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Report

Equipment and systems onboard fishing vessels

Fishing vessels, equipment, handling, and processing, including cooling, freezing, and heating

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ABSTRACT
The Norwegian fishing fleet consists of different types of vessels, ranging from small boats to large factory trawlers. The fishing methods typically used in Norway are also described. Fishing vessels use different technologies and methods for keeping their catch cold and preserving fish quality and shelf life. Vessels may store the fish on ice, chill it in refrigerated fresh- and sea water, freeze the catch in plate freezers, brine freezers or use blast-freezers for single frozen fillets or deep-water shrimps.

Refrigeration systems contribute to greenhouse gas (GHG) emissions and, consequently, climate change. However, refrigeration is also necessary to avoid food losses, by keeping the fish quality more stable and increasing shelf life. Most Norwegian vessels have refrigeration or chilling of the fish as a standard practice, but many smaller vessels in other countries do not have that possibility.

This report covers description of fishing vessels, fishing methods and equipment for fish handling. It also describes different processing methods, including slaughtering, refrigeration, filleting etc. Energy saving methods are proposed and issues related to sustainability are described.

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Table of contents

1 Introduction

The Norwegian fisheries sector has always played a key social and economic role, nationally and regionally, and has been the basis for settlement and employment along the entire Norwegian coast. Ever since the 12th century, stockfish has been an important export product.

Today, Norway is one of the largest seafood suppliers in the world, including both wild catch and aquaculture, with an export value of 102 billion NOK in 2020 (Statistics Norway, 2021). Seafood from Norway is exported to more than 150 countries and its main markets in terms of export value are the European Union (EU), the Russian Federation, Japan, China, Ukraine, and the United States of America. Due to the ongoing COVID-19 pandemic, Norway has faced changes within their export markets.

At the start of the pandemic in March 2020, Norway encountered difficulties in maintaining its seafood exports. With looming uncertainty of cross-board travel and disease outbreaks, Norway's exports of fresh salmon to China fell 97% to 15 tonnes compared to the nearly 600 tonnes exported the year prior (Seafood Norway, 2020). Although seafood exports have since resumed, Norway has found a rise in countries wanting to import frozen cod, leading the demand for better and more sustainable freezer and refrigeration systems.

Norway has established three economic zones of 200 nautical miles: the Norwegian economic zone, the fishery protection zone around Spitzbergen and the fishery zone around Jan Mayen. The legal regime for the Norwegian Exclusive Economic Zone around the Norwegian mainland is enshrined in the UN Law of the Sea Convention of 10 December 1982. A fishery protection zone around Svalbard was established with effect from 15 June 1977, and the fishery zone around Jan Mayen was established with effect from 29 May 1980 (Regjeringen.no, 2014).

Norwegian fisheries policy and management are based on the principles of sustainable harvest of marine living resources based on healthy marine ecosystems. Today, nearly all stocks with commercial value are regulated through quotas (total- and individual quotas) and licensing.

Norway has a diversified and technologically advanced fishing fleet, encompassing everything from small one-person inshore fishing vessels to large sea going trawlers and purse seiners. Developments have moved towards fewer and more efficient fishing vessels. The main principle in Norway is that the fishing vessels are owned by persons who are active in the field, but the land-based fishing industry can be up to 49% part-owners in a fishing vessel. The industry is also very diversified from large companies quoted on the stock exchange to smaller family-owned fish processing companies.

This report is about methods and equipment onboard fishing vessels, especially from Norway. Many of the systems and equipment are also found in fishing vessels from other countries, depending on the types of fish caught. Chapter 2 describes types of fishing vessels and sizes in Norway, it also briefly describes the quota system and regulations. Chapter 3 goes more into details on the fishing methods and gears and chapter 4 describes refrigeration equipment and use. Freezing and chilling is part of the processing onboard, but the vessel may also have other processing equipment, which is described in chapter 5. To solve many of the issues regarding environment and emissions, it is necessary that fishing vessels also reduce their contribution to emissions and energy use. Some of these measures are described in chapter 6. More details on this topic, with focus on alternative fuels and propulsion systems can be found in a CoolFish report by Gabrielii et al (2020, a). In Chapter 7 the sustainability of fisheries is briefly addressed, in terms of carbon footprint, traceability and governance. Another CoolFish report by Gabrielii et al (2020, b) provides an overview of standards and certification schemes, as well as previous studies on carbon footprint assessments. Finally, in Chapter 8 the report is summarized and some suggestions for further work are provided.

SINTEF

2 The Norwegian fishing fleet

This chapter gives a brief presentation of the Norwegian fishing fleet, the main fisheries, regulation of the fisheries and environmental regulations.

2.1 Types of fishing vessels and sizes

As of March 2021, there are 5709 active Norwegian fishing vessels registered, half of them being less than 10 m long (Fiskeridirektoratet, 2021a). Figure 1 shows the development in number of Norwegian fishing vessels in the period 1985-2020.

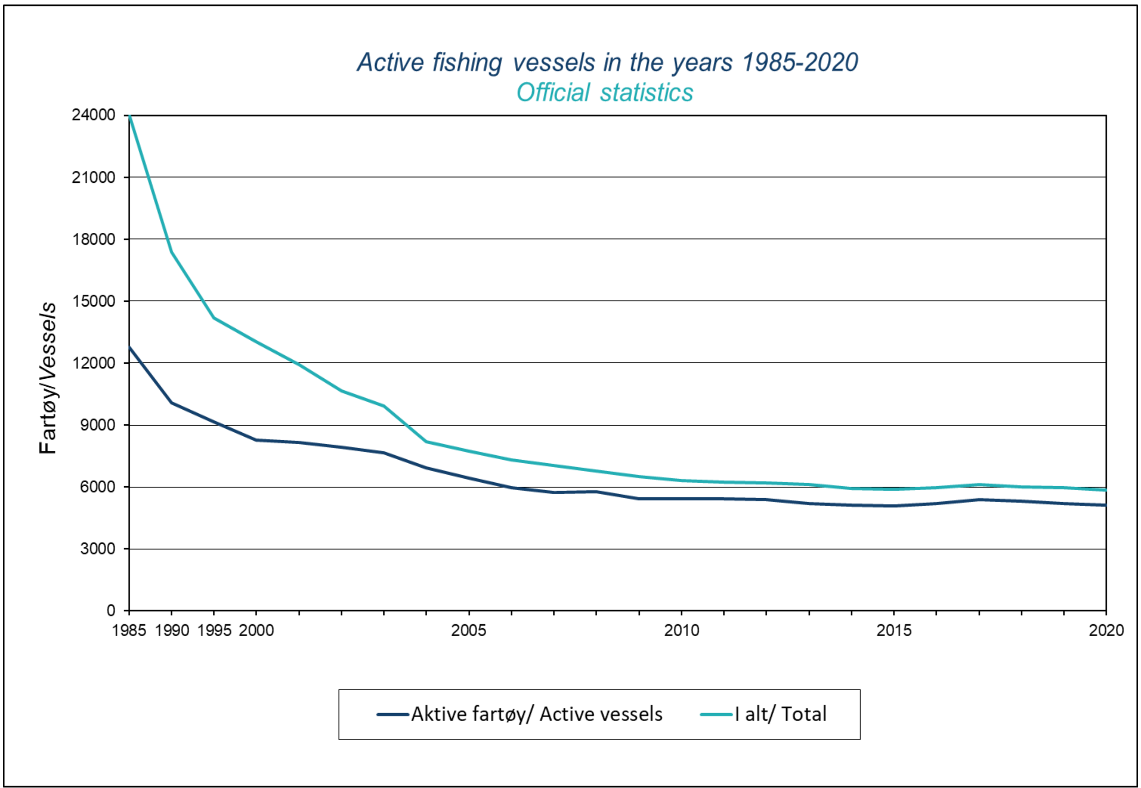

Figure 1. The development in total number of Norwegian fishing vessels in the period 1985-2020.

Figure 1 shows that the number of fishing vessels since the year 2010 has been stable. Construction and operation of Norwegian fishing vessels is subject to regulations implemented by the Norwegian Maritime Authority (NMA). The vessel groups are mainly divided into vessels under and above 15 meters in length, being subjected by different regulations. Table 1 shows the length distribution of Norwegian fishing vessels per 2020. Of the 5709 registered vessels, 473 vessels are above 15 m. Number of vessels within each length segment is shown in Figure 2.

Table 1 Length distribution of Norwegian fishing vessels per 2020

Lenght	Below 10m	10-14,9m	15-20,9m	21-27,9m	> 28m
No. of vessels	3 164	2 348	110	104	256

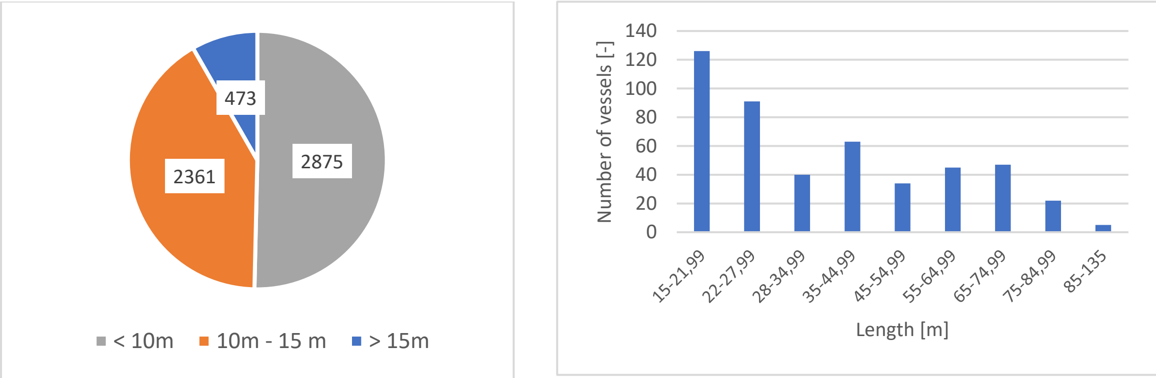

Figure 2. Number of fishing vessels in different length segments (2021)

Norwegian fishing vessels are also categorized into coastal fleet and sea-going fleet. The coastal fleet consists of a closed group with quota rights, and an open group with more limited quota rights, in which all fishers who fulfil the requirements for fishing can participate. Previously the definition of a coastal fleet vessel was one having a length below 28 m. In 2010 this was replaced with a maximum cargo hold of 500 m^3 regardless of the length of the vessel (Standal and Hersoug, 2014). With the new structure there are "coastal" vessels up to 55 m long (Baldursson et al., 2021). Small coastal vessels make shorter trips and usually without any equipment for processing or freezing the catch. The main products from coastal vessels are fresh, whole gutted fish.

Furthermore, the fishing fleet is categorized into which kind of fisheries they are participating in, as an example in the pelagic sector there are purse seiners, coast-purse seiners, pelagic trawlers, and trollers. In whitefish fisheries there are bottom trawlers, Danish seiners, gillnetters, pot fisheries (e.g., king-crab, snow crab, brown crab) and long-liners.

The sea-going fleet, 264 vessels in 2020, consists of larger vessels fishing with bottom trawl, auto-line, purse seine and pelagic trawl (Fiskeridirektoratet, 2021a). The sea-going fleet has 503 fisheries licences, i.e., cod-trawl, shrimp trawl, purse seine, blue whiting, pelagic- and other trawl fisheries.

