aquaculture market has grown in the recent years due to the increasing population and the over exploitation of wild fishing

Main characteristics

Marine aquaculture refers to the farming of aquatic animals at open sea or in coastal areas, including finfish, shellfish and crustaceans. This industry is mainly for human consumption. Since world population is increasing as well as the over exploitation of wild fish capture, the aquaculture is experimenting a huge expansion to meet the demand.



World capture fisheries and aquaculture production

Traditionally, aquaculture has been limited to near shore sites where crustacean and mollusc farming takes places but recently, the number of offshore farms has increased, which have additional challenges regarding the power supply. Those marine aquaculture farms are considered as off-grid systems commonly powered by diesel generators, which have a negative environmental impact and a dependence to the fossil fuels. For this reason, wave energy is presented as a potential solution for covering the energy needs of the farms.

Figure: http://www.fao.org/3/ca9229en/ca9229en.pd

Offshore aquaculture is not an energy intensive energy sector

Power Requirements

Offshore aquaculture is not an energy intensive sector since the pumps used in on land aquaculture farms, which are the most power demanding elements, are not needed in the offshore alternative. When considering the different species of the market, shellfish and crustaceans are the ones with lowest power demand and so, are not relevant for this analysis. Finfish species are the ones that require more energy to grow. In 2018, finfish farming represented 66% of the total aquaculture production and 24% of the marine aquaculture.

Energy requirements of an offshore aquaculture farm depend mostly on its size because the main power requirements are the ones of the feeding system, which is linked to the number of fish. The main energy needs of the facilities are:

- Monitoring equipment
- Feeding system, main power consumption
- Supplementary aeration
- Navigation lights
- Acoustic deterrent devices
- Facilities for the workers

The difference on the power requirements between on land and offshore farms are quite relevant. As an example, data for farms of 100,000 salmons is the following

- Installed power capacity: 226kW in the on land farm and 50kW in the offshore farm
- Daily power demand: 4,916kWh in the on land farm and 185kWh in the offshore farm

http://www.fao.org/3/ca9229en/ca9229en.pdf
http://www.aquacultureinitiative.eu/Renewable%20Energy%20Report.pdf
http://www.esru.strath.ac.uk/Documents/MSc_2016/Syse.pdf

Phase 4 of the salmon production chain, which is assumed as a general example for all finfish, is considered in this project

Production Chain

Phase 1. Salmon eggs are fertilized and after 25 – 30 days the fish spawn.
As this phase takes place on land, there is grid connection.

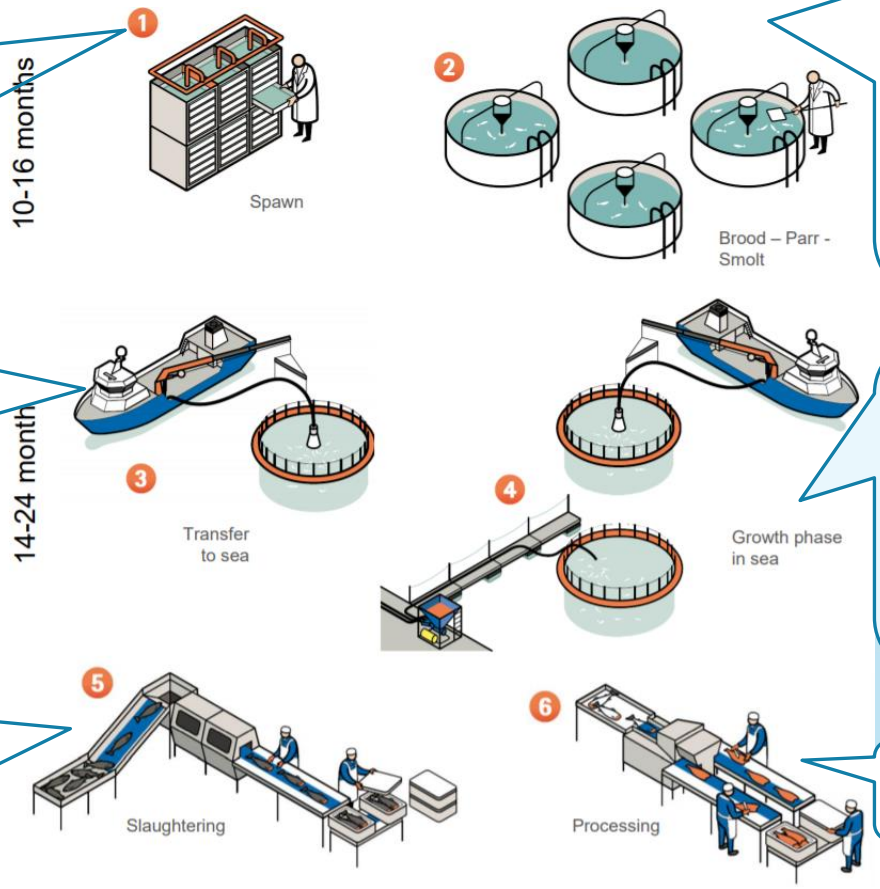
Phase 2. Salmons are moved to a freshwater tanks where they grow until being smolt. It is a very energy intensive phase because of the requirement of pumps, heaters/coolers and artificial lighting. As it takes place on land, it has grid connection.

Phase 3. Salmons are transported to an offshore location, where the water is salty.

Phase 4. When salmons reach a weight of 100 – 1,000g, they are moved to large sea cages where are kept and fed.
For this phase, off-grid systems are required such as diesel generators.

Phase 5. When salmons weight 4.5 – 5.5kg, they are transferred to land to be slaughtered.

Phase 6. Salmons are packed for being sale.



Salmon production chain

Countries with high latitudes have larger marine finfish aquaculture industry

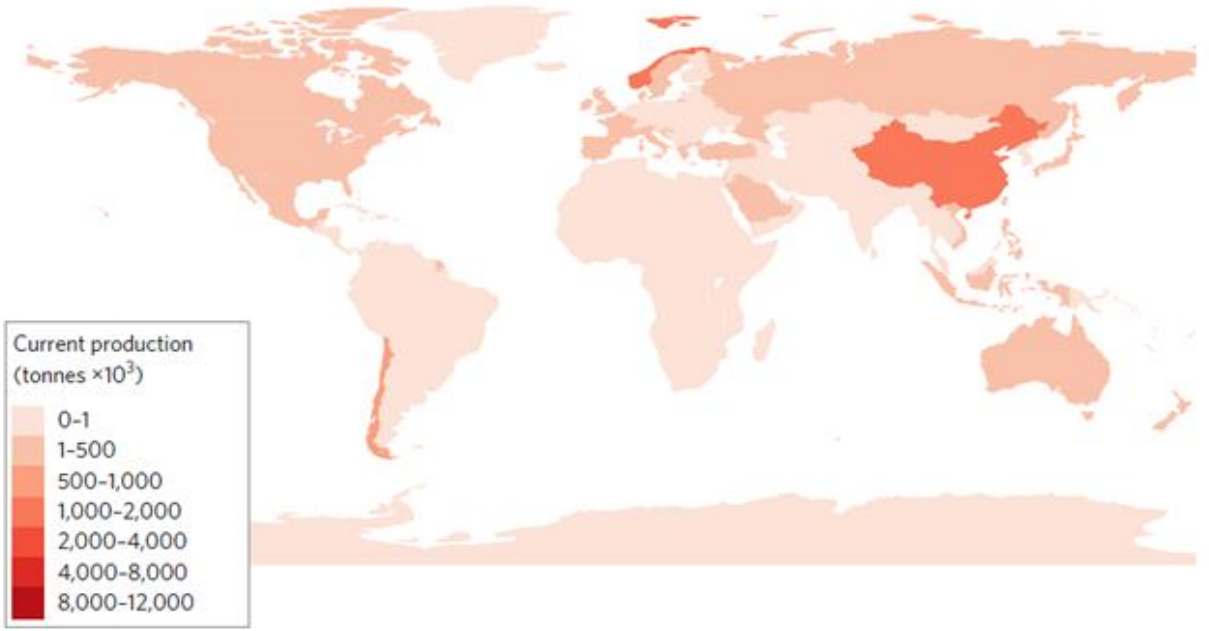
Location

Aquaculture has increased with a growth range of 5.7% between 2003 and 2016 and currently contributes with 47% to the global fishery products demand. Asia dominates the niche of aquaculture since most of the top aquaculture countries are from this continent, such as China (with 60% of the global market), Indonesia, India, Vietnam, Bangladesh, Philippines, South Korea and Japan. Norway is the main country of the European market with its salmon farms and in the Americas can be remarked Canada, the United States and Chile.

