Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions-ANNEXES

European Maritime and Fisheries Fund (EMFF)

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ANNEX 1. CASE STUDIES UTILISED WITHIN THE PROJECT

Summary of Case Studies by category. Information is provided on the species and the type of product (whole, filleted, fresh, frozen, etc, in brackets). Lot number refers to either Lot 1, with a geographical scope of the North Sea and Baltic Sea or Lot 2, with a geographical scope of Atlantic EU western waters, the Mediterranean Sea and the United Kingdom.

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
1	Fish meal/oil	Sprat & Herring (oil and meal)	SWE DNK POL	Small-pelagic fisheries have potentially low GHG emissions. Although this fishery produces seafood suitable for human consumption, in Sweden its products are mainly used for fish meal and oil (especially pelagic species fished from the Baltic). There are a lot of Swedish ambitions in policy to improve utilization of small-pelagics for human consumption, to aid in food security and self-sufficiency. However, some developments stand in the way of this improvement. The prior embargo for export to Russia closed much exports for human consumption, while the recent closure of the Danish mink industry due to covid-19 (substantially disrupting the established supply chain), with strong implications for the Swedish herring and sprat industry (i.e., the largest company has gone bankrupt). A separate issue, not related to human consumption, with sprat used for fishmeal production lies in the Polish fishery and transport to fish meal and oil producers. Costs for transport may cause trade-offs with GHG emissions; transport is cheaper using trucks instead of sea routes. Overall, this CS helps us to understand what happens when there is a problem in a supply chain (which is likely to be a more frequent situation from indirect and direct effects of climate change) while also exploring scenarios and interviewing the industry to identify	The fishmeal and oil industry reports on challenges today with increasing costs (e.g. energy) and changes in the sea that affects fisheries and the raw material (e.g. mixing of stocks); this negative development is likely to continue as an indirect effect from climate change. It was found that to reduce PH GHG emissions in the fishmeal and oil processing industry in Denmark, there is a need for investments in infrastructure for the industry to be able to use electricity from the grid. Furthermore, concentration of processing facilities adds to transport distances in Poland, where choice of transportation mode of raw material (road or sea) affects PH GHG emissions; by volume, most raw material is however landed directly at the processing plants in Denmark. Even if GHG emissions may be reduced in Poland by cutting truck transports and instead process raw material into fishmeal and oil closer to landing ports in Poland, it may prove difficult to change since existing supply chain is optimized economically with restricted opportunities for new actors. Although affected by LCA modelling choices, use of trimmings instead of whole fish	1

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				tangible actions to improve utilization for human consumption and reduce GHG emissions of current value chain.	may slightly add to GHG emissions but utilizing these are important for optimizing resource use. The market for human consumption versus fishmeal and oil production is complex and are sometimes in conflict due to various reasons (e.g. trade embargos, costs, fleet structure). One important finding is the lack of PH data. Mandatory reporting of post-landing destination of catches (direct human consumption or industrial applications) would facilitate these forms of mapping which is today difficult for European sprat and Atlantic herring from the Baltic Sea.	
2		Blue whiting, Boar fish (fishmeal)	IRL	Located in southwest Donegal, Killybegs is synonymous with the seafood industry. In 2020, the Sea Fisheries Protection Authority reported that the port handled 231,000 tonnes of fish worth €111 million at first sale[1]. This is equivalent to 71% by weight and 32% by value of all seafood landed at Irish ports, and 91% of all pelagic fish landed that year. But Killybegs is more than a landing port, it is a town built around seafood, with extensive PH activities including processing, fish-meal, high quality marine ingredients, transport, distribution and other support-services (net-making, refrigeration, electronics, ship building, repair, maintenance etc.) all operating locally. A recent study conducted by BIM shows the Killybegs' seafood sector supports 1,835 jobs with €61 million in wages and €150.3 million in GVA throughout the regional economy. [2] But how resilient is this industry and this town to future change brought about by climate change? This CS builds on the extensive system of data collection already in place (i.e., under the Data Collection	The PH value chain for industrial fisheries in Killybegs is successfully mapped including volumes and value of blue whiting and boar fish as they pass through the traditional processing sector, the fishmeal and bioingredients plants and onward to export. The model developed in the case study links Irish quotas, the Killybegs fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the employment, GVA, wage bill etc of the PH value chain in the town. While clearly demonstrating resilience to the current impacts of climate change, the PH sector has also demonstrated its ability to adapt and add value. For example, an important finding shows how blue whiting, once primarily intended for fish meal is now being utilized more by the traditional small pelagic processors and exported to Africa for human consumption. This generates	2