Freeze trawlers and auto line vessels freeze the catch on board and the main products are headed and gutted (HG) frozen fish. Some of the larger fishing vessels (e.g., whitefish trawlers and autoliners) also have a special permission for onboard production to produce fillets and other products. Onboard production means all (further) processing of fish with exception of freezing, packing, heading, and gutting.

The larger pelagic vessels (purse seine and pelagic trawl) use refrigerated sea water (RSW) and refrigerated fresh water to cool the catch. The catch goes to food production in the land processing industry or to the fish meal and fish oil industry, mainly for feed application. The costal fleet, 1968 vessels in 2020, has various permits, e.g., coast-herring, coast-shrimp, cod/haddock/saithe -north, several coast-purse seine permits.

2.2 First-hand sales

The first-hand sales from the Norwegian fishing vessels to the buyers for further sales and export goes through a sales organization owned and operated by owners of fishing vessels (a ‘coop’). There are five fish sales organizations in Norway:

- Norges Sildesalgslag, https://www.sildelaget.no
- Norges Råfisklag, https://rafisklaget.no
- Møre og Romsdal Fiskesalgslag, www.surofi.no
- Vest-Norges Fiskesalgslag, https://vnf.no
- Fiskehav, https://fiskehav.no/

Norges Sildesalgslag is the only one that is operating nationwide with monopoly on first-hand sales of pelagic species such as herring, mackerel, capelin, sprat. Pelagic species are mainly used for direct human consumption purposes, but some species are also being used as raw material for fish oil and fish meal production, and as ingredient used in fodder for fish farming. The other four sales organisations, where The Norwegian Fishermen's Sales Organization (Norges Råfisklag) is the biggest in turnover, have geographical monopoly right on first-hand sales for other than wild caught pelagic species, including whitefish (as cod, saithe, and haddock), crustaceans and molluscs.

2.3 Main fish species

2.3.1 Pelagic species

The most important species for the Norwegian pelagic fishing fleet is herring, mackerel, blue whiting, and capelin. Most of the national quota in these fisheries is taken by the larger fishing vessels. The total quotas are divided between nations every year through negotiations and is based on historical fisheries data and geographical distribution of biomass within national economic zones.

The result of the quota negotiations, and the fact that these stocks have vast yearly oceanic migrations in the North Atlantic Ocean, means that the fishing boats must be flexible in terms of when and where to fish, and may often travel long distances with the catch. Controlled and rapid chilling of the catch in these fisheries are essential.

(Sildesalgslaget, 2021; Nærings og Fiskeridepartementet, 2020)

2.3.2 Whitefish and demersal species

Norwegian cod catches are generally received fresh from coastal vessels or frozen headed and gutted from cod trawlers, Danish seiners, and auto-liners, in a ratio of about 40% frozen and 60% fresh. The allocation of the cod quota to these groups is shown in Table 2 under the assumption that the Norwegian cod quota is above 330 000 tonnes. The total cod catch has decreased in past years from 473 000 tonnes in 2014 to 328 000 tonnes in 2019 (Fiskeridirektoratet, 2021b). By the allocation rule the trawlers and auto liners each lose about 1% of the cod quota to the coastal fleet vessels (Baldursson et al., 2021).

Table 2 shows the 2020 fishing quotas for the main whitefish species. Other countries include EU, England, Iceland, and Greenland. Norway and Russia extract the main share of the total quota.

Table 2. 2020 quotas for main species of whitefish caught in the north-east Atlantic (north of 62° latitude)

	TOTAL QUOTA FOR 2020 (TONNES)	NORWAY'S QUOTA	RUSSIA'S QUOTA	OTHER COUNTRIES
Cod (*gadus morhua*)	759 000	45%	43%	12%
Saithe/pollock (*Pollachius virens*)	171 982	91%		9%
Haddock (*Melanogrammus aeglefinus*)	215 000	50%	45%	5%

2.3.3 Crustaceans

The yearly catch of crustaceans with Norwegian fishing vessels in the years 2017 to 2020 are shown in Table 3 (Fiskeridirektoratet, 2021c).

Table 3. The yearly catch of crustaceans with Norwegian fishing vessels in the years 2017 to 2020.

	YEAR/ROUND WEIGHT (TONNES)			
	2017	2018	2019	2020

Brown crab (*Cancer pagurus*)	4 924	5 850	5 343	4 734
Snow crab (*Chionoecetes opilio*)	3 101	2 812	4 049	4 451
Raudåte (*Calanus finmarchicus*)	760	1 362	352	n.a.
King crab, male (*P. camtschaticus*)	1 777	2 112	1 527	1 847
King crab, other (*P. camtschaticus*)	167	200	199	234
Deep-water shrimp (*Pandalus borealis)*	13 313	28 220	27 758	24 185
Antarctic krill (*Euphausia superba*)	202 216	206 097	236 844	249 113
Other crustaceans, molluscs & echinoderms	1 458	1 523	1 938	1 254
TOTALS	227 717	248 176	278 011	285 819

Beside the traditional Norwegian species as brown crab and deep-water shrimp, the landed quantities of "new" species Antarctic krill and snow crab are growing as shown in table 3. The fishing grounds for Antarctic krill is 5-6 days from shore. Krill contains active endogenous enzymes and the catch need to be deep frozen or processed onboard (meal, protein concentrates, oil). To utilize the limited onboard storage capacity, water reduction (evaporation and drying) is needed.

Snow crab fished in the Barents Sea & Svalbard area is normally fully processed on board. The processing involves live storage, slaughtering, bleeding, boiling, chilling, brine freezing, glazing, packing before freeze storage on board. The snow crab is very sensitive for high temperature and when stored live the crab must have sea water temperatures below 5°C. The temperature sensitivity, the need for large (live) storage capacity onboard, and the fragility of the snow crab (it easily loses legs) when stored live has resulted in snow crab fished in the Barents Sea & Svalbard area being processed onboard.

2.3.4 Tracking of activity / catch

Today, all fishing vessels over 15 meters must be tracked with the secure tracking system VMS (vessel monitoring system) and their activity and catch are reported through the electronic reporting system, ERS. Within a few years these requirements will apply for all fishing vessels, starting in 2020 for vessels down to 11 meters. In addition, all fishing vessels must send notice of when and where they will land with their catch[1].

2.4 Environmental regulations

The Norwegian maritime legislation is to a large extent characterized by the fact that shipping is a global industry, meaning that Norwegian regulations must be in accordance with international regulations. The main regulatory institution for the shipping sector is the International Maritime Organization (IMO). The IMO convention MARPOL aims at preventing pollution of the marine environment due to operational or accidental causes. The Norwegian government ratifies IMO conventions and introduces them as part of Norwegian laws. The Norwegian Maritime Authority (NMA), which is subordinated to the Ministry of Trade, Industry and Fisheries and the Ministry of Climate and Environment, exercises preventive and investigative control and prepares regulations.

2.4.1 Emissions to air

Sulphur Oxides (SOx): According to MARPOL, ships operating within a sulphur emission-controlled area (SECA) must, since 2015, use fuel with a maximum sulphur content of 0.1%. The sulphur limit for ships operating outside of SECAs has, until 2019, been 3.5%, but was reduced to 0.5% in 2020. The

[1] https://www.regjeringen.no/no/aktuelt/ny-side3/id2828262/e krav til rapportering fra fiskeflåten - regjeringen.no

established SECAs today are the Baltic Sea, the North Sea, and some designated areas in North America. Examples of SECAs that are under discussion include the Mediterranean and the Norwegian west coast (IMO, 2019a).

Nitrogen Oxides (NOx): As of 1 January 2021, the strictest MARPOL NOx requirements, so called Tier III, will be applicable in the North Sea area. This includes newly built fishing ships with an engine power output of more than 130 kW, but also existing ships subjected to a major conversion of such engines. To go from complying with the current Tier II down to Tier III, the NOx emissions must be reduced by approximately 75%. However, under certain conditions the legislation opens up for NMA allowing fishing vessels to not comply with Tier III (NMA, 2020).

Carbon dioxide (CO_2): MARPOL was revised in 2011 to also control CO_2 emissions, by introducing the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), with the aim of establishing a mechanism to increase energy efficiency in a cost-effective way. However, the EEDI does not apply to fishing vessels, and the SEEMP only applies to fishing vessels of 400 GT and above (around 30 m length). In 2018, IMO agreed on a strategy on greenhouse gas (GHG) emissions, with the initial target of reducing the annual emissions from ships by at least 50% by 2050, compared to 2008 (IMO, 2019b).

Norway's Climate Action Plan for 2021–2030 includes a goal of reducing GHG emissions in fisheries and domestic shipping with 50% by 2030. To increase the incentives for more climate-friendly operation, the fishing fleet now (from 2021) must pay the full CO_2 tax. To facilitate the restructuring, a compensation scheme over a five-year period has been introduced (Regjeringen.no, 2020).

Refrigerants: MARPOL regulates the use of refrigerants with an Ozone depleting potential (ODP), such as the traditionally used refrigerant HCFC-22. For example, MARPOL prohibits new installations of equipment utilising ODP substances from 2020, both on new and existing ships. The most used synthetic refrigerants with zero ODP, such as HFC-134a and HFC-404A, has a high global warming potential (GWP). These are not yet constrained by any IMO mandatory requirements. However, the EU Regulation on F-gases, also implemented in Norway, limits production and use of refrigerants with a high GWP. The F-gas regulation includes a service ban on existing high GWP-systems, which also applies to ships. This implies that an equipment using a refrigerant with a GWP > 2 500 and an amount corresponding to 40 tonnes CO_2 equivalents are prohibited to be recharged with new refrigerant from 2020 and with recycled refrigerant from 2030 (Gluckmann Consulting, 2016).

2.4.2 Emissions to sea

Generally, the most environmentally damaging discharges to sea comes from oil or oily water, chemicals, sewage, garbage (including fishing gear), and chemicals, all regulated by MARPOL. Moreover, in 2017 the Ballast Water Convention came into force, with the purpose of preventing the spread of alien species and pathogenic organisms via ballast water. It only applies to fishing vessels constructed for carrying ballast water and with trade area Bank Fishing I or greater trade area (NMA, 2017).

3 Fishing methods and types of fishing vessels

This chapter includes sections introducing the most used fishing gears in Norwegian fisheries.

3.1 Use of different fishing gears

According to the Norwegian Directorate of Fisheries the catch from the Norwegian fishing fleet in 2020 was accomplished by using 54% trawl, 24% seine, 6% hook and line, 6% other fishing gear, 5% Danish seine, 5% gillnet and <1% pots and traps, as shown in Figure 3. Taking catching of whitefish like cod, haddock and saithe as an example, the total Norwegian catch in 2019 was made up of 35% trawl, 20% Danish seine, 19% gillnet, 13% auto line, 8% hand line and 5% purse seines (Baldursson et al., 2021).