In the map below it can be seen the largest marine aquaculture geographical markets but only finfish marine aquaculture markets are going to be considered due to the power requirements.

The most relevant countries where **marine finfish aquaculture industry** takes place are listed below.

- Australia
- Canada
- Chile
- New Zealand
- Norway
- Spain
- United States



Location of the global marine aquaculture market

http://www.fao.org/3/i9540en/i9540en.pdf
Figure: https://www.researchgate.net/publication/319110152_Mapping_the_global_potential_for_marine_aquaculture

The analysis is divided in **3 independent sections**, with the **available information**

Structure

The study of the market niche has 3 sections and each one analyses different prioritization criteria. The first section analyses the criteria considering the optimum locations where marine aquaculture is done. The study is conditioned by the available information. The sections and each analysis points are:

- **Main geographical markets.** It is studied in 3 different areas.
  - Market size. Considering the harvested species and their annual production in tonnes.
  - Location of marine aquaculture farms. An approximate value of the existing offshore structures and if it is possible, their location. As these farms are located nearshore, and not in the open sea, bathymetry of the site is not considered.
  - Wave energy resource. Description of the wave energy density of the site.
- **Power requirements.** An average value of the power demand per farm regarding the type, size and fish species.
- **Opportunities for wave energy.** It is analysed describing 2 different points.
  - Competitiveness. Main advantages and disadvantages that other energy sources present.
  - Examples. Real cases where diesel engines have been replaced by other renewable source.

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2. Overview of the niche market
3. **Analysis of the marine aquaculture**
   - **I. Main geographical markets**
   - II. Power requirements
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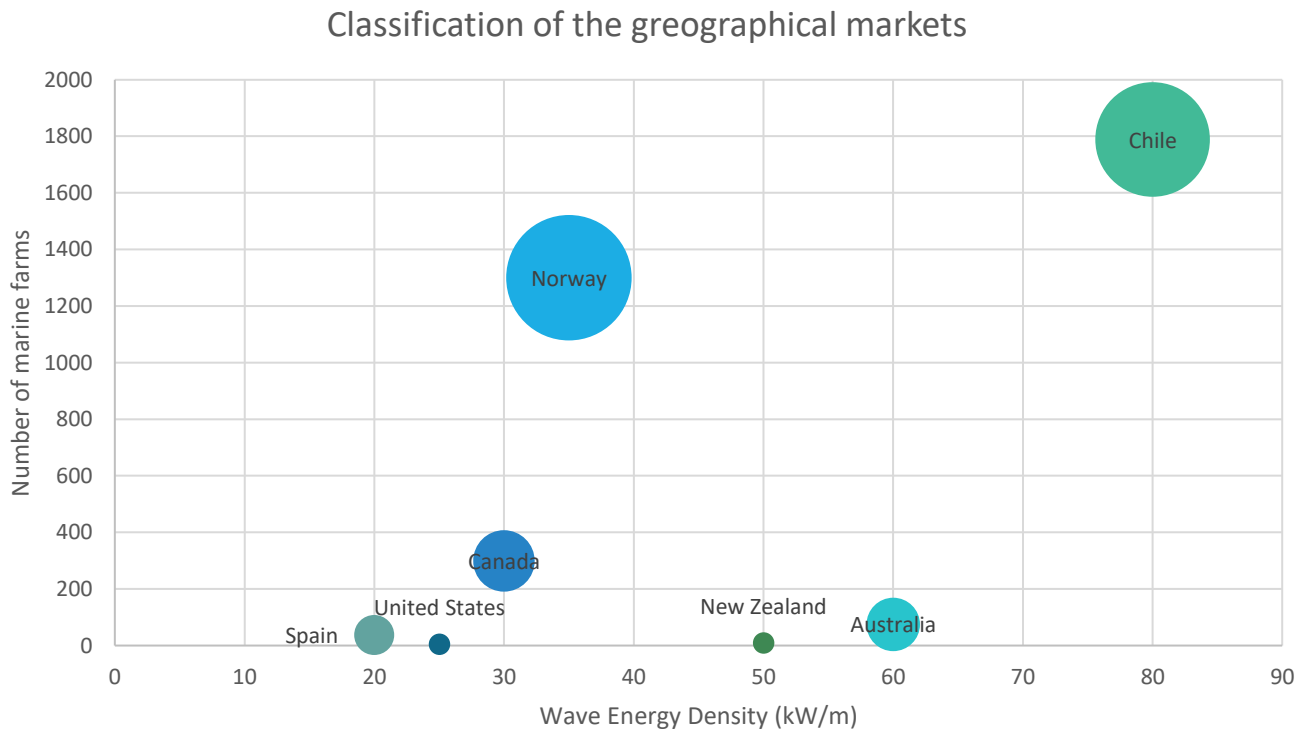
- Norway
- Canada
- Australia
- Chile
- New Zealand
- Spain
- United States

Overview of wave energy resource and bathymetry of each region, as well as their market size

Classification

The matrix comprises all the regions, considering the wave energy resource (horizontal axis) and the numbers of marine finfish farms (vertical axis). The size of the ball of each geographical market represents the size of the market, this is the production of finfish.



Salmon farming accounts for 94.6% of the Norwegian aquaculture market

Description of the market

Fish farming is a huge market in Norway, the most important exports industry after O&G exploitation, and it is increasing rapidly. Because of this, they are looking for sustainable farming methods that include reducing the utilization of diesel generator in marine farms. 50% of the country's farms are far from the coast and, so, use this type of energy source. The rest are connected to the main grid. Fish farming generate a lot of waste coming mainly from the fish. With the aim of taking care of the fjords' environment, they are moving the grid-connected farms far away, into the open sea, which is increasing the number of off-grid farms.

In 2018, **salmon farming** share was of 94.6%, the main specie produced in the Norwegian aquaculture farms, followed by the rainbow trout farming with 5% of the market. Translated into tonnes:

- Atlantic salmon farming: 1,282,003 tonnes (94.6%)
- Rainbow trout farming: 68,345 tonnes (5%)

Atlantic salmon farming started in Norway in 1969 and the country is now the world's first producer by supplying almost the half of the global production. Today, salmon farming has industrial scale and the nets where salmons are kept are much larger. Sea cages can hold up to 500,000 fish and so, automatic feeding systems are required. Norwegian companies are ahead in terms of the technological development of fish farms.

https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/fiskeoppdrett/aar
https://ml.globenewswire.com/Resource/Download/1766f220-c83b-499a-a46e-3941577e038b

There are more than 1,300 salmon and rainbow trout farms in Norway

Location of offshore aquaculture farms

There are more than **1,300 salmon and rainbow trout farms** in Norway (see the figure of the right). They are distributed along the coast and can be divided by provinces:

- Rogaland: 92 licenses
- Hordaland: 233 licenses
- Sogn og Fjordane: 110 licenses
- Møre y Romsdal: 153 licenses
- Trondelag: 242 licenses
- Nordland: 244 licenses
- Troms – Romsa: 131 licenses
- Finnmark: 107 licenses
- Others:32 licenses

Map of location of offshore aquaculture farms in Norway

https://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/fiskeoppdrett/aar
Figure: https://portal.fiskeridir.no/portal/apps/webappviewer/index.html?id=87d862c458774397a8466b148e3dd147

Norwegian coast has a high wave energy resource

Wave Energy Resource

The offshore aquaculture farms are spread along the Norwegian coast and so, the wave energy density (WED) that will have each of them changes regarding their location. Each region can be classified with respect to WED as:

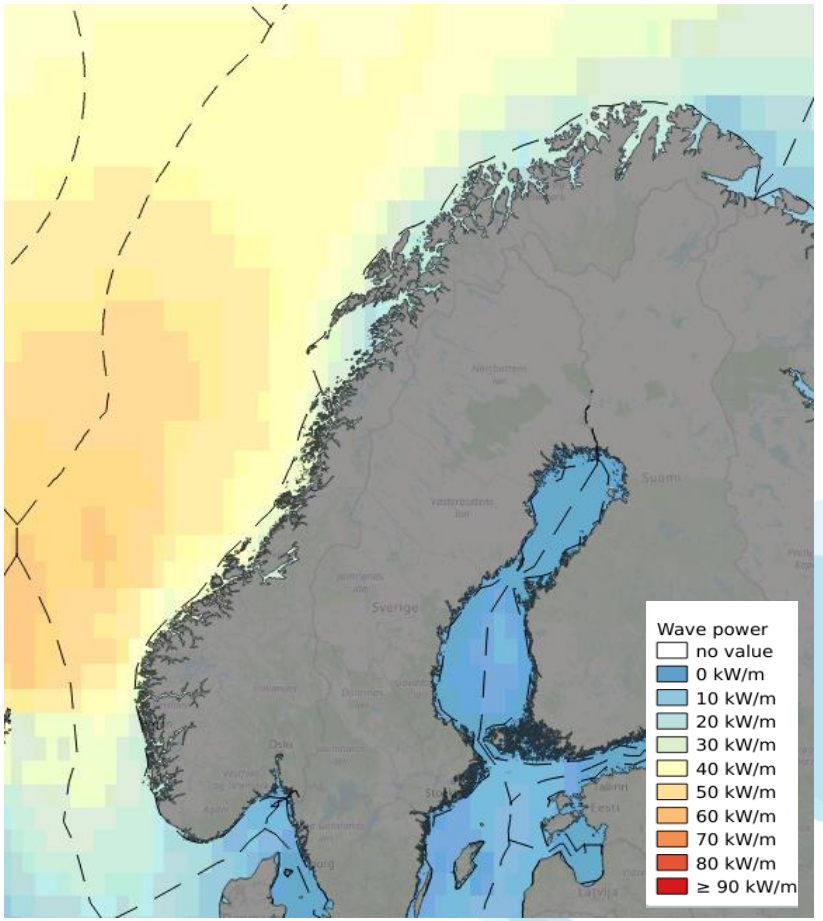
- Medium, 20 – 30kW/m. Farms that are southern that Bergen, in the south of the country, and in the north, around Lofoten.

  The regions with this potential are Rogaland, Hordaland, Troms – Romsa and Finnmark with a total of 563 marine aquaculture farms.

- High, 30 – 50kW/m. Along the rest of the Norwegian coast.

  The regions with this potential are Sogn og Fjordane, Møre y Romsdal, Trondelag and Nordland with a total of 749 marine aquaculture farms.

Generally, the wave resource that Norway has is quite high.



Map of the WED in the coast of Norway

Atlantic salmon farming accounts for 92% of the offshore finfish production market in Canada

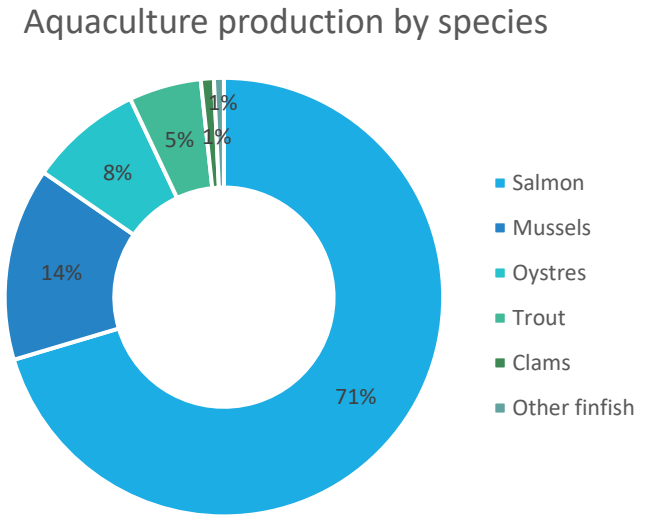
Description of the market

The aquaculture industry in Canada has a significant impact on the employment and on the economy of the country, specially in coastal, rural and aboriginal communities. In 2017, the aquaculture market production volume was of 191,416 tonnes including finfish and shellfish, which accounted for 16% of Canada's total seafood production. More than 50% of the production is exported, mainly to the United States (94% of the exports) and to other countries like Japan, China, Taiwan, Israel and Hong Kong.

The aquaculture market in Canada is composed by finfish production (76%) and shellfish production (24%). As it has been mentioned before, shellfish are not going to be considered due to the low energy demand required for their production. **Atlantic salmon and trout** are the finfish species with greater production volume:

- Salmon farming: 123,184 tonnes (92%)
- Trout farming: 9,323 tonnes (7%)

Although aquaculture market is spread along the country, **British Columbia** (71%), New Brunswick (23%) and Nova Scotia (6%) are the provinces with greater salmon farming. Regarding trout farming, Ontario (58%) is the main producer followed by Newfoundland and Labrador (15%), British Columbia (13%) and Quebec (11%).



https://www.aquaculture.ca/aquaculture-in-canada-intro
https://www.dfo-mpo.gc.ca/stats/aqua/aqua18-eng.htm

There are around 300 marine aquaculture farms

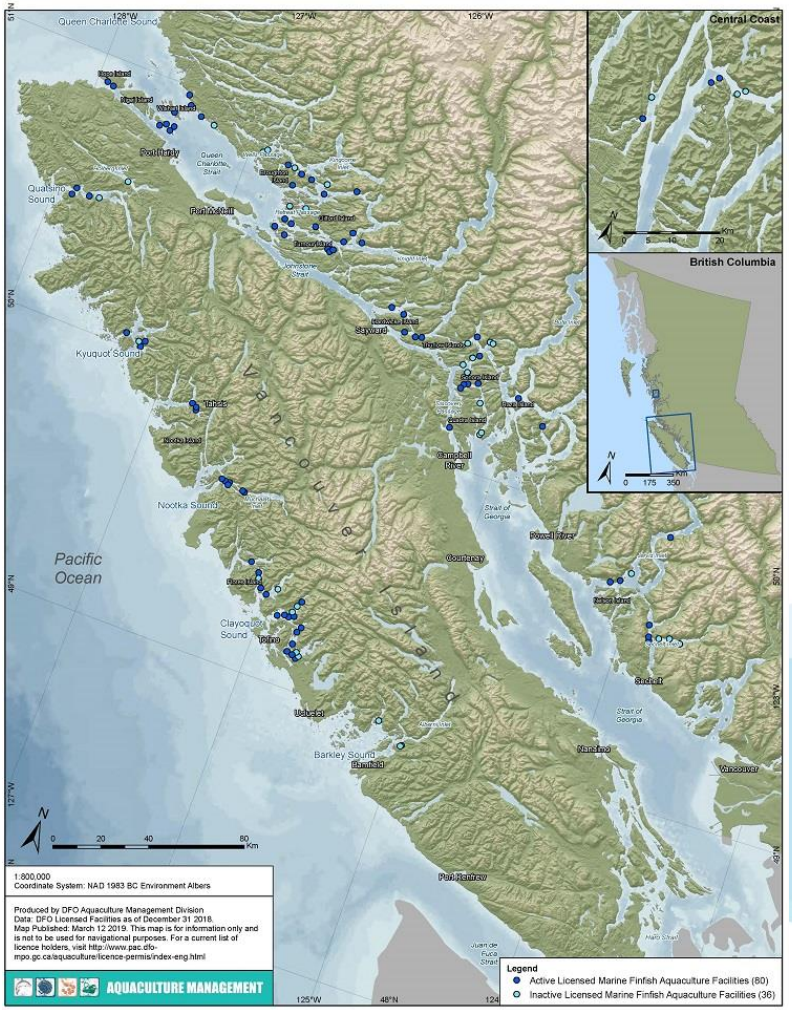
Location of offshore aquaculture farms

The province with the biggest marine aquaculture market is British Columbia although its number of farms is not so high, which means bigger farms. The marine farms are distributed along the both west and east coast and can be divided by provinces:

- British Columbia: 80 licenses
- New Brunswick: 92 licenses
- Nova Scotia: 31 licenses
- Newfoundland and Labrador: 88 licenses

Quebec and Ontario are not analysed due to their low WED (see next slide).

There are **around 300 marine aquaculture farms** destinated to the salmon and trout production in these four provinces.