1 https://www.sfpa.ie/Statistics/Annual-statistics

2 Curtin, R., 2020. The Economic Impact of the Seafood Sector: Killybegs. Book, 6-11-2020. 10.13140/RG.2.2.34067.50722

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				Framework (DCF)) and a number of studies that detail the seafood economy in detail, including direct, indirect, and induced economic activities. Blue whiting and boar fish are of critical interest to the fishmeal and bio-ingredients sector PH. *Note: this case study should be considered in conjunction with CS 5, 17 and 21.*	greater added value and has attracted additional landings of blue whiting to the port. Further, the recent extensive redevelopment of the fish meal plant in the town along with the development of a second bioingredients plant, currently under construction, will position Killybegs to take full advantage of other climate change driven opportunities as they arise. This includes fisheries operating at lower trophic levels than today (i.e., levels in the ocean food web below the carnivore levels currently mostly exploited) which has been recommended by SAPEA (Science Advice for Policy by European Academies) as the way to bring about an increase in available food from the oceans. '	
3	Small pelagics	Herring & Mackerel (fresh / frozen)	NED DEU DNK NOR	There are a number of different impacts to the PH value chain for herring and mackerel mainly in the Netherlands, but partly as well in Germany, Denmark and Norway, which will be examined in this CS. Three different PH value chains are analysed: - Frozen herring as a whole aboard by pelagic freezer trawlers destined for in particular the African market - Herring fillets better known as the Hollandse Nieuwe' (translated as 'soused herring': raw herring soaked in a mild preserving liquid) processed for the EU retail market - Mackerel, fresh landed and processed as smoked or fresh for EU market 'Hollandse Nieuwe' (translated as 'soused herring': raw herring soaked in a mild preserving liquid) are no longer caught by Dutch and German vessels but rather by Danish and Norwegian vessels for decades. For this type of product, the smoking process could be carbon inefficient, while there may also be inefficiencies for those being frozen.	Herring and mackerel are landed in fisheries only; there is no aquaculture for these species. The most likely climate change effects for the three PH value chains of frozen herring as a whole (African market); herring fillets; and mackerel (EU market), are changes in the fish stocks. Changes are for example displacement, higher abundance (in case of mackerel) due to rising sea water temperature, decreasing recruitment due to less feed (plankton) for herring larvae and smaller sized mackerel. For the nearby future (5-10 years), the consulted stakeholders do not expect any major threats for the financial or physical resilience of the PH value chains of herring and mackerel. However, first steps are taken by the industry to reduce their footprint and costs, in order to act upon EU climate change policy (e.g. Green Deal) and to meet the increasing need from customers to become more sustainable throughout the entire PH value chain. First steps are for instance: - Machinal processing (filleting machines) locally (Netherlands) instead of manual	1