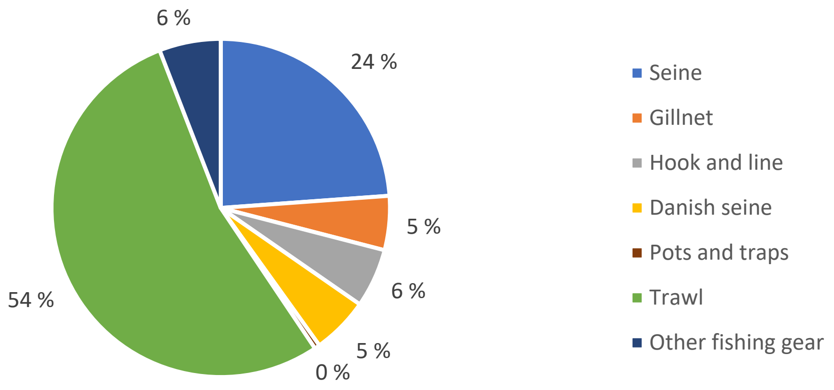

Figure 3. Norwegian catch by fishing gear in 2020 (Fiskeridirektoratet, 2021b)

Fishing gears are commonly classified in two main categories: passive and active. This classification is based on the relative behaviour of the target species and the fishing gear. With passive gears, the capture of fish is generally based on movement of the target species towards the gear, while with active gears capture is generally based on an aimed chase of the target species. Some examples of passive fishing gear are nets, hook, line, pots and traps, while trawls, purse seine, spears and harpoons are examples of active fishing gears (Bjordal, 2002). By sorting the total catch of 2020 by gear and length group of fishing vessels, as presented in Figure 4, it is especially clear that smaller Norwegian vessels usually employ gear like gillnet, hook and line, or seine, while larger vessels' preferred gear of choice are hook and line, seine, Danish seine, or trawl.

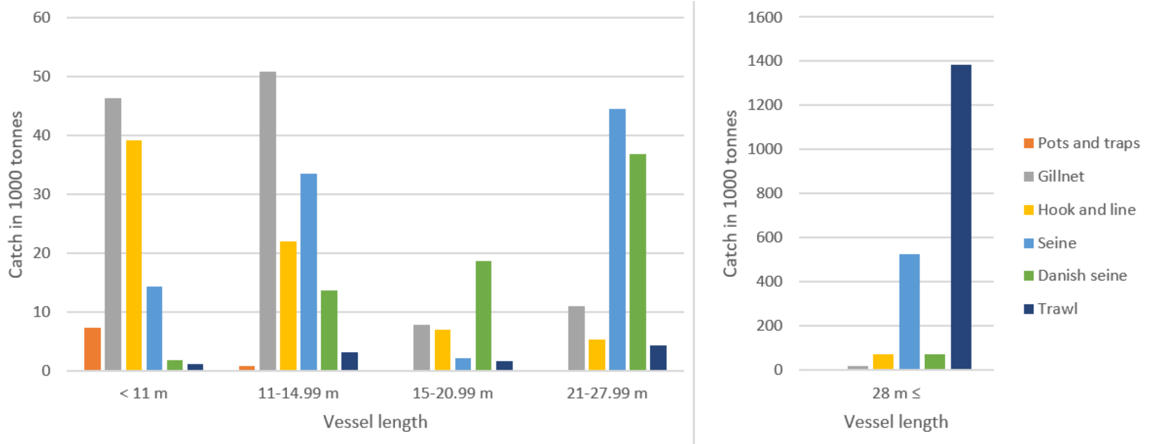

Figure 4. 2020 total catch in thousand tonnes sorted by fishing gear and vessel length. There is far more catch from larger vessels (>28m), so the scale on the y-axis is different in the two graphs. There were 156 000 tonnes registered from "not specified length", which is not included in the graph (Fiskeridirektoratet, 2021b).

3.2 Trawling

Trawling is a fishing method that involves pulling a fishing net through the water behind one or two boats. Stern trawling with one boat is the dominating method in Norway. The net used for trawling is called a trawl. Fish trawls have long metal cables, called sweeps, connecting the trawl boards with the net which allow the boards to spread much further than the overall width of the net. The sweeps 'herd' fish until they tire and drop back into the net where they are finally caught. Trawling can be divided into bottom trawling and pelagic trawling. In bottom trawling the trawl with heavy weights are dragged along the seafloor while in pelagic trawling the net is towed above the seafloor.

Cod (*Gadus morhua*) fisheries are the most important fisheries in the Barents Sea (Yaragina et al., 2011) and approximately 30% of the Norwegian Total Allowable Catch for this species (412 000 tonnes in 2017) is caught by trawl (Fiskeridirektoratet, 2018). Trawlers fishing cod in the Norwegian Exclusive Economic Zone are required to use a sorting system composed of a 55 mm bar spacing sorting grid and a codend[2] with a minimum mesh size of 130mm (Sistiaga et al., 2016; Herrmann et al., 2013). However, fishermen are free to decide the construction materials and the overall dimensions of the codend (Fiskeridirektoratet, 2018). A typical codend would be constructed as a 2-panel codend (100–140 meshes in length, 70–100 meshes around) made of 8–10mm single polyethylene (PE) twine (meshes of 130–140 mm). Most commonly, knotted twine is used in the lower panel of the codend, while knotless twine is used in the top panel. Fishers use this construction as they believe that knotless materials may reduce catch damage to captured fish and escaping juveniles. Knotted materials are substantially cheaper, more resistant, and easier to repair if gear damage occurs. This is especially important when considering the fact that the bottom part of the codend often is in contact with the seabed while towing (Tveit et al., 2019).

As the sea-going fishing vessels in Norway have become fewer and larger over the last decades, technological advances have made it possible to reduce the number of fishers on each vessel considerably. Particularly on larger vessels such as bottom trawlers and demersal seiners, large volumes of fish can be taken on board from a single haul (Erikson et al., 2019). Once on board, the trawl-gear, containing the catch, is usually emptied directly into a steel bin without water (dry bin) located below deck. Depending on storage time there, live, moribund, or dead fish are subsequently processed and frozen. Due to the comparatively low number of personnel on board, catch processing may be delayed. Additionally, some vessels delay catch processing until the fish has become less active after capture to facilitate easy and safe handling. Delay in catch processing can, however, result in poor bleed-out. Additionally, for large catch volumes, processing may take several hours. It is therefore questionable whether the whole catch can be processed before fish eventually die in the dry bin and the blood starts to coagulate (Erikson et al., 2019). SeeTable 6 in section 5.4 for examples of Norwegian factory trawlers with on board fillet production. Figure 5 shows an example of process flow sheet for a Norwegian trawler.

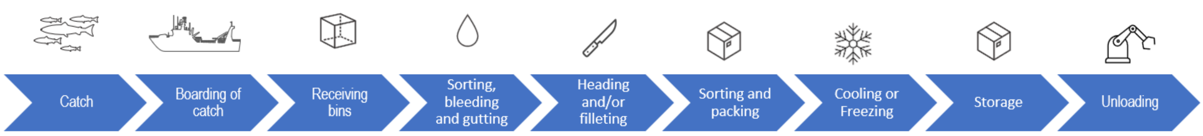

Figure 5. A possible flow sheet for Norwegian trawling.

Research has shown that fishing gear has an impact on fish quality and may result in catch damage and quality degradation of the fish products, as has been shown for trawling, gill nets, Danish seiners, and longlining (Tveit et al., 2019; Esaiassen et al., 2004; Botta et al., 1987). Additionally, both weather conditions, duration and size of the haul may affect the quality of catches by trawl or Danish seiners (Margeirsson et al., 2006). Trawlers in general, but especially those that deliver headed and gutted

[2] the rearmost part of the trawl

fresh cod, often see a substantial reduction in price for the fish they deliver compared to those that deliver frozen fish. For some vessels this reduction affected up to 10% of the catch during 2017, which represented a considerable loss of income for fishers and vessel owners (Tveit et al., 2019). According to fishers, the reason for this phenomenon is that some of the damage to the fish is only visible over time and is not noticeable if the fish is frozen right after capture.

Pelagic trawls and midwater trawls are used by larger fishing vessels (with special permits) to fish after the same pelagic species as with purse seine (especially mackerel and herring), but also after e.g., blue whiting. Pelagic trawl is basically the same gear as bottom trawl, but the pelagic trawl does not touch the seabed.

3.3 Purse seine

Purse seining is a fishing technique used to harvest species of pelagic fish that school or aggregate close to the surface. It uses a large net supported at the surface with a float-line, a leaded rope, and a series of heavy metal rings at the bottom of the net, to quickly sink the net around the targeted catch (known as "purse rings"). The target school is usually located and tracked using hydro-acoustic fish detection technology (e.g., sonar and echo-sounders). Once in position, the fishing vessel sets the net around the target school (~10 minutes). After the net has sunk below the depth of the target school, to prevent the fish escaping beneath the net, the bottom of the net is closed beneath the school by heaving on a wire rope or "purse line", that passes through the purse rings. Using hydraulic winches, the net is slowly hauled in. The hauling process reduces the volume of the net, crowding the catch (Breen et al., 2021). Figure 6 shows photos from the hauling process.

Figure 6. Examples from hauling of net during Norwegian purse seining. Photo by TYD and Guro Møen Tveit, SINTEF Ocean.

When the catch is sufficiently crowded, it is decided whether the catch will be retained or released. If retained, the catch is then transferred into the vessel's refrigerated seawater tanks using a pump, while continuing to haul the net to maintain the catch at a sufficient density for efficient pumping. If the catch is unsuitable (e.g., species composition, high catch amount, fish size or quality) it can be released by opening the bunt-end of the net and slackening the purse-line to create a large opening in the bottom and side of the net. Controlling the catch size may be very difficult, and skippers may end up with more fish in the net than planned. Unless the excess catch can be pumped to a nearby vessel (Digre et al., 2016) they have no choice other than to release parts of the catch. According to Norwegian regulations, the discharge opening must be prepared and opened before 7/8 of the net length is hauled (marked by a visible white float) and must be sufficiently large to permit the unwanted catch to swim out freely (NSFR, 2014) For more detailed descriptions refer to Ben-Yami (1994), Marçalo et al (2018) or Breen et al. (Breen et al., 2021). An example of process flow sheet for a Norwegian purse seiner is shown in Figure 7.

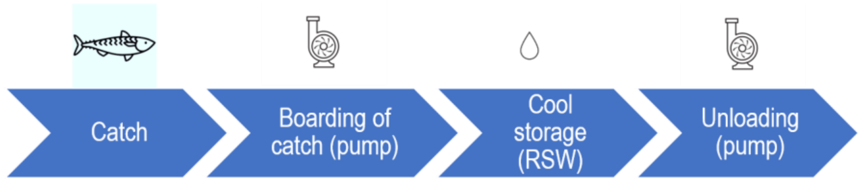

Figure 7. A simplified flow sheet for Norwegian purse seining.

Seine-caught fish often have less skin and scale damage, as well as a higher survival rate, than trawled fish (Gregory and Grandin, 2007; Sørensen and Mjelde, 1992). Typical damage accruing from the fishing gear is bruising or mechanical damage, that often occurs when the fish are pumped automatically from seine nets (Digre et al., 2016).

Capture of fisheries resources by purse seine is globally significant (Watson et al., 2006) and is amongst the most important and energy-efficient wild fish capture methods used in Norway (Schau et al., 2009; Fiskeridirektoratet, 2008). The Norwegian purse seining industry targets smaller pelagic species such as mackerel (*Scomber scombrus*), herring (*Clupea harengus*), and capelin (*Mallotus villosus*), and in 2019 the seining vessels in Norway landed around 1.3 mill. tonnes of fish at a value of approximately 6.7 bill. NOK, with mackerel accounting for more than one third of the value (Fiskeridirektoratet, 2020). Although purse seining is an important and energy-efficient wild fish capture methods (Suuronen et al., 2012) the process can be harsh on the fish and expose them to e.g. crowding and hypoxia (Huse and Vold, 2010; Lockwood et al., 1983). Mackerel is a delicate species and highly susceptible to stressors, meaning that these factors may negatively impact both their short- and long-term welfare. This is also seen in that mortalities for unwanted fish released during purse seining operations (a process called slipping) can exceed 80% (Huse and Vold, 2010), depending on the density and duration of the crowding (Olsen et al., 2012; Tenningen et al., 2012; Lockwood et al., 1983).