Map of the location of offshore aquaculture farms in British Columbia, Canada

https://www.dfo-mpo.gc.ca/aquaculture/bc-cb/maps-cartes-eng.html#sites
https://nbdnr.maps.arcgis.com/apps/webappviewer/index.html?id=24c65e8718724c5db1de77899172630d&locale=en
https://novascotia.ca/fish/aquaculture/site-mapping-tool/
https://www.findnewfoundlandlabrador.com/files/2018/03/seafood_review_2017.pdf

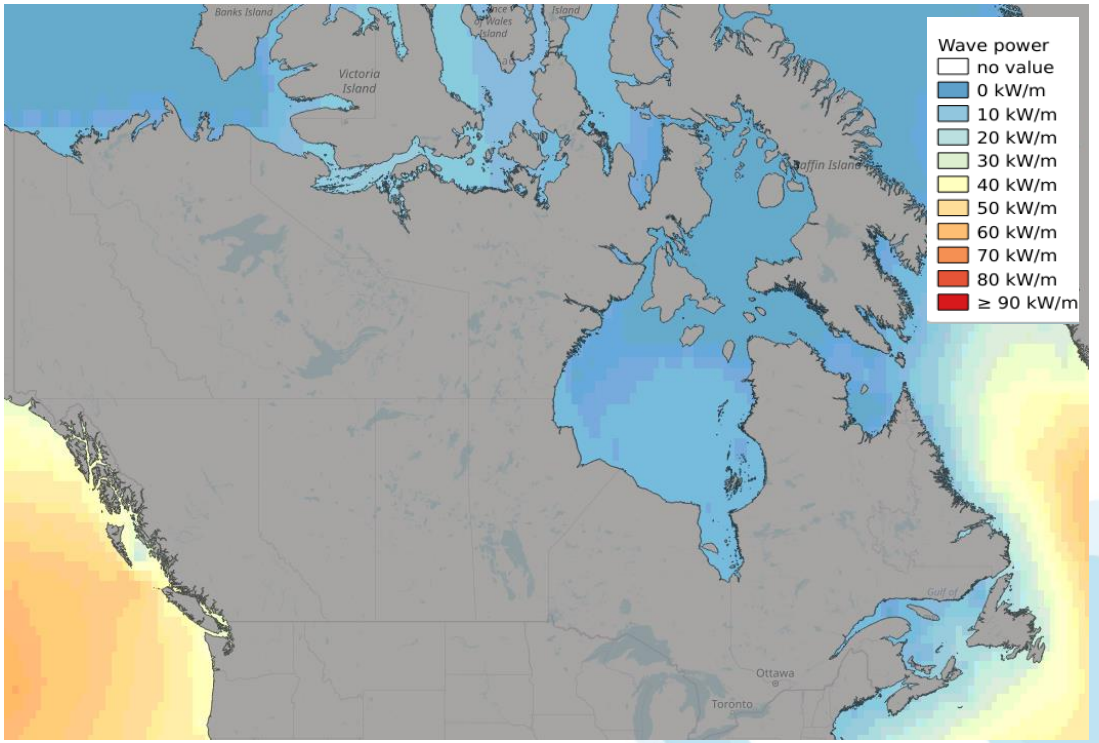
West coast of Canada has the greatest wave energy resource of the country

Wave Energy Resource

The offshore aquaculture farms are spread along the west and east coasts of Canada and so, the WED that will have each of them changes regarding their location. Each province can be classified with respect to WED as:

- Low, 10 – 20kW/m. Provinces located more in interior like Ontario, Quebec and New Brunswick.
- Medium, 20 – 30kW/m. East coast provinces such as Newfoundland and Labrador and Nova Scotia.
- High, 30 – 50kW/m. Farms located in the west coast, British Columbia.

There is more wave resource in the west coast although, in less range, there are certain provinces of the east coast where there is also wave potential.



Map of the WED in the coast of Canada

Salmon and tuna are the most commonly farmed finfish species in the marine aquaculture market of Australia

Description of the market

In the recent years in Australia, aquaculture production has increased its contributions to the fisheries and aquaculture gross value added (GVP) in 27%. This has been thanks to the declining of wild-caught production as well as the increase of the salmonids farming industry in Tasmania. In 2018, Australian aquaculture market accounted for 36% of the total seafood production of the country and it is expected to reach the 50% by 2024.

There are certain species that aquaculture production in Australia is focused on: finfish species such as **salmon and tuna**, crustaceans like prawns and shellfish like oysters. In this project, only finfish species are considered. In 2018, the values of the finfish market were:

- Atlantic Salmon and Trout farming: 61,413 tonnes (78.2%)
- Southern Bluefin Tuna farming: 8,000 tonnes (10.2%)

Although Australia exports a great amount of what it produces, it is a small producer worldwide, contributing only to 1% to the global market. Regarding tuna exports, Japan is the main destination for the production of the country. Due to the decrease of the wild tuna, tuna offshore farms have increased in the last decade.

https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1030023/0
https://www.agriculture.gov.au/sites/default/files/abares/documents/AustraliaCommercialFisheriesAquaculture20181218_v1.0.0.pdf
https://www.frdc.com.au/media-publications/fish/FISH-Vol-27-4/australian-aquaculture

Tasmania is the main producer of salmonids and South Australia has the monopoly of tuna offshore farms

Location of offshore aquaculture farms

Tasmania is the main producer of salmonids in the country. Salmonids include not only the **Atlantic Salmon** but the **Trout** too. Out of the 61 tonnes of salmonids production, 60 tonnes were farmed in Tasmania, 97.8%. The farms are owned by 3 companies: Tassal (29,306 tonnes), Huon Aquaculture (23,681 tonnes) and Petuna (7,058 tonnes).

There are around **60 salmon farms** in the state. They are distributed along the coast and can be divided by the next locations:

- Tamar Estuary: 1 license
- Great Oyster Bay & Mercury Passage: 1 license
- Tasman Peninsula & Norfolk Bay: 9 licenses
- Storm Bay North: 1 license
- Storm Bay Off, Trumpeter Bay North & Bruny Island: 5 licenses
- D'Entrecasteaux Channel & Huon River: 32 licenses
- Macquarie Harbour: 11 licenses

All the production of **Southern Bluefin Tuna** of the whole country takes places in **South Australia**, a total of 8,000 tonnes. There are **16 tuna marine farms** and all of them are located in Eyre Peninsula.

Map of the location of offshore aquaculture farms in Tasmania, Australia

https://salmonfarming.dpipwe.tas.gov.au/
https://pir.sa.gov.au/aquaculture
Figure: https://maps.thelist.tas.gov.au/listmap/app/list/map?bookmarkId=433946

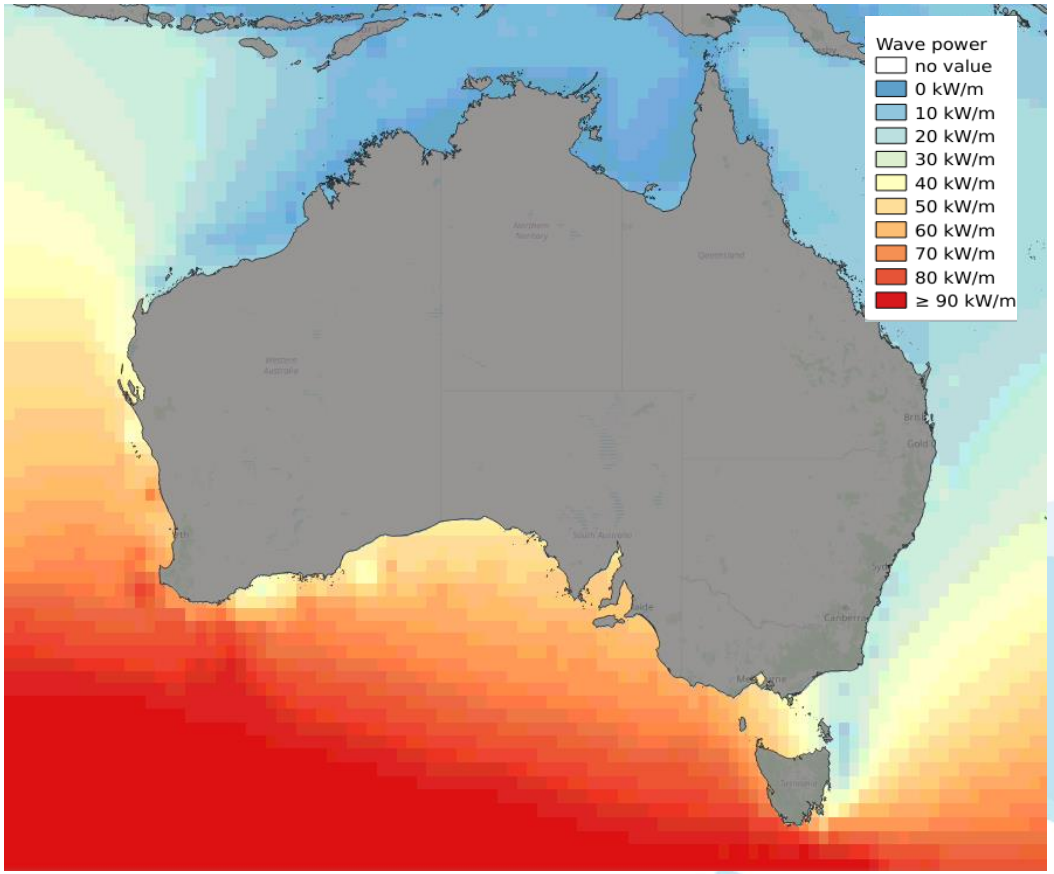
South coast of the country, where finfish farms are located, has a huge wave energy potential

Wave Energy Resource

The offshore aquaculture farms are spread along the south coast of Australia. Since the coast has thousands of miles, the WED that will have each farm changes regarding their location. Each state can be classified with respect to WED as:

- Low, 10 – 20kW/m. North provinces like Queensland or the north part of Western Australia.
- Medium, 20 – 30kW/m. New South Wales province.
- High, 30 – 50kW/m. Farms located in southern provinces like Victoria, Tasmania, South Australia and the south part of Western Australia.