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				The potential lessons learned from this CS could be the utility in joint ventures and cooperation to lower risk of impact by climate change.	processing by workers in lower-cost producing countries abroad (e.g. Poland). This saves not only costs and processing time (machinal filleting is more efficient) but also reduces unnecessary transportation between processing locations and the following activities in the PH chain. Therefore, energy costs and GHG emissions could be further reduced. - Electrification of transporting trucks that currently use fossil fuel. - Solar panels on roofs of factory building to generate renewable energy. Management interventions that appeared to be successful to become more resilient to climate driven events, are vertical integration and joint ventures by the PH chain of small-pelagics. The advantage of vertical integrated companies and joint ventures within the PH chain are specialization and the ability of outsourcing activities close to place of landing and processing and distribution. Also, by geographical diversification (having different production locations in different regions worldwide owned by one PH company), this makes the PH activities less vulnerable for climate change effects (e.g. storms, floods, heats etc.) in one particular region. With multiple physical production locations, it is easier to remove one factory or production line if climate changing disrupt production here, to increases the physical resilience of that specific PH chain. Financial resilience is high for vertical integrated companies by increased buying power for materials and predictability of supply flows due to scale advantages. Various activities in the PH chain induce significant GHG emissions: processing,	

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					international transport, consumer packaging, refrigeration in retail. A specific dominant hotspot was not identified, thus reducing GHG emissions along PH chains will require multiple solutions. Consumer packaging, especially jars, induce relatively high GHG emissions.	
4		Chub mackerel, horse mackerel, sardine (canned)	PRT	The abundance of sardines declines in Portuguese waters. Also, sardine's mean length decreases. This is a result of several causes, including overfishing and altered abiotic conditions. Fish canning is characterized as carbon inefficient in comparison to minimally processed fish (e.g., it has been estimated that GWP emissions reach more than 7 kg CO2-eq per kg of canned sardine vs 1 kg CO2-eq per kg of frozen sardine). Pelagic trawlers from the Portuguese fleet have to travel further to find enough fish, resulting in higher carbon emission. New ways of processing for the small pelagic fish species as well as an ecologically more efficient canning industry could bring progress and reduce effects on GHG emissions.	This case-study highlighted the importance of fish processing to many industries, such as the canned fish industry, and the potential sensitivity of such PH chain to disruptions as well as long-term evolutions brought forth by climate change. There are several environmentally critical aspects and significant GHG by the industries in the sector. In particular, the canning industry generates a lot of GHG and was sensitive to any increase in the energy costs, given the fact that it encompasses energy-intensive transformation processes and logistics. Three main areas in the operation of this PH sector contribute to GHG emissions (directly or indirectly) and are more critically affected by increases in energy expenditure: transport; thermal processes (essentially in the canning industry); cold and frozen storage as well as room cooling in general (low temperatures are also required for the processing of fish). The sector's stakeholders did not show a large concern with the environmental issues involving their companies, at least, in what regards their own direct and indirect GHG emissions. They were not concerned with their vulnerability to the multiple incidences of climate change either. Nevertheless, they acknowledged the energy cost problems and the associated GHG emissions and estimable CO2 equivalent costs. In accordance with this concern, stakeholders were	2

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					looking into ways to increase energy efficiency and exploit alternative energy sources. Being mostly small companies, they manifested their difficulty in performing investments in equipment with better energy efficiency and reduced GHG emissions or in advancing towards a full electrification of the transport fleet.	
5		Mackerel, Herring, Horse Mackerel	IRL	Small pelagic fish, particularly mackerel, horse mackerel and herring, are the most valuable species landed at Killybegs and are the mainstay of the processing sector in the port. Processing is estimated to support 1,225 FTEs (480 directly and 740 FTEs indirectly/induced) with an annual wage bill of €38 million and to generate €92 million in GVA[3]. But the future of this once very profitable sector has been impacted significantly by Brexit. Reliance of certain markets on particular traditional species including mackerel, herring and horse mackerel has been considered and the CS considers the possible impacts of climate change in this light, taking account of the 'in combination' impact of Brexit. It has also examined alternative target species, perhaps unfished, and critically reviewed how the capacity of the PH sectors to respond to a species replacement situation, and the management implications thereof. *Note: this CS should be considered in conjunction with CS 2, 17 and 21.*	The small pelagic PH value chain in Killybegs is successfully mapped including volumes and value of mackerel, horse mackerel and herring as they pass through the traditional processing sector and onward to export. The model developed in the case study links Irish quotas, the Killybegs fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the employment, GVA, wage bill etc of the PH value chain. Of the three case studies developed around pelagic fisheries and the port of Killybegs (case studies 2, 6, 23) that for small pelagic species demonstrates the highest indirect impact of climate change. This manifests itself as changes to the migratory pattern of, in particular, mackerel in recent years (>10 years), leading to demands for increased quota from states including Iceland and the Faeroes Islands. When taken with the additional impacts of the Brexit trade and cooperation agreement, the potential to result in lower quotas for EU member states including Ireland is clear. This will have a direct and immediate impact on the availability of raw	2