3.4 Danish seine

The Danish seine operated from a fishing boat consists basically of a conical netting body, two relatively long wings and a bag ahead of the wings, and long ropes which are used to encircle a large bottom area with the purpose of herding (catching) fish form that area (FAO, n.d.). This fishing technique is particularly applicable where there are areas with flat seabed but no large trawlable bottom; a Danish seine can be operated between several rough spots. An illustration is shown in Figure 8.

The size of the fishing boats using Danish seine varies from below 11m to more than 50m. Vessels over 11m are not allowed to fish with this gear near the coast inside of the baseline. There are more specific regulations regarding fishing areas, size of the netting, opening of the netting opening, length of the ropes etc. (Nærings- og fiskeridepartementet, 2004).

Often, the largest Danish seiners have also other fishing gears such as purse seine and gillnets (Digre et al., 2010a). The handling of the catch varies from delivery of live fish (especially cod) for capture-based aquaculture to iced- or frozen HG products.

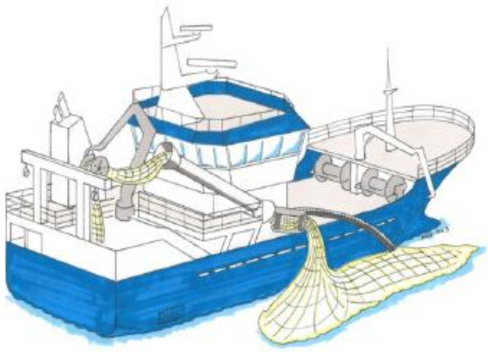

Figure 8. Illustration by Mats Heide, SINTEF Ocean (Digre et al., 2015)

3.5 Longline and handline

Longline consist of baited hooks connected to a line. The largest fishing boats use auto line, a highly automated system with automated onboard baiting and setting of the line. These boats can operate with 30 000 - 50 000 hooks per day. Smaller fishing boats often use pre-baited longlines. Table 6 (section 5.4) shows examples of Norwegian longliners with permission for on board fillet production. The main target species for longline are cod and haddock, but considerable quantities of ling, tusk, redfish, and halibut are also landed.

3.6 Gillnetting

In Norway, gillnets are among the most important methods, especially for smaller vessels in the coastal fleet. The main target species are Atlantic Cod (*Gadus morhua*), Pollack (*Pollachius virens*), Greenland Halibut (*Reinhardtius hippoglossoides*), and Monkfish (*Lophius piscatorius*) (Humborstad et al., 2003).

The name gillnet indicates that the fish are meshed behind the gill cover, and the tool consist of panels of netting held vertically in the water column by a series of floats attached to their upper edge and weights attached to their lower edge. These nets are either staked or anchored in shallow water or set to drift in open water. Gillnet is a form of passive capture technique which involves the capture of fishes or other aquatic animals by entanglement, entrapment, or angling devices that are not actively moved by humans or machines while the organisms are being captured. Thus, it is the behaviour and movements of the animals themselves that result in their capture (Hubert et al., 2012). An example of process flow sheet is shown in Figure 9.

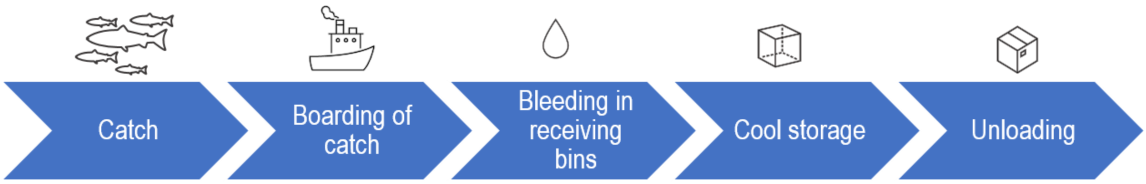

Figure 9. A general flow sheet for Norwegian gillnetting on board small coastal vessels.

As a sidenote it should be noted that biodegradable gillnets are being tested in Norway since 2016 as an attempt to reduce ghost fishing and marine litter caused by lost gillnets (Grimaldo et al., 2018). Norway is one of few countries in the world having a program for systematic annual retrieval of lost and abandoned or otherwise discarded fishing gear (Macfayden et al., 2009) from the most intensively fished areas. Since 1983, more than 20 000 gill nets have been retrieved. However, they represent only about 40–50% of all gill nets that were reported lost (Grimaldo et al., 2018). These retrieval operations are highly demanding because of operation depth (500–1000 m), strong currents, and uncertainties associated with the accuracy of the lost gear's position. Therefore, and parallel to the gear retrieval program, current research is focused on assessing the possibility of using biodegradable plastic materials to manufacture gill nets. Similar research is also being done on other types of fishing gear[3].

3.7 Pot fishing

In Norway crustaceans such as Norway lobster (*Nephrops norwegicus*), brown crab (*Cancer pagurus*), red king crab (*Paralithodes camtschaticus*), and snow crab (*Chionoecetes opilio*) are fished with baited pots. These species, except the snow crab, are delivered live from the fishing fleet for further processing. Snow crab is a new species in the Barents Sea and the fishery has shown a potential to be very profitable. The Snow Crab stock is growing and are expecting to be one of the most important fisheries in the Artic areas of the Atlantic Sea. The quota in the Svalbard Protection area for 2021 is 6 500 tonnes compared to 4 000 tonnes in 2018 (IMR, 2020). The snow crab is processed onboard, and the crab is slaughtered from live hold buffer bins, cooked, cooled, brine-frozen, glazed, packed, and stored onboard in cold storages. (Grimsmo, L & Olsen, L. et al.,2017).

[3] Dsolve – Biodegradable plastics for marine applications. https://uit.no/research/dsolve-en?p_document_id=704783

4 Refrigeration equipment and use

This chapter describes refrigeration systems used onboard and the most common methods of cooling and freezing.

4.1 Systems and refrigerants

Most vessels have methods for keeping the fish cold, to preserve fish quality and shelf life. There are mainly three different methods: Store the fish on ice (brought from land or produced onboard), chilling in RSW (refrigerated sea water) tanks, and freezing in blocks in plate freezers. A few vessels also have quick freezers for single frozen fillets or other products. Keeping the fish cold is necessary to avoid food degradation and losses, but these systems are substantial electricity consumers and would almost always benefit from efficiency improvements. The Norwegian land-based industry has, during the last decades, had an increasing focus on reducing energy consumption and it is necessary to extend this work to the fishing fleet to improve competitiveness in the world economy. One possibility is to better use the surplus heat and cold generated. There are also other possibilities in improving energy efficiency, which has been described by several (Widell et al., 2020; Indergård et al., 2018; Verpe et al., 2018; Ates et al., 2017; Stonehouse and Evans, 2015; Walnum et al., 2011; Widell and Eikevik, 2010).

The refrigeration system capacity and temperature levels, along with the operational range, are important factors for determining which refrigerant is most suitable with respect to energy efficiency and total cost of ownership. There is no one perfect refrigerant, although ammonia has been successfully used in industrial refrigeration systems in Norway and many other countries for more than one hundred years. Ammonia systems are energy efficient, and large-sized components are available on the market. In general, refrigerants having a high critical point compared to the system temperatures, good transport and heat transfer properties, low molecular weight and viscosity will improve the energy efficiency of the refrigeration system (Widell et al., 2020; Forbes Pearson, 2003).

Today's refrigerants can be divided into three groups: saturated, unsaturated, and natural working fluids. The saturated CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons) and HFCs (hydrofluorocarbons) have a global warming impact and are therefore part of phase-out programs (F-gas regulation). Unsaturated HFCs are flammable and have toxic decomposition products (even without a fire) when leaking. Consequently, the most sustainable alternative refrigerant are the natural working fluids.

Table 4 gives an overview of some refrigerants, with ODP (Ozone Depleting Potential) and GWP_{100} (Global Warming Potential, calculated over 100 years). (Hafner et al., 2019)

Table 4. Information about different refrigerants. (The Linde Group, 2020)

Formula (name)	Type	ODP	GWP_{100}
R12 (freon)	CFC	1 (high)	10 900
R22	HCFC	0.055 (medium)	1 810
R404a	HFC	0	3 922
R410a	HFC	0	2 088
R134a	HFC	0	1 430
R32	HFC	0	675
R1234yf	HFC / HFO	0	4
R1234ze	HFC / HFO	0	6
R717 (NH_3/ammonia)	natural	0	0
R744 (CO_2)	natural	0	0
R290 (propane)	natural	0	3

4.2 Refrigerated sea water (RSW)

RSW is a suitable and common method for fast chilling of large fish quantities, typically found onboard purse seiners and trawlers equipped for pelagic fishing. The system consists of several tanks, tubes, pumps, and valves, in which seawater is mechanically refrigerated and circulated. Herring and mackerel are species typically transported in RSW tanks, while species like Blue whiting are stored in refrigerated fresh water. These species are used for fish oil and meal production, and using fresh water lowers salt uptake in the fish (Grimsmo et al., 2016; Olsen and Norum, 2010).

Chilling systems onboard fishing vessels have improved over the years, but they are far from optimal. Uneven cooling, especially in large tanks (300 m^3), has been reported as a problem. If the fish are too warm, decomposition rates increase, which can be measured at landing. If volatile nitrogen values are too high, the price of the fish will be reduced. Another problem which occurred earlier but has been overcome was "lumping" of the fish. Blue whiting can form a doughy mass, which is difficult to circulate water through. Adding acetic acid to the refrigerated water has been shown to act both as a preservative and prevent lumping. (Grimsmo et al., 2016; Widell and Nordtvedt, 2016)

Few research papers address the topic of onboard chilling using RSW systems. Thorsteinsson et al. (2003) performed a dynamic simulation to assess the feasibility of a hybrid RSW/CSW[4] system. Wang and Wang (2005) have described different types of refrigeration systems onboard, including heat-driven absorption systems. Larminat (2018) also gives an overview of refrigeration systems in fishing vessels and different use of them. Some reports have been published in Norwegian, mainly supported by the Norwegian Seafood Research Fund[5], which has the production of top-quality fish as a focus area.

Norway has used RSW systems to chill fish onboard for more than 50 years, especially for pelagic fish. These refrigeration systems use natural refrigerants, mainly ammonia, but a few also use CO_2. Much of the research on CO_2 RSW systems has been conducted in Norway. The development of CO_2 RSW systems has been described in a range of articles (Bodys et al., 2018; Brodal et al., 2018; Widell et al., 2016; Rekstad et al., 2015; Nordtvedt and Ladam, 2012; Andresen et al., 2011; Neksa et al., 2010).

4.3 Freezing

4.3.1 Fish freezing plate freezers

On board trawlers, whole fish are frozen in vertical plate freezers, while fillets are frozen in horizontal plate-freezers as interleaved fillets or standardized blocks (Bøknæs et al., 2001).

In a plate freezer, packed fillets or small trunks are frozen by contact between two plates with some pressure applied on them. Nowadays, the market requires a lot of packaged frozen fish, which is wrapped in plastic, and it should be noted that this practice results in a decrease in energy efficiency. This is explained by the drop in heat transmission coefficient due to the air that remains in the package, considerably increasing the time required for freezing.