There is huge wave resource, specially in the south coast where mostly of the finfish farms are located.



Map of the WED in the coast of Australia

Chile is the world's second largest producer of salmon, with almost 670,000 tonnes per year

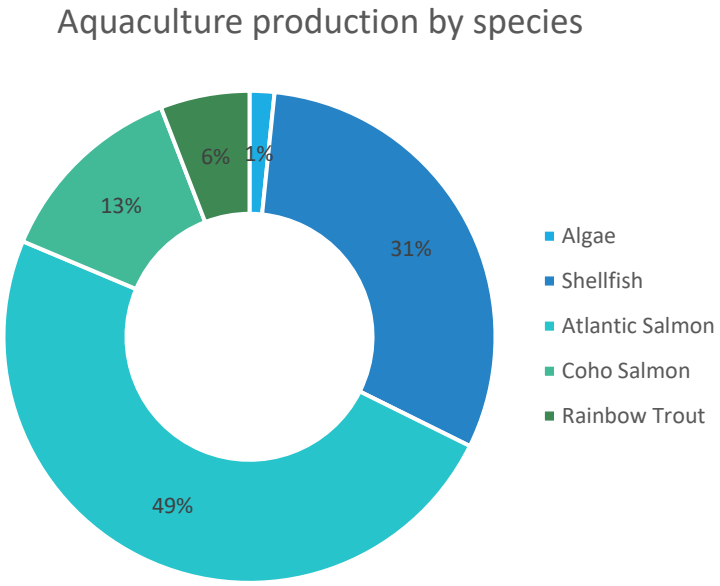
Description of the market

In Chile, aquaculture is one of the main industries of the country and it can be thanks to its geographical characteristics since it has more than 4,200km of coast. Aquaculture market has been developed in parallel with the global market. In 1980, aquaculture accounted only for 6.8% of the fish national market increasing to 29.9% by 2002. In 2018 the aquaculture market represented 36.6%. The United States are the main consumers of the Chilean fish accounting for 36% of the exportation followed by Japan with 32%.

The aquaculture market in Chile is composed by finfish (68%), shellfish (31%) and algae production (1%). As it has been mentioned before, shellfish and algae are not going to be considered due to the low energy demand required for their production. In 2018, **Atlantic salmon, Coho salmon** and **rainbow trout** were the finfish species with greater production volume:

- Atlantic salmon farming: 669,237 tonnes (72.4%)
- Coho salmon farming: 174,594 tonnes (18.9%)
- Rainbow trout farming: 80,069 tonnes (8.7%)

Chile is the second worldwide salmon producer, only after Norway. The 62% of the aquaculture market is destinated to the production of both Atlantic and Coho salmon. The salmon production in farms started in the 1960s but it was not until the 1990s that this kind of production boomed in Chile.



https://www.conicyt.cl/documentos/drj/ue/Pesca_Acuic_Fishery_Aquac_BD.pdf
https://ml.globenewswire.com/Resource/Download/1766f220-c83b-499a-a46e-3941577e038b
http://www.sernapesca.cl/informacion-utilidad/anuarios-estadisticos-de-pesca-y-acuicultura

There are almost 1,800 of salmon and rainbow trout farms in Chile, mainly in the south coast

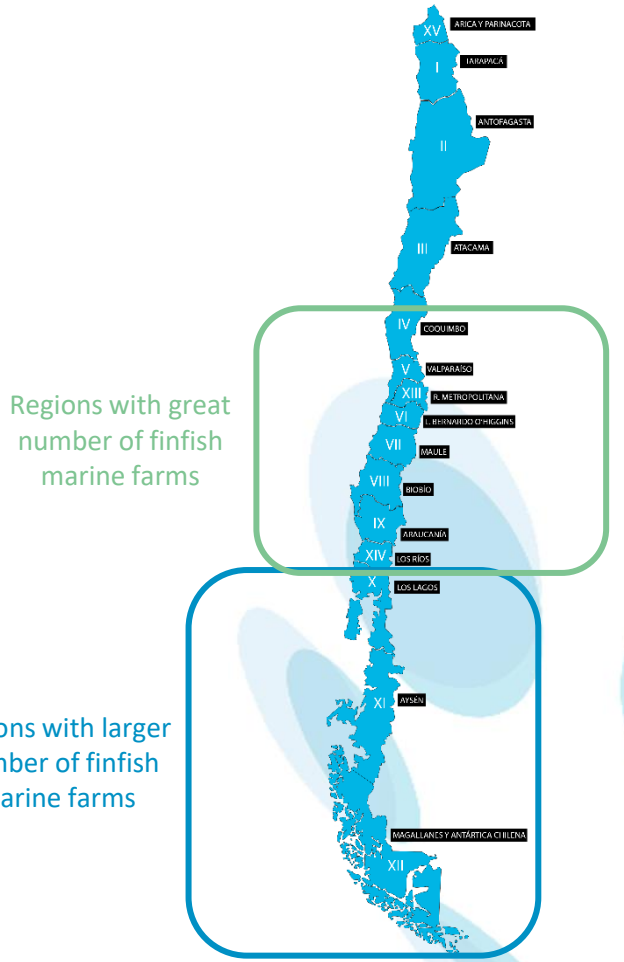
Location of offshore aquaculture farms

In 2018, **there were 1,789 aquaculture farms producing finfish**. Although being spread along the Chilean coast, the farms are mainly concentrated in 3 regions:

- Region X (Los Lagos): 664 licenses
- Region XI (Aysén): 766 licenses
- Region XII (Magallanes): 140 licenses

Other regions with great number of finfish offshore farms are:

- Region IX (Araucanía): 95 licenses
- Region XIV (Los Ríos): 54 licenses
- Region VIII (Biobío): 24 licenses
- Region VII (Maule): 15 licenses
- Region IV (Coquimbo): 12 licenses



Map of the location of offshore aquaculture farms in Chile

https://www.conicyt.cl/documentos/drj/ue/Pesca_Acuic_Fishery_Aquac_BD.pdf
http://www.sernapesca.cl/informacion-utilidad/anuarios-estadisticos-de-pesca-y-acuicultura

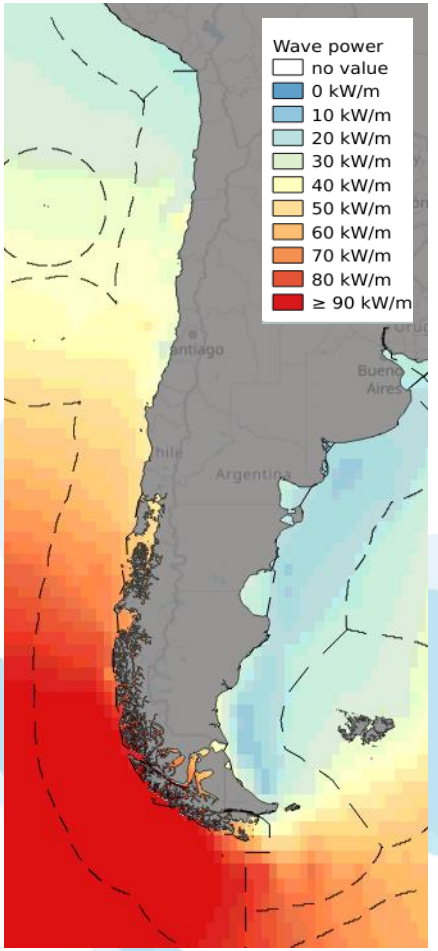
The Chilean coast have great wave energy potential, from 20kW/m in advanced

Wave Energy Resource

The offshore aquaculture farms are spread along the Chilean coast and so, the WED that will have each of them changes regarding their location. Each region can be classified with respect to WED as:

- Medium, 20 – 30kW/m. North regions such as Arica and Parinacota, Tarapacá, Antofagasta and Atacama.
- High, 30 – 50kW/m. Those regions located in the middle of the country, from Conquimbo to Los Lagos region.
- Very high, > 50 kW/m. Southern regions like Aysén and Magallanes.