[3] Curtin, R., 2020. The Economic Impact of the Seafood Sector: Killybegs. Book, 6-11-2020. 10.13140/RG.2.2.34067.50722

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					material to the PH value chain leading to reduced turnover, GVA and employment.	
6	Round fish	Salmon aquaculture (whole, fresh, filleted, frozen)	NOR ISL GBR NED DEU Eastern Europe	There is a range of issues related to climate change associated with aquaculture of salmon, for example higher mortalities because of algae blooms and increased numbers of sea lice resulting from higher water temperatures. Some other issues are in part due to high GHG emissions associated with processing and transporting of salmon in the PH sector. This CS also examined salmon recirculating aquaculture systems and potentially determine whether there is the possibility to cluster processing, packing, logistics and wholesale much closer to the consumer. Possible advantages of such clustering could be: (i) reductions in CO_2 emissions from transport and storing; (ii) Bringing a much fresher product to the consumer; and (iii) keeping seafood clusters alive and make them resilient to climate change effects, including loss of traditional species.	Farmed Atlantic Salmon is one of the most traded and most consumed seafood species in the EU. Most products are imported from outside EU and the transport by truck from origin to processing and from processing to consumption can easily exceed 2.000 km. The long-cooled truck transports and the cooled storing are the main causes of energy use and GHG emission. There is no easy solution to bring down the energy use and the emissions but several small developments that promise improvements in this respect. The interviewed stakeholders such as Salmon traders, Salmon processors and Salmon retailers were not aware of direct climate change related impacts to their business but mentioned some climate change related impacts in the Salmon farm origins.	1
7		Red mullet, gurnard (& squid) (whole, fresh & frozen)	NED BEL FRA	Rising water temperature caused by climate change resulted into higher abundance of red mullet, squid and gurnard in the North Sea and increasing fishing effort by purse seine/flyshoot fleet led to introduction of these 'new' species to the existing (e.g. traditional flat fish) market in the Netherlands, Belgium and France, which has been examined in this CS.	There has been a successful management intervention to solve the issue of decreasing landing volumes of European plaice due to displacement (climate change related by rising sea water temperature). Dutch processors analysed increasing landings of red mullet, gurnard and squid: these three 'new' species are sold at Dutch fish auctions. As landed volumes of flatfish were decreasing the processors utilized the opportunity offered by the increased landings of the 'new species' . These processors started with introducing these fresh squid, red mullet and gurnard to their existing foodservice customers as sample to taste and to try. After these customers were convinced of the high quality and freshness increasing volumes were supplied by the Dutch PH companies to their customers in mainly France, Spain and Italy. As often occurs in food	1