4.3.2 Freezing of seafood in blast freezers

Freezing tunnels are defined as any refrigerated space which gets a temperature range of -25 / -32 °C and it is used for fast freezing of a product. It may be continuous, where the fish is moved along the freezing chamber in a direction opposite to the forced flow of cool air, or discontinuous, in which the chamber is filled and emptied completely in cycles. This latter type is more versatile and less expensive, but it requires more labour, and the energy consumption is higher. This type of freezer is common in land-based processing plants, but not onboard. Some examples of installed freezing capacities are shown in Table 5. Catch capacity is limited by the freezing capacity per 24 hours.

[4] Chilled sea water, ice added to sea water

[5] www.fhf.no

Table 5 Examples of freezing capacity (cargo hold) installed

	Length [m]	Freeze hold [m^3]
Factory trawlers (frozen fillets)	70-80	1200-2000
Factory long-liner (frozen fillets)	45-65	500 - 1200
Freezer trawlers	60-80	900-1800
Combi trawlers (fresh and frozen)	30-50	300-600

4.3.3 Brine freezing

Brine freezing is an old method for freezing of food already described by the Greenland Inuit's in the 18th century, were a supercooled liquid for freezing of fish was achieved when mixing seawater with ice. Today, brine freezing is tested out for industrial freezing of mackerel before filleting (Østvik, 2018) and there are ongoing R&D projects on brine freezing of whitefish[6] (Larssen, 2019). Freezing of snow-crab clusters produced onboard are often frozen with chilled salt brine (-18°C) before freshwater glazing, packing and freeze storage. The method is quick and can give a significant reduction in energy consumption compared to blast freezing.

[6] https://www.fhf.no/prosjekter/prosjektbasen/901580

5 Processing equipment

This section provides examples of processing equipment which does not involve chilling or freezing.

The onboard processing equipment varies greatly between the different Norwegian vessel types. Smaller coastal vessels like gillnetters have very basic equipment, mostly focused on gentle loading of catch, bleeding, chilling, and delivery of fresh fish to land-based processing facilities later in the day (see flow sheet for gillnetting, Figure 9). On the other side of the scale, the larger vessels like trawlers and long-liners have many different equipment installed on board. This section will focus mostly on the latter, as these are the most technologically advanced vessels. An example of an on-board processing line is shown in Figure 10.

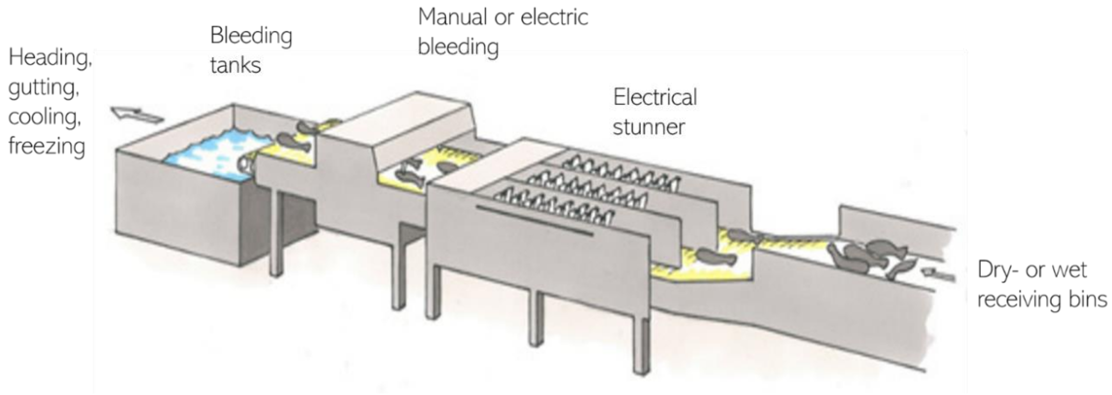

Figure 10. A generalized on-board processing line. Illustration: Mats Heide, SINTEF Ocean (Digre et al., 2015).

5.1 Live storage

Equipment for on board live storage is currently installed on a few larger Norwegian fishing seiners and trawlers. For trawlers, the fish has traditionally been stored in dry receiving bins before further processing (Figure 11, right). A drawback with this procedure is the time the fish is stored prior to further processing. Catch processing may take several hours (Olsen et al., 2013), and in some instances even longer if the catch is left to calm down after landing to facilitate easy and safe catch handling. Thus, for large catches, it is questionable whether the vessel will in fact have the time to process all of it before the fish eventually die and the blood starts to coagulate.

The idea of extending the period where the fish are kept alive after landing by introducing *short-term live storage* (Figure 11, left and middle) represents another remedy to improve bleed-out (Erikson et al., 2019). Short-term live storage refers to a few hours after capture until the entire catch is processed, not to be confused with live fish carriers or capture-based aquaculture. In addition to potentially better bleed-out methods on larger vessels, short-term live storage also improves fish welfare.

Figure 11. On board short-term live storage (left and middle picture) as an alternative to traditional storage in dry receiving bins (right picture) on board a trawler. Photo: Hanne Digre and Guro Møen Tveit, SINTEF Ocean.

5.2 Electrical stunner

The modernization of the Norwegian fishing fleet over the last decades has meant a considerable reduction in the crew on board. This is particularly true for larger vessels such as trawlers and Danish seiners, where large volumes of fish can be brought on board from a single haul. Due to the comparatively low number of personnel and the possibility of delayed processing, poor bleed-out may occur. As a solution to this, a compact version of electrical stunners used in the salmonid fish farming industry has been introduced and integrated into the processing line on trawlers and Danish seiners. Erikson, U., Grimsmo, L. and Digre, H. (2021). "Establishing a Method for Electrical Immobilization of Whitefish on Board Fishing Vessels", s, Journal of Aquatic Food Product Technology. For a description of the stunner and its use on farmed Atlantic cod in laboratory scale, refer to Digre et al. (2010b) and Erikson et al. (2012). Some photos of electrical stunning are shown in Figure 12.

Figure 12. Electrical stunning of fish on board. Photo: SINTEF Ocean. (Erikson et al., 2014)

On fishing vessels, fish welfare considerations (instant stunning) are not required by legislation, and the stunners were primarily introduced for two other reasons. Up to now, the common catch handling practice for whitefish has been to postpone the bleeding operation (cutting of gills or throat) until the fish become easier to handle or after they have died. The reason for this is to avoid the rather cumbersome handling of live fish. However, delayed bleeding can result in poor bleed-out and consequently reduced product quality due to residual blood in fillets (Erikson et al., 2014). The main remedy to avoid poor bleed-out of the catch is immediate bleeding after capture. Electrical stunning for immobilization of fish just after the catch is brought on board has the potential to make rapid bleeding of live fish more feasible.

The other reason for using stunners on board is related to SHE (Safety, Health and Environment) considerations since the fish are easier and safer to handle during the bleeding operation (Erikson et al., 2014). This method is also reported by the industry to result in more efficient bleeding operations. On vessels, the fish are electrically stunned in air on a conveyor belt just ahead of the personnel who bleed the catch (shown in Figure 12). A drawback of electrical immobilisation is the possibility of spine fractures and blood spots in some species (mainly haddock) (Erikson et al., 2016).

5.3 Heading, bleeding and gutting

Systems for controlled stunning, bleeding and gutting of fish immediately after boarding the catch improves the exsanguination (the process where an animal is cut so that it bleeds to death). There are several ways of on-board fish handling, and traditionally the slaughter method has been used, based on its simplicity and low operating expenses. Bleeding techniques such as cutting of the throat (ventral aorta) or the arteries in the neck (dorsal aorta), and even direct evisceration are frequently used methods to accelerate death and drainage of blood from the muscle.

On most Norwegian fishing vessels removal of heads (Figure 13), as well as the bleeding and gutting of fish is still done manually. There is both previous and ongoing research on automation of these processes (Bondø et al., 2017; Toldnes et al., 2017), and many vessels are interested in such an automation. However, procedures for the automatic bleeding of fish have faced several challenges when applied on board fishing vessels. The main problems are related to the fact that the technology must be able to handle movements of the vessels, and possibly also the fish on the conveyor belt. Additionally, the equipment should be able to handle fish of different species, sizes and orientation. The limited space on board also is a challenge (Bondø et al., 2017).

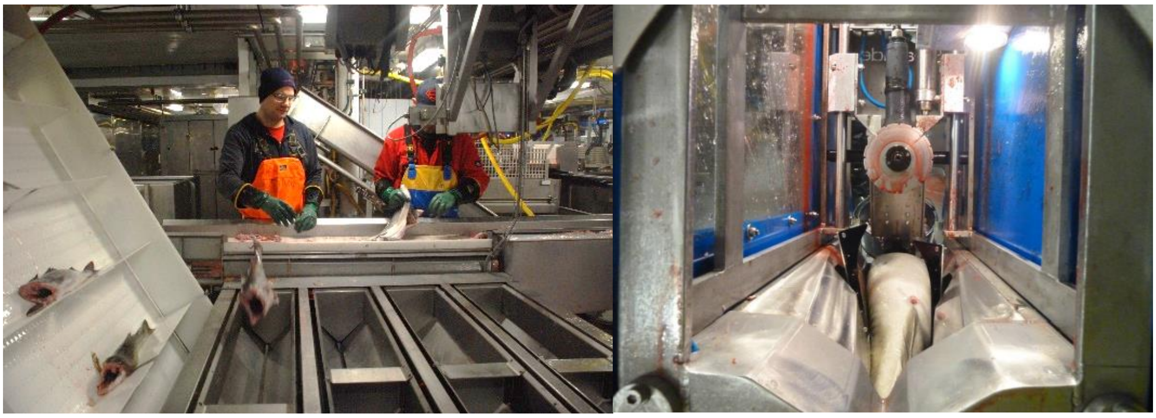

Figure 13. Both electrical and manual heading are used on board Norwegian fishing vessels. Some vessels only bleed and gut the fish (not removing the head). Photo: SINTEF Ocean.

5.4 Filleting

Filleting is strictly regulated and rarely used on-board Norwegian fishing vessels. Currently there are three Norwegian factory trawlers (Granit, Ramoen and Langøy) and four longliners (Østerfjord, Leinebris, Atlantic and Geir) producing high quality seafood products, fresh frozen at sea. The on board production assures the highest quality standards as fillets are frozen to below -18°C within a few hours after catching[7]. Table 6 shows all available factory trawlers and longliners producing fillets on board.

Table 6. Norwegian vessels with on board filleting, their owners, vessel types and processing equipment.