Generally, the wave resource that Chile has is quite high. The regions with larger number of marine farms match with those ones that have greater WED.



Map of the WED in the coast of Chile

New Zealand has positioned its aquaculture industry at the high-end of the market, farming King salmon in the finfish category

Description of the market

New Zealand has positioned its aquaculture industry at the high-end of the market, exporting premium seafood products to 79 countries. In 2018, there were farmed mainly 3 species: mussels (86.5%), King salmon (12%) and oysters (1.5%). If considering only the production of finfish species the production can be translated into tonnes as 14,338 tonnes of King salmon farming.

King salmon, the unique salmon species farmed in New Zealand, was introduced in the country as game fish in the late 19th Century from Northern California. Farming of salmon started in the 1980s. Today, 35% of the King salmon production is exported to 26 countries and the rest is consumed locally. This industry, New Zealand's salmon farming, won a prize for being the world's greenest by the Global Aquaculture Performance Index.

There are more than 10 sea farms across the country

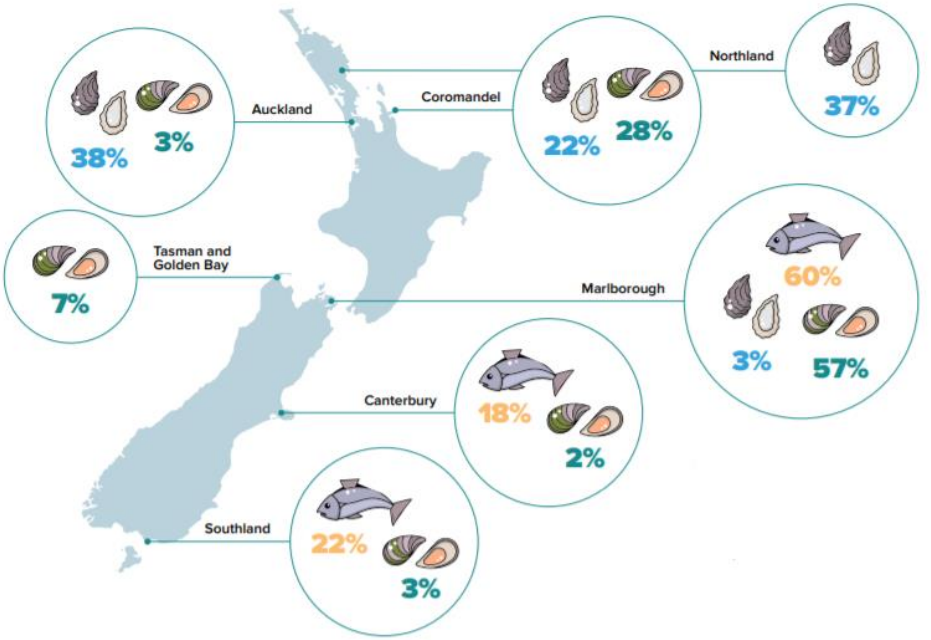
Location of offshore aquaculture farms

King salmon is adapted to life in both fresh and sea water. They are harvested at land-based farms and then, transferred to sea pens. Fresh water farming occurs in Canterbury, Otago and Tasma taking advantage of hydro canals. Sea water operations take place in areas with specific characteristics regarding their isolation, water quality and flow. Areas with strong currents are usually selected to avoid effects of the waste on the environment. As the site selection is so critical, there are few suitable sites:

- Marlborough Sounds: 8 farms accounting for the 60% of the salmon production.
- Southland: 2 farms located in Big Glory Bay accounting for the 22% of the salmon production.
- Canterbury: 18% of the salmon production. The number of farms is not available.

In total, there are **more than 10 marine farms of King salmon.**

The common size of the nets used is of 18,000m^3. These sea pens are designed specifically for the characteristics of the country and are placed up to 17m deep.



Map of the location of offshore aquaculture farms in New Zealand

http://www.salmon.org.nz/
https://www.aquaculture.org.nz/
Figure: https://www.fisheries.govt.nz/dmsdocument/15895-the-governments-aquaculture-strategy-to-2025

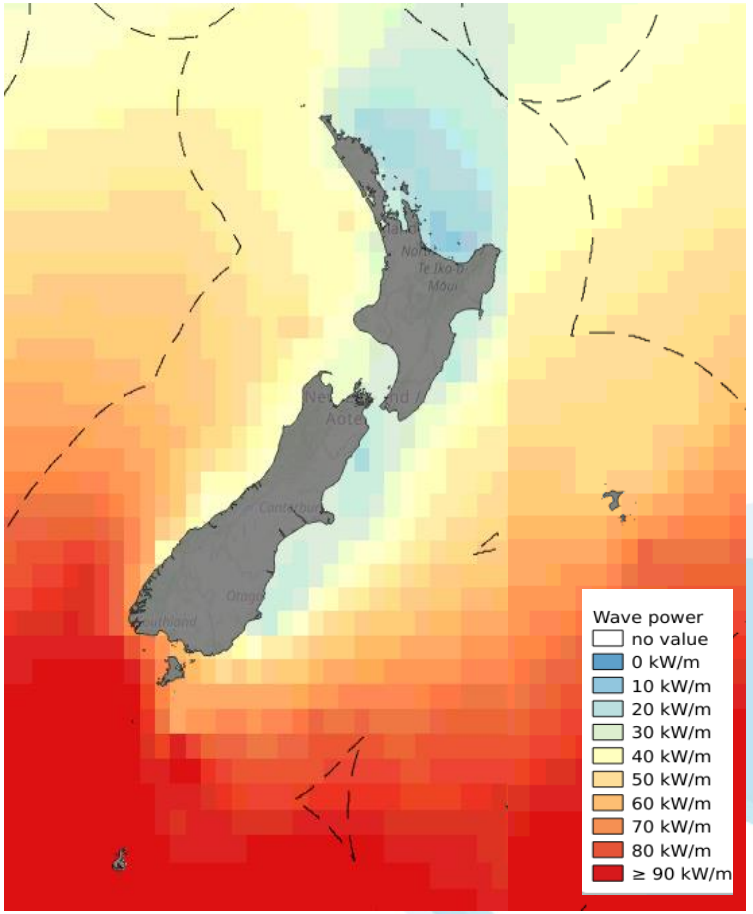
Southern coast of New Zealand, where the salmon farms are located, has a very high wave energy resource

Wave Energy Resource

The offshore aquaculture farms are spread across the southern half of New Zealand coast and so, the WED that will have each of them changes regarding their location. Each region can be classified with respect to WED as:

- Medium, 20 – 30kW/m. North and east coast of New Zealand. Farms located in Marlborough Sounds and Canterbury which are more than 8.
- High, 30 – 50kW/m. West coast of the country.
- Very high, > 50 kW/m. South coast of New Zealand where farms of Southland are placed, a total of 2.

Generally, the wave resource that New Zealand has is very high and enough to power any farms regardless its location.



Map of the WED in the coast of New Zealand

Spain is the third EU's country in the aquaculture farming of finfish

Description of the market

In 2017, Spain was the European Union's country with the largest aquaculture market (considering produced tonnes) and the third one regarding the production of finfish.

The main farmed species in the country are mussels (78.5%), **European sea bass** (6.4%), rainbow trout (5.4%) and **sea bream** (4.3%). All the finfish accounted for 14% of the whole aquaculture market and the following species can be remarked:

- Sea bream farming: 14,930 tonnes
- European sea bass farming: 22,460 tonnes
- Turbot farming: 7,450 tonnes
- Sea bass farming: 2,500 tonnes

At the early 1980s, marine finfish aquaculture started in Spain and this market increase rapidly until 2009, when its growth slowed down. In recent years marine aquaculture has started again to increase. The main autonomous communities with presence of this industry are Valencia with 31% of the marine finfish market, Murcia (22%), Canarias (17%), Galicia (16%) and Andalucía (14%). The amount of production by species and autonomous community can be seen in the next table.