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					sectors, subsequently to the Hotel, Restaurant, Catering (HORECA) industry, retailers started to ask for these frozen and glace 'new' species. The financial and physical resilience of the traditional flatfish PH chain was strengthened by introducing new species to their current market. This CS illustrates how a threat of climate change for one particular species (flatfish, plaice here) could be mitigated by the opportunity of new species that have an increasing abundance in local fishing areas due to climate change (rising sea water temperature). GHG emissions in PH value chains are estimated around 1 kg CO2-eq per kg food product for squid. Half of this is related to food loss and waste in the retail phase (because it induces extra catch; according to the information source catching of squid induces relatively high GHG emissions). For other products of this case study no estimate for catching GHG emissions was found, and consequently the effect of losses cannot be estimated.	
8		Whitefish (& crustaceans) (fresh)	FRA	This CS examines the PH value chain for fresh whitefish in France. It explores the specific requests imposed by retailers to the rest of the supply chain, notably those that may constrain logistic chains, and the effect on the transporters GHG emissions.	The current constraints imposed by supermarket chains is pushing the entire value chain towards an ultra-fresh chain that has to complete all its operations in a 24 hours timeframe, from landings to delivery in individual supermarkets, several steps have to be performed within these 24 hours, and notably: auctioning, primary processing, packaging and transport to close to 10 000 supermarkets. At the same time, external constraints are further restricting logistic operators who experience a regular decrease in trucks average speed adding more pressure to respect the 24 hours window to distribute all fresh fish products. This organisation leads to several inefficiencies in the system that are detrimental to GHG	2

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					emissions: route duplications to meet the time requirements, sub-optimal load levels for most trucks in the system, loss of market for auctions that are too far to serve all supermarkets, suboptimal seafood flows.	
9		Seabass & Seabream (primarily whole & fresh)	GRC ESP ITA HRV FRA CYP TUR	This CS examines the PH value chain of European seabass and gilthead seabream aquaculture within the Mediterranean and how processing, packaging, and delivery processes contribute towards the global warming score (Global Warming Potential – GWP). In addition, this CS determines the impact on different steps in the PH value chain to climate change, while also providing an analysis of trends in technological evolutions aiming at improving energy efficiency and reducing GHG emissions.	The main producing Countries are Greece and Turkey and the main markets are in Italy, North Europe and Spain which are 2 to 5,000 km away. For European seabass and gilthead seabream, packaging and delivery (for 300 km only) contribute to the Global Warming Potential (GWP) by 41%, whereas feed production and rearing contribute to GWP by 10% and 49% respectively. With transportation in the main European markets the GWP in the PH value chain is more than 50%. The packaging and delivery process' GWP is primarily driven by polystyrene production (48%) and electricity that is needed for the operation of the packaging units (40%). The electricity production energy mix in each Country, meaning the range of energy sources used for electricity production, affects the GWP. The lower the energy mix in hydrocarbons (petroleum products and natural gas) and solid fossil fuels and the higher in renewable energy sources, will favour the GWP footprint and will reduce the climate impact of the aquaculture industry. There are relatively fewer steps in the processing of European seabass and gilthead seabream compared to other seafood sectors, which reduces cost. However, there is still limited capacity to invest in adaptation measures due to low economic outcome/high economic costs, while transport needs substantially increases GHG emissions and therefore potential costs of the getting products to market, while low fish prices do not allow investments in new technologies.	2

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					The surveyed stakeholders declared they had an adaptation or mitigation policy for climate change, which included investments for more energy efficient systems (e.g. heat pumps, LED lights, installation of photovoltaic panels) and recycling schemes. The current distribution systems to the destination markets in Europe, Middle East and GCC countries are primarily with trucks, whereas exports to the USA are sent by air for chilled fresh products and by sea for frozen products. If truck manufacturers will provide alternative distribution systems using electricity (i.e. batteries) or hydrogen in competitive prices, the GHG emissions footprint will be reduced.	
10		Cod	SWE	This CS offers a review of a historical event that could also happen to other stocks and industries in the future due to climate change: a change in biological conditions that reduce the abundance (and size distribution) of a species. The change in biological conditions might stem from a variety of sources such as eutrophication, salinity changes, and increasing seal populations.	1. Climate change may contribute to slower growth of cod individuals. This affects the processing industry since small cod is harder to process into valuable fillets. Small cod is less valued on the market and the price difference compared to larger size categories has become more important over time. 2. Declining landings, lost MSC certification, and strong consumer demand for environmentally labelled cod products decrease the use of local cod catches in the Swedish value chain. 3. Cod imports to Sweden (primarily from Norway) have increased from about SEK 300 million in 2008 to about SEK 1000 million in 2020 (SEK 1 ≈ 0.1 Euro). Total cod exports have declined although exports of processed cod have recovered slightly since 2006. 4. The Swedish processing industry has become more reliant on fish import since 2012. Increased imports have, however, not significantly lowered the profitability of the industry. However, data are not available for a specific analysis of cod processing firms.	1