Photo[8]	Vessel	Owner	Vessel type	Processing equipment
	Granit	Halstensen Granit AS	Factory trawler	– Heading machines: Breivik S424/Breivik 415 – Filleting machines: Baader 190/Velfag M700 – Skinning machines: Breivik 51/Velfag M 800 – Cutting & portioning: Valka – Scales and graders: Marel/Optimar – Shrimp factory: Intech/Optimar – Freezing equipment: Optimar automatic horizontal plate freezers https://www.granitseafood.com/
	Ramoen	Eros AS, Vartdal Fiskeriselskap AS	Factory Trawler	– Heading machines: 3 x Breivik 424 SS – Filleting machines: 3 x Baader 190 – Skinning machines: 3 x Baader 52 – Portions/Boneless production: Valka X-ray cutting machine

[7] Norwegian Frozen at Sea is a cooperation between the Norwegian factory trawlers, the Norwegian longliners producing fillets and their sales agents. The cooperation is administered by The Norwegian Fishing Vessel Owners Association. https://www.norwegianfrozenatsea.no/fleet

[8] All pictures are copied from Norwegian Frozen At Sea https://www.norwegianfrozenatsea.no/ (shared with approval)

				– Graders: 2 x hg graders and 1 fillet grader, Marelec – Shrimp production line – Holmek palleting system – Freezing equipment: 4 x horizontal plate freezers, 6 x vertical plate freezers https://www.ramoen.no/about/the-boat
	Langøy	Prestfjord AS	Factory trawler	– Heading machines – Filleting machines – Freezing equipment https://www.tekfisk.no/nyheter/prestfjord-bygger-ny-supertraler-hvert-fjerde-ar/8-1-60542
	Østerfjord	Østervold AS	Longliner	Not specified
	Leinebris	Leinebris AS	Longliner	– Heading machines: 2x Baader 162+J/cutmachine – Filleting machines: Baader 190 – Skinning machines: Baader – Freezing equipment: Pam.5 vertical+1 horizontal (Optimar Autofreezer) + tunnell+ IQF Freezer http://leinebris.no/
	Atlantic	Atlantic Longline AS	Longliner	– Heading machines Breivik Mek – Filleting machines: Breivik Mek – Skinning machines: Breivik Mek – Freezing equipment: Teknoterm, 6 vertical plate freezers. 192 stations, One horizontal plate freezer (11 tonnes per day) – Factory: Optimar
	Geir	HP Holmeset AS	Longliner	Not specified https://www.tekfisk.no/fiskeri/bygger-nye-geir-med-rustfritt-staldekk/2-1-633813

5.5 Boiling

The seagoing shrimp trawlers sort out and boil the largest shrimps before freezing in blast freezers, packing and freeze storing onboard. The Norwegian snow-crabbers are also boiling the product before brine freezing, packing and freeze storage.

5.6 Processing of rest raw materials

Marine rest raw materials (RRM) like heads, bones, visceral fractions, cut-offs and trimmings are high value raw material rich in proteins, lipids and other important components (calcium, phosphorus, etc.) that can be used to produce ingredients for food and feed. Approximately 29 % of the total landings of fishing vessels in Norway can be considered as under-utilized, unexploited or as by-catch, and around 964 000 tonnes of RRM is generated in Norway each year (Myhre et al., 2020; Richardsen et al., 2019). While the Norwegian aquaculture industry and pelagic fisheries regards RRM as valuable products, the whitefish and shellfish industry struggle to increase the utilization of their underutilized RRM resources. See an overview of the utilization in Table 7.

Table 7. RRM by sector (measured in tonnes) in Norway 2019 (Myhre et al., 2020).

	Whitefish	Pelagic fish	Aquaculture	Shellfish	Sum
Raw material base	683 000	1 268 000	1 543 100	52 100	3 546 200
Available RRM	297 400	194 000	458 200	14 800	964 400
Available RRM (%)	44%	15%	29%	28%	27%
RRM utilized	181 000	194 000	429 000	7 600	812 000
RRM utilized (%)	61%	100%	93%	51%	84%

In 2019, the pelagic sector represented about 1.27 million tonnes of raw material with approximately 194 000 tonnes as RRM. In the pelagic sector the species that produce RRM are herring, mackerel, blue whiting and capelin. All RRM resulting from filleting of pelagic fish enter the fishmeal and oil factory, securing 100 % utilization of the RRM for the sector (Myhre et al., 2020).

It is mainly the RRM from the whitefish sector that is not utilized. The whitefish sector represented about 814 000 tonnes raw material in 2019, with approximately 683 000 tonnes landed from Norwegian vessels. RRM from this sector was 297 000 tonnes with 84% of the generated RRM occurring at sea or upon landing. It is estimated that around 120 000 tonnes of RRM were not utilized of the total RRM. Almost everything that is brought to land is utilized and the main focus is therefore to reduce the discards of RRM at sea and specifically the sea-going fleet which only utilized about 24% of their RRM compared to the small and large coastal fleet that utilized about 88% and 60%, respectively (Table 8). The main RRM from whitefish included heads (36%), viscera (18%) and liver (16%). Investment in technological solutions to handle and preserve the RRM have resulted in an increased utilization for the sea-going fleet in the last couple of years, from around 10 % to above 20% utilization in 2019 (Myhre et al., 2020).

Table 8. RRM by fleet, whitefish sector (measured in tonnes) in Norway from 2019 (Myhre et al., 2020)

	Small coastal fleet	Large coastal fleet	Sea-going fleet	Total
RRM	129 000	64 000	104 000	297 000
Not utilized	16 000	25 000	79 000	120 000
Utilized	113 000	39 000	25 000	177 000

Utilization of RRM from the Norwegian fleet is mainly done by oil and meal production (common for pelagic fish), silage or enzymatic hydrolysis. There is also an increased focus on utilizing more of the fish as food. Cod heads are for example dried and sold to Africa (mainly Nigeria) and Asia, while cod livers are used for production of cod liver oil (Tveit et al., 2020).

6 Energy saving measures

Except from optimization of hull shape and propeller selection there are several options to increase the energy efficiency of a fishing vessel. Enova has awarded grants for various technological measures to improve energy efficiency in different segments of the fishing fleet. These mainly include battery-hybrid propulsion, heat recovery, and electrification of fishing gear (Regjeringen, 2019).

6.1 Hybrid propulsion

Conventional diesel engines are most efficient when operating at 60% - 80% of their rated power, such as during transit to and from fishing grounds. The specific fuel consumption is significantly increased below 50% of rated power (corresponding to speeds below 70% of top speed), such as when idling or moving at 2- 3 knots hauling fishing gear. For ships with operation at low engine load during certain periods, a hybrid propulsion system might be the most efficient solution. Hybrid drives allow propulsion power to be delivered from multiple sources. For example, during operation at low speed, the main engine can be shut off, and the propulsion power is instead provided by an auxiliary engine or battery bank (Gabrielii and Jafarzadeh, 2020a).

One suggested measure for reducing Norway's non-quota GHG emissions is that 21 fishing boats will have rechargeable battery hybrid operation in 2030 (Miljødirektoratet, 2020). Hybrid battery propulsion can offer significant energy efficiency improvement over conventional systems by running the engine(s) at optimal load and absorbing many of the load fluctuations by using batteries. Exactly how much fuel could be saved using a hybrid propulsion system depends on the fishery, vessel operating procedures, and design details, but savings between 10% and 30% have been reported. An additional benefit with a battery bank is the facilitation of including intermittent renewable power production (e.g., solar, wind) on-board. The batteries can also be used for storing regenerated energy from, for example, heavy winches for fishing gears (Gabrielii and Jafarzadeh, 2020a).

6.2 Shaft generator with PTO/PTI

As an alternative or complement to using auxiliary engines for electric power production onboard, a shaft generator can be applied to convert mechanical energy from the main engine shaft to electrical energy. Energy savings are achieved since the specific fuel consumption is normally lower for the main engine compared to the auxiliary engines. Shaft generators is not a new technology but there are more advanced forms where they can be operated in different modes; power take-off (PTO) for auxiliary power supply, and power take-in (PTI) for propulsion power supply. This can provide large energy savings especially for ships with some operations at much higher power load than other operations (Gabrielii and Jafarzadeh, 2020a).

6.3 Energy management of auxiliary systems

Optimization of auxiliary systems towards ship-specific operational profiles can lead to significant reduced energy consumption. Auxiliary systems are often designed to support engines and other primary systems (cooling, circulation, ventilation, compressed air, etc.) at extreme ambient values and at 100% load, which rarely or never occurs. For ships that apply "slow steaming" and / or long periods of low engine utilization, the load can be lower than 50%, implying lower efficiency. There are several measures that can be taken to enable the auxiliary system to still operate at its optimal/design conditions such as (Fiskebåt, 2018):

- Speed control of pumps, compressors, fans through installations of variable frequency drives (VFD).
- Control strategies for cooling water systems and ventilation.
- Smarter heat recovery from both high and low temperature circuits and exhaust gas systems.
- Smarter sensors and power management, controlling distribution and consumption of energy.

6.4 Waste heat recovery

In diesel (or gas) engines, only half of the energy supplied by the fuel is converted into mechanical energy which is used for driving the propeller(s) and/or electric generators. The other half is lost as heat; both to the ambient air by exhaust gases at 300°C - 400°C and to the sea water by engine cooling water at 40°C - 90°C. Some of this heat could be recovered. There are also possibilities for waste heat recovery from the refrigeration systems onboard.

Only little can be done to reduce the heat emission from diesel engines since this is limited by the laws of thermodynamics. This means that there will be vast amounts of thermal energy available, as long as the ships runs on a diesel (or gas) engine. Ideally this energy should be used for direct heating purposes, but it can also be used for producing cold energy or electrical energy (Bjørshol, 2007).

Heat-to-heat: Currently, the waste heat recovery on fishing vessels is almost limited to the recovery of engine cooling water for heating tap water. Space heating is today mostly supplied by electric heat, but large savings could be made by shifting from electricity to waterborne heat distribution system, based on waste heat supply. Other potential users for the surplus heat are tank heating, de-icing of decks and stairs, freshwater generation, and heating demands for raw material processing.

On modern trawlers, 10 - 15% savings in total fuel consumption can be achieved by utilising the engines waste heat to freshwater generation and raw material processing (meal factory and shrimp boiling), compared to producing electricity for these purposes (Pedersen and Vegsund, 2012).

Heat to cold: While traditional compression refrigeration systems are powered by electric energy, the absorption system can be driven by surplus heat from the ship's engine. The first marine installation of an absorption system was onboard a Norwegian trawler[9]. The reported savings in electrical energy from daily operation was approximately 80%, compared to traditional compressor-driven refrigeration. However, some compressor capacity must be installed, to be used when sufficient surplus heat is not available, either during short periods of refrigeration peak load or when the ship is laying in harbour. There are also other heat-driven cooling technologies, but still only in a development phase. For example, a waste heat powered adsorption refrigeration ice maker was developed to provide parts of the required cooling power for conserving fish on fishing boats (Palomba et al., 2019).

Heat-to-power: There are technologies available and applied in the shipping sector for utilising the engine's waste heat to produce electricity onboard. Traditionally this was conducted via steam turbines, or more recently by the Organic Rankine Cycle (ORC), enabling the recovery of heat at a lower temperature. However, neither of them is yet applied on fishing vessels, mainly due to the large investment costs and space required. The total fuel savings by installing an ORC on large trawlers is estimated up to 10%, assuming all waste heat is used for power production (Bjørshol, 2007). The first demonstration of an ORC module on a fishing vessel (25 m Irish trawler) showed that the ORC turbine could cover half of the boat's electricity needs during fishing mode. However, the estimated savings in fuel consumption was below 5%[10]. Another heat-to-power technology is thermo-electric generation (TEG) which has been introduced into the shipping sector through pilot installations and will be applied on a new-build Norwegian fishing vessel.

6.5 Cold recovery

Liquefied natural gas (LNG) is a more environmentally friendly fuel compared to diesel and is being increasingly used in the shipping sector. So far, there are only a few LNG-powered fishing vessels in operation/ordered (all Norwegian). LNG is stored on board under cryogenic conditions, and fuel preheating is required before engine injection. The cooling effect associated with this preheating can

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[9] https://www.worldfishing.net/news101/products/fish-processing/ice-and-refrigeration/grenco-absorption-refrigeration-system

[10] https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=4869&docType=pdf

be "recovered" for cooling purposes onboard, and thus, reduce the onboard energy consumption. There are systems available for using LNG cold energy to decrease the energy consumption of HVAC chillers (Baldasso et al., 2020). Potential applications for LNG cold recovery onboard fishing vessels was analysed by Saeed et al. (2020), including subcooling of refrigerant in the RSW system or direct chilling of the fish tank.