Species	Andalucía	Canarias	Cataluña	Galicia	Murcia	Valencia
Sea bream	1,560	2,380	-	-	3,184	7,806
European sea bass	4,479	5,793	30	-	7,525	4,633
Turbot	-	-	-	7,350	-	-
Sea bass	50	-	-	-	-	2,450

Marine finfish production in Spain, 2018 (tonnes)

Out of the 37 marine farms of Spain, 15 are located in the Atlantic coast and 22 in the Mediterranean Sea

Location of offshore aquaculture farms

In 2017, out of the 5,100 aquaculture farms there were **37 marine finfish farms in Spain**. From the available data it is known that 15 marine farms are located in the Atlantic Ocean and other 22 in the Mediterranean Sea. They can be classified by autonomous communities:

- Galicia: 4 farms
- Canarias: 11 farms
- Cataluña: 2 farms
- Valencia: 13 farms
- Murcia: 6 farms
- Andalucía: 1 farm

Map of the location of offshore aquaculture farms in Spain

http://apromar.es/sites/default/files/2019/InformeAcui/APROMAR%20Informe%20ACUICULTURA%202019%20v-1-2.pdf
Figure: https://servicio.pesca.mapama.es/acuivisor/

The Atlantic coast of Spain has a great wave energy resource

Wave Energy Resource

The offshore aquaculture farms are spread along the Spanish coast, which is in both Atlantic Ocean and Mediterranean Sea. Therefore, the WED that will have each of them changes regarding their location. Each region can be classified with respect to WED as:

- Low, 10 – 20kW/m. The Mediterranean coast and so, the autonomous communities placed on it like Cataluña, Valencia, Murcia and Andalucía.
- Medium, 20 – 30kW/m. Northeast coast and Canary Islands.
- High, 30 – 50kW/m. Northwest coast and so, Galicia.

The Atlantic coast of Spain has a great wave energy resource but that is not the case for the Mediterranean one, where most of the finfish marine farms are placed.

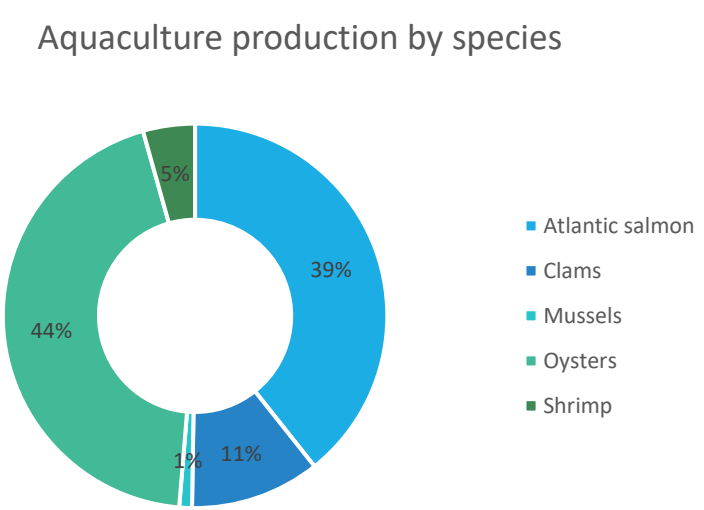
Map of the WED in the coast of Spain

The main finfish producer in the United States is the Atlantic salmon although the country is not a global main producer

Description of the market

The United States is the 17th on the worldwide ranking of aquaculture production with 37,347 tonnes of marine farming. However, half of the consumed seafood comes from aquaculture imports. Considering marine aquaculture, it can be remarked different species such as Atlantic salmon considering finfish and oysters when considering shellfish.

In 2017, the production of Atlantic salmon was the largest one of the finfish species, accounting for 39% of the marine aquaculture production. Translated into tonnes, 14,685 tonnes of Atlantic salmon was farmed.



Atlantic salmon production is placed in northern states such as Washington and Maine

Location of offshore aquaculture farms

Although there are 1,071 finfish farms in the United States, most of them are freshwater species. There are around **6 marine finfish farms** in the United States. They are distributed along both the west and east coast and Hawaii islands. With the available information of 6 of those marine farms can be done the next division:

- Hawaii: 3 licenses. The farmed species is the Hawaiian kampachi with a total annual production of 729 tonnes.
- Washington: 1 license. It harvests Atlantic salmon, with an annual production of 7,711 tonnes.
- Maine: 2 licenses. The farms are specialised in the Atlantic salmon production, with an annual production of 4,082 and 10,886 tonnes.

The annual production of the farms is a mean value. Although in 2017, the total production was of almost 15,000 tonnes, in previous years it was greater.

Map of the location of offshore aquaculture farms in the United States

https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Aquaculture/Aqua.pdf
https://www.arcgis.com/apps/Cascade/index.html?appid=e97ddd2cd9cf46218cefeed813e26c87

Pacific coasts, continental and Hawaiian coasts, have greater wave energy resource

Wave Energy Resource

The offshore aquaculture farms are spread along the different American coasts and so, the WED that will have each of them changes regarding their location. Each state can be classified with respect to WED as:

- Low, 10 – 20kW/m. Great part of the east coast, including Maine, and the Gulf of Mexico.
- Medium, 20 – 30kW/m. Hawaiian coast and south west coast.
- High, 30 – 50kW/m. Along the west coast of the United States, including the state of Washington.

Due to the size of the country, the wave energy potential changes a lot from one point to other but it is remarkable that the Pacific coasts have greater resource.

Map of the WED in the coast of the United States

1. Introduction

2. Overview of the niche market

3. Analysis of the marine aquaculture

I. Main geographical markets

II. Power requirements

III. Opportunities for wave energy

4. Main conclusions

Power demand data has been obtained from the examples of 3 Norwegian salmon marine aquaculture farms

Characteristics

As it has been mentioned before, marine aquaculture is not an energy intensive industry since the pumps used in the on land aquaculture farms, which are the most power demanding, are not necessary. In this case, markets such as shellfish and crustaceans' production are neglected due to their low power demand. This analysis considers only finfish species since they are the ones that require more energy.

For the analysis of the power demand it has been studied the data of 3 offshore aquaculture farms of Grieg Seafood company. The farms harvest salmons in the Norwegian coast. The values given in the following slides correspond to those farms and may not be a rule for the rest of the farms and finfish species worldwide. Salmon is assumed as a reference specie since the demand for other finfish species should not vary drastically.

General information about the farms:

- Location: Rogaland region, Norway
- Capacity of the sea cage: 150,000 salmons
- Information about the farms: Dale with 3 sea cages, Teistholmen with 6 sea cages and Laupland with 8 sea cages. All of them have grid connection and so, they are not suitable options for the installation of wave energy. However, that grid connection allowed to know the exact energy consumption.

The peak power demand takes place during the day due to the feeding system

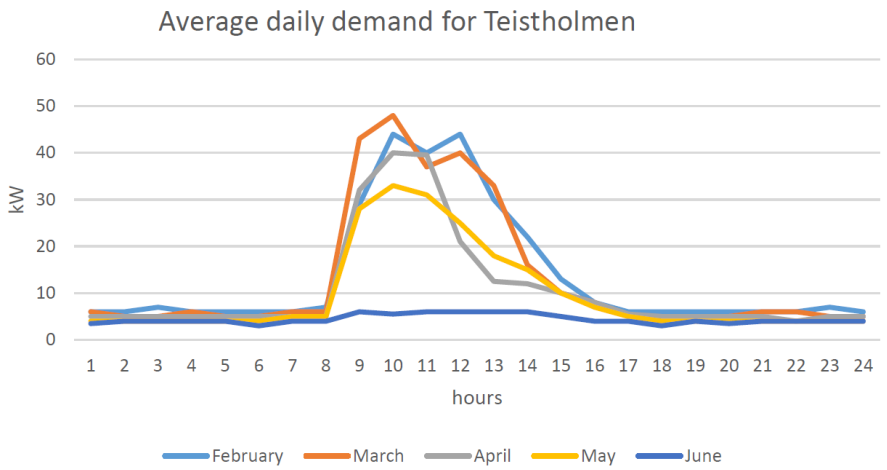
Power demand

Although salmon can be harvested during the whole year, the power demand in winter is greater than in summer due to special lights needed to take care of the fish. It can be distinguished the demand between the day and the night. The energy consumed during the night, which is the base demand, is for:

- Heating
- Lights
- Computers
- Surveillance system
- Kitchen

During the day, it must be added other power demand: the feeding process, which is the most energy intensive. The crane and the dead fish handling are also used during the day hours despite not being used every day. For this reason, the peak of the power demand is during the day. Therefore, the average power demand of a finfish farm with 900,000 fish is:

- Base demand: 4 – 5kW
- Peak demand: 40 – 50kW



Mean daily demand at Teistholmen farm (with 900,000 salmons)

In the previous plot, it can be remarked that during June there were no salmons in the offshore farm and so, the demand was the base demand.