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		Bream (freshwater)	SWE	Bream (*Abramis brama*) is considered an underutilized species with market potential. The species is common in the Baltic but not fully utilized since it is traditionally not consumed locally. However, the species is promoted as a new species for consumption and might also be exported. There is no well-developed industry around this species yet, but investments are being made to improve processing capacity etc.	Cyprinids, such as bream, are an alternative to cod since they are expected to benefit from a warmer climate. It is up to the PH chain to timely adjust their strategy of diversifying into 'new' species such bream. However, it requires a fisheries management at MSY, promotion of the product to consumers and imports of cod from elsewhere as the landing volumes of bream could not compensate the lacking production volumes of cod by climate change.	1
11		Carp fishes (bream, ide, roach and carp) (freshwater)	SWE FIN POL	Nordic countries have today vulnerable seafood production and consumption, due to e.g., reliance on temperature-sensitive species, such as salmonids and cod. However, many freshwater species within these countries (such as carp fishes (cyprinids)) have higher temperature optima and are predicted to increase in abundance with climate change. Since the carbon footprint of cyprinids in Sweden are low relative to other seafood, increased utilization may add to domestic production volume and allow for diversification for small-scale businesses. In addition, for professional fishermen it may be beneficial to catch the fish – but a value chain based on local, small-scale fishing is challenged by current competitiveness. Carp in Poland is one of the most important aquaculture products (45% of total production). Depending on the size of aquaculture there are different systems of distribution and strategies of leading the business farm. Climate change may cause water shortage and result in higher costs of production and higher predator activity (e.g., otter, cormorant) leading to lower production. At the same time, carp is a more robust species compared to e.g. salmon, potentially offering opportunities for increased EU production if consumer interest and production economy allows.	Integrating more species in a value chain is by industry in Sweden seen as an opportunity to increase resilience when traditional species are negatively affected; however, there are many uncertainties related to climate change effects on ecosystems and species, and production costs will be negatively affected by climate change, and possibly fishing opportunities. Today, low demand and high production costs of new seafood with low GHG emissions is challenging sustainable growth in Swedish value chains based on different cyprinids. For Polish value chains of carp, one challenge is to optimize for a stable volume of carp production and to continue logistic improvement made by market integrators. In Sweden, there is a scarcity of value-adding processing facilities which makes efficient logistics important to GHG emissions. Furthermore, when exploiting new species in fisheries, there are data deficiencies and national fishery management needs to define objectives and monitoring suitable to allow for sustainable exploitation.	1