6.6 Thermal storage

Thermal energy storage onboard ships are generally gaining increased attention as a measure for energy savings and for enabling periods of zero-emission operation. The chilling and/or freezing load on fishing vessels varies with operation mode. For example, the load differs between transfer to the fishing field, fishing, and return to port, but also within a refrigeration cycle. A cold thermal energy storage (CTES) can be implanted to balance the load and/or supply extra capacity at peak loads. This enables operation of the refrigeration system at a more stable, energy-efficient level, and a reduction in installed refrigeration capacity. In addition, to boost the refrigeration capacity with cold supply from the CTES, enables a faster chilling of the catch, ensuring high product quality (Saeed et al., 2020).

One challenge with TES implementation on ships is space limitations. By using phase change materials (PCM) a more compact TES system can be designed. There are a few experimental and theoretical studies showing the benefits of CTES onboard fishing vessels. Verpe, et al. (2019) showed an increase in production capacity of 3% by integrating a CTES with a low-temperature R744 plate freezing system. The CTES system, utilizing CO_2 as PCM, stores energy when the compressor capacity is larger than the required refrigeration load, and releases cold energy when needed, typically in the beginning of a freezing process. Björk and Kongstad (2016) analysed a CTES, also with CO_2 as PCM, for a fish freezing cascade (R717/R744) refrigeration system. The study showed a reduction in energy use up to 40%, partly because of the better system COP achieved through running the compressors at a stable level. (Saeed et al., 2020) evaluated several CTES concepts, including both a CO_2- and water-based PCM, for chilling and freezing applications onboard a trawler.

6.7 Energy recovery

Installation of electric (instead of hydraulic) fish pumps, winches, and other deck equipment not only reduce energy consumption but also enables recovery of electrical energy. For example, applying electrical winches offers the possibility to install an energy regeneration system for the unspooling of winches when setting out trawls / net. This recovered energy can be utilized to supply any electrical demand onboard or to charge batteries. For a stern trawler with a "normal" operation profile, yearly savings are estimated to 150-200 MWh (Fiskebåt, 2018).

Another innovative energy recovery solution is an anti-roll stabilization system with integrated turbines/generators in the roll-damping tanks, recovering stabilization power from the water load in motion. Two such turbines of 30 kW capacity will be installed on a Norwegian fishing vessel[11].

6.8 Refrigeration systems

Refrigeration of food is energy demanding, but many types of food (especially seafood) will deteriorate quickly if not chilled or frozen immediately after harvest. Refrigeration and energy efficiency is therefore important topics in the seafood industry. Increasing energy efficiency of refrigeration systems can be done in several ways (Widell, 2012):

- Operation
    - Prevent that equipment is on and running when not necessary, not in use.

[11] https://www.cemreshipyard.com/en/articles/anti-roll-tank-operation-in-fishing-vessels

  - Measure and survey the energy use.
  - Prevent the ambient from heating up cold equipment (minimizing door openings and enough insolation).
- Efficient components and systems
  - Screw compressors regulated with frequency converters instead of slide valves.
  - Efficient fans in cold rooms (fans add heat to the cold room).
  - Efficient defrosting, long enough to melt the ice, but not overheating the evaporators.
  - Systems for purging air and remove water from the refrigerant, which can reduce heat transfer in condenser and evaporator.
- Heat and cold recovery
  - Heat from engine or from the high-pressure side of refrigeration system can be used, either directly or upgraded in a heat pump.
  - Cold recovery is not so common, but a possibility is to heat exchange outgoing cold water with incoming warm water if the water must be changed. Another possibility is to recover the cold from the ice which has been used to chill the fish (at the fish processing plant after loading).

6.9 Waste material recovery

On fishing vessels with processing onboard, such as factory trawlers, there is a steam/hot water demand. This heat demand is normally supplied by an exhaust gas boiler, utilising waste heat in the engine's exhaust gases. When there is lack of excess heat, such as at idle or low-speed operation the boiler is fuelled with diesel. To minimise the use of diesel, the boiler can be designed to combust any excess fish oil available from the fishmeal and fish oil factories onboard[12].

[12] https://www.motorship.com/news101/ships-equipment/parat-extends-combined-steam-boiler-functionality-with-electrical-elements

7 Sustainability

This section describes topics related to sustainability, including carbon footprint, traceability, and governance. It also includes a section about policies for fishing fleets and how this sector can contribute to the UN Sustainable Development Goals (SDGs).

7.1 Carbon Footprint

However well the seafood industry compares to other food industries, in terms of its carbon footprint (CF), i.e., GHG emissions, there is still room for improvement across the supply chain. Even though estimating the CF of seafood products is fraught with many variables, there is much to be learned by looking at the key components contributing to the CF of both wild-caught and farmed fish. For products originating in capture fisheries, the fishing stage itself is typically the dominant contributor, while for farmed fish it is primarily related to the feed. Transportation can in some cases generate significant emissions, depending on the distance and mode of transportation (Parker et al., 2018). It is therefore vital to factor in transportation costs when assessing the GHG emissions of farmed fish. For example, a 2016 study found that the CF doubled when factoring in air freight transportation costs. This suggests salmon grown on land in a recirculating aquaculture system in the US emits less GHG (7.41 CO_2eq/kg) than open net farmed Norwegian salmon (15.22 kg CO_2eq/kg) when accounting for cross Atlantic transport emissions (Liu et al., 2016).

Life Cycle Analysis for captured seafood products, on a global scale, typically shows that 75% – 95% of the overall GHG emissions are related to the fishing stage of the product (Gabrielii and Jafarzadeh, 2020b). This high contribution is primarily caused by emissions from diesel fuel to power the fishing vessel. In some fisheries refrigerant leakage also has a noticeable effect. Whether products are fresh or frozen mainly affects the CF if it requires a change in transport mode. The significant contribution of the fishing vessel's fuel consumption to the overall CF implies that the applied fishing method and gear type have a considerable impact. In general, pelagic fisheries are efficient while demersal trawling is one of the most energy intensive, but data sources on fuel usage shows huge variations between and among different fish species, fishing areas and fishing techniques (gears) (Gabrielii and Jafarzadeh, 2020b).

A recent study shows that the CF of Norwegian seafood products range from 1.1 to 29 kg CO_2/kg edible product delivered to wholesaler. Various factors affect the GHG emissions, such as species, fishing gear, product form, transportation mode, distance to market, edible yield and utilisation of by-products. Pelagic fisheries (i.e., herring and mackerel) have the lowest emissions. Demersal fisheries (i.e., cod, saithe and haddock) also have relatively low emissions. Crustaceans (i.e., shrimp and king crab) are the most fuel intensive species, mainly due to the low catch per unit of effort. Among the studied seafood products, farmed salmon has the highest emissions at landing/harvest, mainly due to the feed (Ziegler et al., 2021).

Even if processing is generally found to have a minor contribution to CF, the location of processing, i.e., onboard ship or land-based, may have a non-negligible effect on the final CF. On-board processing facilities are normally powered by diesel fuelled generators, which contribute to a higher CF compared to most land-based plants. However, the CF for land-based processing is country-specific due to different CO_2 emission factor for grid electricity. The amount of waste in processing facilities of various countries and, consequently, CF per kg of edible fish may also differ (Sandison, 2016).

7.2 Traceability

Traceability is the ability to track the origins of a product, the processes it went through, and where it ended up; in the case of fish and seafood – from boat or farm to fork. Drivers for traceability in the food sector include requirements and certifications related to food safety, quality and sustainability, and business-related drivers such as inventory control, promoting efficiencies, and communication along the supply chain. Figure 14 indicates a range of those drivers and where they overlap. Mandatory traceability systems are in operation within the fisheries and aquaculture sector, and international traceability norms for food safety assurance are also well established. In addition, there are several private voluntary certification schemes with their own traceability requirements. Thus, various stakeholders in the fisheries value chain faces multiple traceability requirements, and there is a need for standardization and better understanding on what each verification and certification entails (Washington and Ababouch, 2011).

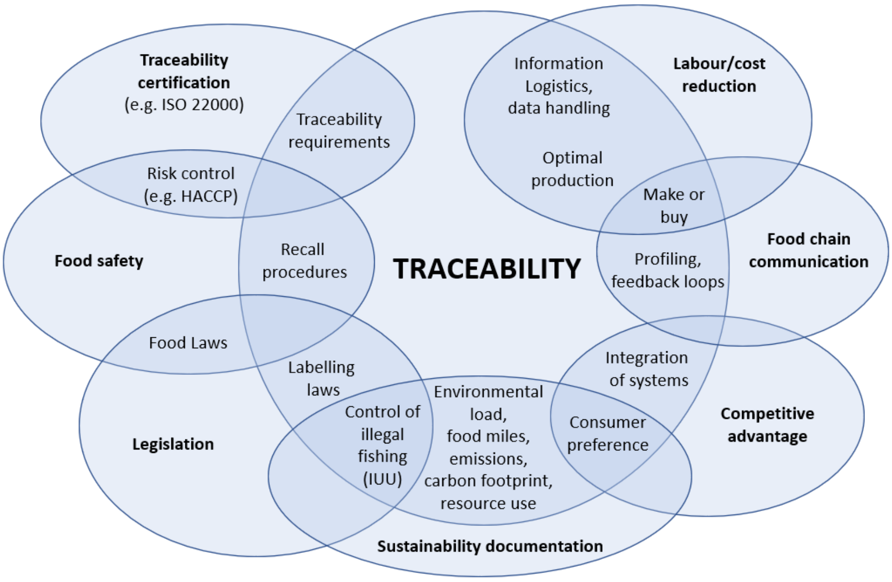

Figure 14: Traceability drivers in the food sector, adapted from (OECD and FAO, 2009)

Working towards sustainability in any industry requires a holistic approach. (Osmundsen et al., 2020). Within the seafood industry having a certified, sustainable and traceable source of a fish is a growing standard demanded by consumers (Olsen and Osmundsen, 2017). Certifications have come to define sustainability within the seafood industry, and it is therefore important to understand how traceability schemes are operationalized. (Osmundsen et al., 2020) demonstrated the importance of sustainability in a study which found that sustainability certifications overwhelming focus on environmental and governance indicators. This would imply that the certification schemes currently in place today do not give a full picture on sustainability in a full system thinking conceptual framework. The research investigated eight common and widely used certification schemes in aquaculture. Osmundsen demonstrated how the focus of sustainability is concentrated on environmental impacts and governance, while leaving various other important factors such as culture and economics in the backdrop.

Typically, the governance aspect (negotiation, coordination, enforcement) dominations sustainability in terms of having high importance within a given certification scheme. The strongest sub-domain, *transparency and traceability*, covers impacts on other domains, specifically on the *environment*, and ensures traceability of certified fish. Future work and certifications will need to bridge the knowledge gaps of culture and economics within the creation of certification schemes. Previous research has also demonstrated that traceability truly goes hand in hand with governance when it comes to sustainability in the fishing industry (Garcia-Torres et al., 2019).

7.3 Governance

The previous section clearly demonstrates how governance currently plays a pivotal role in achieving greater sustainability goals within the seafood industry. Agreeing on how sustainability is defined becomes the starting point for effective governance. Fisheries governance has international, national and local dimensions, and is multi-faceted. It includes legally binding rules, such as national policies and legislation, international treaties and customary social arrangements. It covers long-term, strategic planning as well as short-term operational management and includes local fisheries as well as whole ecosystems (FAO, 2021).