The farm's power demand depends mostly on its capacity since the feeding system is the most energy intensive

Power demand by equipment

In a marine aquaculture farm, 94.2% of the energy demand corresponds to the feeding of the fish and other 4% to the demand of running the farm. Divided by equipment, the power and daily energy demand* is the following one:

	Equipment	Peak power (kW)	Average power (kW)	Daily energy demand (kWh)
	Feeding system (compressor)	92.8	32	98 - 256
Constant demand	Crane	30	5	2.5
	Monitoring system	3	1	24
	Dead fish handling system	28	7.5	12.5 - 22.5
	Underwater lighting	6	6	0 or 144**
	Indoor lighting	0.5	0.5	1 - 5
	Outside lighting	1	0.5	3 - 8
	Electronic heating	8	2	0 - 48
	Hot water tank	2	1	4 - 10
	Kitchen (fridge, coffe maker)	8	7	4.5 - 7.4
	Others (removable equipment)	10	1	0 - 8
		189	**63.5**	**149 - 535**

Summary of the power and daily energy demand of the equipment of a marine farm

The mean daily power demand is of 340kWh in a farms of 900,000 salmons.

The **mean daily constant demand** is of **165.5kWh**, which can vary depending on the power of the equipment of the farm, and the **mean daily demand per 100,000 salmons** is of **20kWh**. This last one corresponds to the feeding system that depends on the number of fish.

** Data is given for a farm of 900,000 salmons.*

*** Depending the season. Depending on the location of the farm, during summer can has solar light during all day while in winter can happen the opposite.*

1. Introduction

2. Overview of the niche market

3. Analysis of the marine aquaculture

I. Main geographical markets

II. Power requirements

III. Opportunities for wave energy

4. Main conclusions

To change diesel generators, a hybrid off-grid system of renewable energies and batteries would be a competitive option

Competitiveness

Diesel generators

Today, most of the marine fish farms rely on diesel generators because they can power the facilities when it is necessary, they have a reduce space to locate them in the feed barge and they have a well proven technology. However, the fuels costs are high due to the diesel transportation and fluctuate. With the aim of cutting this dependence and looking forward to a cleaner environment, aquaculture companies are considering changing them. Environmentally, generators are a risk because of the spills and the pollution threw to the ocean.

- Capital cost: 500$/kW without including the price of the diesel that must be used

Wind energy

Wind resource is greater in open sea. Turbines can be placed in the feed barge, where small turbines must be used, or fixed into the bottom for shallow waters or floating for deeper waters. The most economical option is to use the feed barge as base for the generator. Nevertheless, the limitation of space in the feed barge could cause wake effect problems. Batteries are recommended for a reliable supply.

- Capital cost: 5,000$/kW

Solar energy

By using PV solar panels, the fish farm can be directly powered. These panels can be place on the feed barge or floating, although this last option is not the best one because they can be damaged by waves and salt. As disadvantages of this resource are the space limitation of the farm for the installation of the panels and the low resource that northern places have. As a positive aspects it can be mentioned the few maintenance that the panels need and that the peak power supply matches with the peak demand. It has been proved that the efficiency of the solar panels is quite high in open sea thanks to the reflection of the ocean water. However, batteries still being required.

- Capital cost: 2,500$/kW

http://www.esru.strath.ac.uk/Documents/MSc_2016/Syse.pdf

Grieg, a salmon farming company, pioneered the installation of wind and solar energy to power a marine salmon farm

Examples

Solar and Wind energy

- Grieg Seafood, a Norwegian salmon farming company, is pioneer in reducing greenhouse gas (GHG) emissions by changing the powering sources. Their target is to reduce 30% of GHG emission per kilo by 2030 having as baseline the 2017.
- The company was the first installing renewable energy for powering its salmon farm in Rogaland.
- The pilot project consisting in a hybrid system, which is composed by a wind turbine (14kW), PV solar panels (35kW), lithium-ion battery bank (146kWh) and two diesel generators (130kW and 10kW), allows to save 36,000 litres of diesel and 98 tonnes of CO_2 per year.
- The solar panels are installed at the site, on the roof of the feed barge, while the wind turbine is located in the side of the vessel.

Grieg salmon farm's solar installation

- Although a renewable system was not economically profitable, it was demonstrated that a hybrid system is cheaper than a diesel one.
  - Diesel generator system (110kW and 10kW generators): NPC of 1,032,545$ and COE of 0.61$/kWh
  - Current hybrid system: NPC of 864,101$ and COE of 0.51$/kWh
  - Complete renewable system (59kW of wind, 109kW of PV and 1,183kWh of Li-Ion battery): NPC of 1,703,810$

https://www.griegseafood.no/en/
https://uis.brage.unit.no/uis-xmlui/bitstream/handle/11250/2460955/Nuland_Svein_Erik.pdf?sequence=1&isAllowed=y

In Malta there is a hybrid aquaculture farm with wave energy

Examples

Wave energy

- AquaBioTech company in collaboration with Albatern integrated WECs in fish farms 6km far away from the Malta's coast.
- AquaBioTech is an aquaculture consulting and technology supply and Albatern, a Scottish company, supplied the WECs called WaveNET.
- The pilot project deployed in 2017 used the Subflex submersible cages that were at TRL 7 state, as well as the WECs. The TRL 9 state project was expected to be launched in 2019.
- Although this WEC did not generate a great amount of energy, it was enough for powering a fish farm.
- The commercial scale wave farm was composed by 96 Series 6 WaveNET Albatern of 7.5kW each. The total power capacity was of 720kW. The WaveNET converters serviced 48 Subflex cages (7,240m^3 each) that had an expected output of 6,000MT/year.
- The project was located at 5 – 8km from the southeast of Malta Mainland in a water depth of 50 – 70m.

WaveNET converters

1. Introduction

2. Overview of the niche market

3. Analysis of the marine aquaculture

   I. Main geographical markets

   II. Power requirements

   III. Opportunities for wave energy

4. Main conclusions

Conclusions of the Marine Aquaculture

- Marine aquaculture market has grown in the recent years due to the increasing population and the over exploitation of wild fishing.
- Offshore aquaculture is not an energy intensive sector since the pumps used in on land aquaculture farms, which are the most power demanding elements, are not necessary. Only finfish species farms have been considered because they are the ones that require more energy to grow, not considering shellfish and mollusc. In 2018, finfish farming represented 66% of the total aquaculture production and 24% of the marine aquaculture.
- Salmon is the most finfish farmed species although there are other ones such as trout, tuna and sea bass. The main finfish markets are located in high latitudes. These are Australia, Canada, Chile, New Zealand, Norway, Spain and the United States.
- Most of the considered countries have high wave potential, from 20 – 70kW/m of wave energy density (WED). Spain and the United States are the ones with lower potential and their markets are also less relevant.
- Chile and Norway are the countries with larger marine finfish market, between 900,000 – 1,350,000 tonnes. Norway has a greater production but, Chile has more marine farms, around 1,800. Canada followed them with only 10% of the Norwegian production. Thanks to the wave potential of these regions, Australia and New Zealand could be considered though the lower production of finfish.
- The power requirements of the farms consist on the one hand, on a base demand including lights, computers, etc. and on the other hand, on the feeding system that is the most energy intensive. This last one is variable depending on the number of fish. For example, for a 900,000 fish farms there is a base demand of 165kWh and a feeding system demand of 175kWh. It is worth mentioning that the peak demand takes place during the day.
- There are already projects involving renewable energies with the aquaculture market such as the integration of wind and solar energy in the power supply system of a Norwegian marine farm and a pilot project with wave energy. The Norwegian project has demonstrated that a hybrid power system is cheaper and, obviously, more environmentally friendly than a pure diesel system.

All the bibliography used is in an additional file.

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