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12	Demer-sal fish	Sole & plaice (fresh and frozen)	NED DNK BEL ESP ITA	Many Dutch specialized flatfish processors became financially vulnerable to annually decreased landing volumes of plaice and sole. Therefore, they introduced salmon next to flat fish to process. This transition made these processors much more resilient to change while also being able to cover market demand. Such change has also occurred in Italy, with Italian importers also introducing salmon as new species within their PH value, compared to traditional sole and plaice. Sole and plaice are moving further north to colder waters in the North Sea. These flatfish are likely more carbon inefficient compared to salmon aquaculture from Norway and Scotland. Fishing vessels from Northern EU countries (Netherlands, Germany, Denmark, Belgium) do have to steam much more miles between the more northern fish catching locations at sea and harbour of first sales. Species like farmed salmon are often close to Norwegian coastal location where transport per truck to Northern EU countries is done instead of steaming by a fishing vessel. Transport via inland routes is much more carbon efficient compared to fishing vessels with higher fossil fuel usage (oil, gas etc.).	The flatfish PH chain is mainly affected by climate change with decreasing landing volumes and smaller sized plaice according to literature. Consulted stakeholders perceive the displacement of plaice (due to rising sea water temperature) to outside EU waters and therefore less supply by decreasing landings of EU vessels is problematic for the resilience of PH chain. Another concern of consulted PH stakeholders is the rising energy costs due to Ukraine war. Despite the cost inflation, the rising energy costs stimulates PH companies to invest into renewable energy and to reduce their footprint as freezing processing activities requires high energy and gas consumption. Unfortunately, due to a limited energy infrastructure capacity it is not always possible to implement solar panels. Another problem is that insurance companies are not willing to insure solar panels at the roofs of processing factories due to risk of burn (with too large capital value of the factory to insure that is at risk). Management interventions to mitigate the effects of climate change or other market driven threats to the resilience of PH value chains are: - Importing substitutes such as plaice from third countries - Introducing new and upcoming species like squid (see CS7) - Diversifying to other species like aquaculture, such as salmon or seabass and seabream. Various activities in the PH chain induce GHG emissions: processing, international transport, consumer packaging, refrigeration in retail. However, the emissions are smaller than for species that are frozen and/or transported over large distances. Dominant hotspot are consumer	1

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
					packaging and effects of losses along the chain. Total GHG emissions along the PH chain are – for a typical chain configuration – estimated at 0.54 kg CO2-eq. per kg fish fillet.	
13		Invasive species (lionfish, rabbitfish) (raw / fresh)	GRC CYP Eastern Mediterranean	Climate change drives the continuous increase of thermophilic invasive species and a decline of native commercial species in fish communities of coastal areas in the eastern Mediterranean. In the case of Cyprus, fishers, retailers and consumers have adopted well to such change, with invasive species such as rabbitfishes constituting the main targets of both commercial and recreational fisheries with high market demand and value. Currently, rabbitfishes rank first in terms of both catches and value, among all targeted commercial fishes in Cyprus (Michailidis et al. 2020[4]). On the contrary, in Greece abundant invasive fish such as rabbitfishes and recently lionfish are mostly discarded as there is no or very low demand. The adaptation of the supply chain to the introduction and dominance of new thermophilic invasive species is a major issue for the sustainability of small-scale coastal fisheries.	The main conclusions of this case study are: - Small-scale fisheries in the eastern Mediterranean are already in a bad state. Suffering historical overfishing and bad management, the sector is now in dire straits, independently of any climate change impacts, which are secondary in magnitude. - The main climate change impacts on SSF are changes in species composition (decline in traditional native target species and increase of IAS); lost days at sea due to the increased frequency of bad weather conditions; extensive damages to fishing gear, and thus increased maintenance costs, by certain thermophilic IAS such as *Lagocephalus sceleratus*; an increase of jellyfish and harmful algal blooms that impact gear and catch; and reduced productivity of marine ecosystems. - IAS such as rabbitfishes and lionfish have already been successfully marketed in Cyprus, less so in Greece. Their increased abundance can provide opportunities for SSF in both countries, as they can obtain high demand in a short time, and thus their targeted fisheries contribute to securing fishers' income and the SSF value chain. - The role of management has been inadequate to secure the viability of the SSF sector and the related supply chain.	2

[4] Michailidis N, Katsanevakis S, Chartosia N., 2020. Recreational fisheries can be of the same magnitude as commercial fisheries: the case of Cyprus. ICES Journal of Marine Science 231: 105711.