Many governments and international organisations have adopted the Ecosystem Approach to Fisheries Management (EAFM). Key factors for successful implementation of EAFM are to manage scientific, administrative, and regulatory complexity, effective communication, stakeholder engagement, and simplification, as well as to define management objectives for various species and stocks development. Different frameworks have been developed to meet these challenges, including the ERAEF (Ecological Risk Assessments for the Effects of Fishing).

In 2009, a new Marine Resources Act entered into force in Norway, representing a paradigm shift in the management of Norwegian fisheries. While the previous act focused mainly on the commercial exploitation of marine resources, the new act integrates conservation and sustainable use as basic principles. It is mandatory for fisheries management to apply "an ecosystem approach, taking into account habitats and biodiversity". Compared to other EAFM frameworks, the Norwegian framework is simpler but found to be efficient. For example, the Norwegian Directorate of Fishing has developed a tool providing an overview of management needs, that can help prioritise various issues according to the urgency of new or improved management measures (Gullestad et al., 2017).

7.4 Certification schemes

Private standards, such as eco-labels and related certifications schemes, are becoming significant features of international seafood trade and marketing, posing key questions for governments: What role do these standards play in overall governance for sustainable fisheries and aquaculture? Do they duplicate, complement, or even undermine public regulatory frameworks? What are the essential components of an overall governance framework for sustainable fisheries and how do private market mechanisms fit into that framework (Washington and Ababouch, 2011)?

In accordance with guidelines from the UNs Food and Agriculture Organisation (FAO), the EU has - suggested five criteria as minimum standards for eco-labelling of fish products from capture fisheries (FAO, 2009).

- Precise, objective, and verifiable technical criteria
- Independent third-party accreditation process
- Open to all operators without discrimination
- Properly controlled to ensure compliance with minimum requirements
- Transparent, i.e., consumers should know which criteria are covered by an ecolabel and should thus have easy access to information on the certification standard

The Global Sustainable Seafood Initiative (GSSI)[13] aims to increases comparability and transparency in seafood certification. GSSI's Global Benchmark Tool, which is based on FOA Guidelines and Codes of Conduct, identifies and recognizes robust and credible certification schemes. As per 2020, GSSI has

[13] https://www.ourgssi.org

recognized nine certification schemes. Among those are the "ecolabel" MSC (Marine Stewardship Council)[14], under which 15% of the world's fisheries are certified.

From the Norwegian perspective, the government has highlighted the importance of zero or low carbon vessels for service and transportation for the seafood industry as a means of fulfilling the Paris Agreement. As an alternative to the Marine Stewardship Council, the industry is working to establish the Norwegian Responsible Fisheries Management (NRFM) as a standardisation system for sustainability in Norwegian fisheries. The goal is to have it recognised by the Global Sustainable Seafood Initiative (GSSI). While the seafood industry is more concerned with sustainability than before, only a small number of producers currently have sustainability as part of their strategy (Svorken, 2021).

7.5 Development Goals

Governments have a challenge to link sustainable consumption goals to new policies in hopes of increasing sustainable production. Moreover, nations have agreed to place the United Nations Sustainable Development Goals (SDGs) at the top of their agendas. The harvest, processing, retailing, packaging, and transport of seafood all contributes to pollution and GHG emissions and to reasons behind the SDGs. The goals related towards well-managed fisheries and aquaculture production systems are included below.

SDG 2: Zero Hunger The world population continues to grow making it crucial that there are sufficient and sustainable food options available. Roughly 4.3 billion people are reliant on seafood as part of their protein and nutritional intake (FAO, 2014). It is therefore vital to continue to create pathways to include and protect sustainable fisheries and aquaculture.

SDG 8: Decent work and economic growth FAO estimates that over 820 million people rely on fisheries and aquaculture to provide for their livelihood (FAO, 2020).

SDG 12: Responsible Consumption and Production & **SDG 14**: Life Below Water For fisheries, these goals work together as life below water (i.e., the fish caught onboard the vessels) is regulated by responsible consumption and production. The policies that help establish these goals are found in the next section.

SDG 17: Partnerships for the goals Sustainable fisheries and aquaculture cannot be achieved without globally binding goals. Partnerships, as part of the SDG's can include responsible fisheries management on the local, national, and global level to help fight threats to the industry such as overfishing and climate change.

7.6 Policy

In terms of EU policy, the Common Fisheries Policy (CFP) stands out as the leader when setting management rules for European fishing fleets. Dating back to the seventies, the policy has been updated throughout the years, most recently in 2014. The policy aims at ensuring environmentally, economically, and socially sustainable fisheries and aquaculture, that are able to provide a healthy source of food for EU citizens (European Comission, 2021). Maximum sustainable yields (MSY) and fleet capacity ceilings help to regulate the impacts that could result from overfishing. The policy includes a MSY plans that are regularly updated to improve stock management.

Norway being a nation with 'one foot in, one foot out' of the EU through the European Economic Agreement (EEA), are not obligated to abide by the CFP. However, as almost 60% of Norwegian seafood

[14] https://www.msc.org

is exported to the EU (Regjeringen.no, 2018) cooperation is of utmost importance and therefore similar policies have been established between the EU and Norway. Norway has signed bilateral agreements covering how fisheries stocks are managed in the North Sea, Atlantic, Skagerrak, and Kattegat. After Brexit this has included trilateral arrangements which currently include total allowable catches (TAC) and quota sharing covering 636,000 tonnes of fish (European Comission, 2021). This is an example of how Norway has negotiation power that they would not otherwise, as the EU advocated for a 16.5 percent decrease in TAC, however the 636,000 tonnes is only a 10 percent decrease of 15,911 tonnes from the previous TAC (European Commission, 2021). The most recent agreement includes quota reductions for this year which include saithe (-25%), a 10 percent decrease from 2020, plaice (-2.3%) a 19 percent decrease from 2020, and herring (-7.4%). Increases in quotas include haddock (+20%) which is still a three percent decrease from 2020, and whiting (+19%) 32 percent increase from 2020 (European Commission, 2021).

8 Summary and further work

8.1 Summary

Chapter **one** was an introduction to the topic of equipment and systems onboard fishing vessels.

Chapter **two** gave an overview of types of fishing vessels and typical sizes. In general, Norwegian fishing vessels may be divided into different types of vessel groups based on characteristics like vessel size and cargo hold. However, vessels are still mainly referred to as either the coastal fleet or the sea-going fleet. The type of vessel group is important as it refers to the type of quota licences and permits.

Chapter **three** described fishing methods and types of vessels more in detail than the previous chapter. Norwegian fisheries consist of a mixture of passive and active fishing gears. 54% of all caught fish is fished by trawl. In general, smaller Norwegian vessels utilize gear like gillnet, hook and line or seine, while larger vessels' preferred gear of choice is auto line, purse seine, Danish seine and trawl.

Chapter **four** described refrigeration systems and use. Most refrigeration systems in Norwegian fishing vessels use ammonia as refrigerant, which has no ozone depletion potential and no global warming potential. Refrigeration systems are used either for chilling or freezing. Chilling is done with refrigerated seawater or freshwater and typically when large catches are brought onboard. Freezing can be conducted on headed and gutted fish in plate freezers or on fillets in blast freezers. Brine freezing is also a possibility which is not so often used on fish but more on other types of seafood.

Chapter **five** described other processing equipment onboard. The chapter shows a lot of technically advanced onboard handling and processing equipment. The choice of processing equipment is dependent on available space onboard, licences and permissions (e.g., filleting) and type of fisheries.

Chapter **six** gave suggestions for energy saving measures onboard. There are various technological measures to improve energy efficiency for different segments of the fishing fleet. The ones mostly applied are battery-hybrid propulsion, heat recovery, variable frequency drives and electrification of fishing gear. Other promising options include LNG cold recovery and thermal energy storage.

Chapter **seven** reviewed sustainability surrounding the fishing industry as well as assessments involving governance and policy, traceability, and carbon footprint (CF). Literature related to the CF of fishing vessels indicate that 75-85% of the overall GHG emissions of fish stem from the fishing stage itself but also recognized the importance of accounting for end of destination transport. In addition to an increased consumer awareness of the CF of seafood, consumers place a growing importance on traceability. Governance and environment play a dominant role in creating sustainable certification schemes. Several of the SDGs relate directly to the fishing industry. In terms of policy, the EU Common Fisheries Policy (CFP) includes management rules for European fishing fleets. Although Norway is not required to follow the CFP, their cooperation within EU policy is vital as 60% of Norwegian seafood is exported to the EU.

8.2 Further work

This report has concentrated on fishing vessels in Norway, but the research goes beyond. Fishing fleet owner countries, like Iceland and Denmark, have access to the same type of equipment as Norway and are also fishing for the same types of fish. There can be a variation in the amount of frozen and fresh fish that is produced onboard. Many fishing fleet owners in other countries have much less access to the expensive and advanced equipment, but still need to chill fish for preservation. In those countries there can be a potential of development, for example with small, efficient, and safe refrigeration systems which can contribute to reduced food losses.

The Norwegian fisheries regulations are briefly described in this report, but it is a huge and complicated topic. In Norway and the neighbouring countries, this has been solved to a great extent although there are continuous debates about quota sizes and belongings, but in other parts of the world there is still an absence of approved regulations. One of the main purposes with the Norwegian regulations is that there are persons with a certain documented activity in fisheries who can own a fishing vessel. Another requirement is that a vessel fishing on Norwegian quotas should be primary owned by Norwegian citizens. The regulations also prevent overfishing and gives the fleet owners with individual fishing quotas a certain security for payback of investments in expensive cooling and freezing equipment.

Within the project CoolFish there are several industry cases focusing on different aspects of refrigeration onboard fishing vessels. In one case, energy measurements onboard are explored. A research cruise was conducted last year with the purse seiner Selvåg Senior which mapped energy flows of the refrigeration system. This resulted in an increased understanding of how the fishing cruises are done and how on-board energy usage is linked to the operational mode of the vessel. A new research cruise is currently being planned, this time on a freezer trawler since a freezer trawler and a purse seiner are quite different in terms of operational profile, refrigeration systems and equipment. The idea is to gain a similar understanding for this type of vessels which will be fruitful for exploring energy efficiency measures. It is also necessary to have good overview of the energy demand profile of fishing vessels when new types of propulsion and engines are coming, for example fuelled with LNG.

Another important topic is which refrigerant to use. Many well-functioning refrigerants have over the years turned out to be ozone depleting and/or have global warming potential. Natural refrigerants, like CO_2 and NH_3 are good alternatives and research is conducted to make system even more reliable, efficient, and safer.

Increasing energy efficiency is an essential measure to reach the climate goals. Fishing vessels are typically operated with conventional diesel-mechanical engines. However, new international regulations on maximum sulphur content in marine fuels, as well as IMOs GHG reduction strategy, has and will push further exploration of alternative fuels and propulsion systems. For Norwegian fishing vessels there is a development towards diesel-electric or hybrid systems, often with hybrid power supply (e.g., batteries). In addition, the shift from diesel oil towards LNG fuel has started, and there are several projects addressing the use of hydrogen or ammonia as future fuels. The change of propulsion system and/or fuel implies changes in the energy system onboard, for example the waste heat characteristics. Therefore, a holistic approach should be applied when designing the energy systems onboard fishing vessels, including refrigeration and processing equipment.

In upcoming years, it is believed that fish welfare will play an increasingly important role. Both for better fishing practices, but also in development of better and gentler fishing gear and processing technology. Additionally, wasteful on-board processing is being looked into in relation to food waste. This relates to both better utilization and handling of caught bycatch, but also rest raw materials from on board processing like cut-offs, innards and fish otherwise deemed not suitable for food.

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