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
					Removing administrative barriers for measures to improve energy efficiency and control IAS, and coordinating active promotion campaigns of new alien species to the market would substantially contribute to the viability of the sector.	
14	Inverte-brates	Mussels & Oysters (fresh, with shell)	NED FRA DEU BEL	Rising sea water temperature and invasive species like starfish, Japanese oyster borer and oyster herpes virus threatened the production of mussels and oysters. New techniques have been introduced to reduce the negative effects of these invasive species. In addition, the packaging process of bivalves with MAP (Modified Atmosphere Packaging) has been found to be GHG inefficient. Also, more efficient energy use for refrigerating and transport have been implemented and will be discussed.	For bivalves (blue mussels and oysters) the most impact by climate change to the PH chain is the lower quality and produced volumes by fisheries (higher mortality and decreased growth performance of mussels). It is expected that lower quality result into decreasing financial result to the market for the PH chain. A management intervention by the PH chain to mitigate or adapt to the impacts of climate change is to lower the risk of locally lower quality of produced mussels by vertical integration or joint ventures. Another management intervention is to source blue mussels from other regions (e.g. Ireland or Denmark and Germany) by Dutch processors if climate change impacts are less impactful there for the production at sea. GHG emissions in PH value chains are estimated around 0.35 kg CO_2-eq per kg mussels. This is low compared to other seafoods, which is related to absence of freezing step and mostly moderate transportation distances. The packaging is – as for most other seafoods – a hotspot in terms of GHG emissions. For oysters significantly more packaging plastics and other materials are used, and consequently the GHG emissions associated to packaging are at least 2x times higher. Emerging distribution channels related to online shopping are not expected to reduce GHG emissions of the PH chains.	1
15		Mussels & Oysters (fresh, with shell)	NED FRA		For live mussels, impact of climate change is twofold:	2

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
			DEU BEL		Structural: most of the sector is located on the coastline, in areas that are at risk of being submerge (sea rising) and more frequently impacted by rough weather. Operations happening in the intertidal zone are also affected by these changes which may disrupt further the operations of businesses that are mostly vertically organised (production and primary processing). Resource: warming waters may have profound impacts on the ability of mussels to grow at the current commercial size, which may dramatically change the ability of the sector to offer any product without a complete rethink of the product range that can offered to consumers.	
16		Pandalus (peeled)	SWE NED DEU	Shrimp is perceived as locally produced with important cultural traditions, but it can have long and complex supply chains and can have some of the highest GHG emissions amongst seafood (e.g., fisheries in the North Sea, processing in Poland/Bulgaria/Morocco, consumed in Sweden, Germany). There are a range of potential improvements in GHG emission in this PH value chain and also a range of threats from climate change which will be examined. Exploring scenarios/interviewing the industry and basic LCA calculations may identify how a high emission GHG seafood PH value chain may reduce GHG emissions, and potential climate-related threats/risks with current supply chains. In addition, within the PH value chain resource efficiency could be improved. For example, out of 10 kilos of fished shrimp only 3-4 kilo remain for consumption (peeled). Such side-streams could be valorised for improved resource efficiency (chitine as ingredient, broths, etc.)	Actors in the PH value chain experience a lot of uncertainties indirectly or directly related to climate change but mainly related to fisheries, e.g. how fishing opportunities may be affected from ice conditions and fuel costs and availability of raw material. The GHG emission contribution from PH value chain is generally small compared to the contribution from fisheries. Sourcing raw material from the most efficient fisheries is most important action for overall GHG emissions reduction of the product; this may be hindered by current trade agreements and tariffs. In the Northern shrimp fisheries in divisions 3.a and 4.a east, enforcement and control of EU CFP regulations, and member state management actions related to national fleets, negatively affects GHG emissions of one of the fisheries supplying raw material. Actors in the PH value chain are experiencing increasing costs, and although at the moment driven mainly by the Russia-Ukraine conflict, this is also an indirect effect from climate change likely to increase. Concentration of EU processing	1

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
					facilities negatively affects GHGs due to increased transporting distances. Peeling by hand offers opportunities for higher edible yield but cost and availability of work force in the EU are limiting factors. However, industry with machine peeling experience limitation in raw material and are subjected to high price competition with shrimp peeled by hand that are perceived to be of higher quality. For shrimp value chains, it has been found that having diversified markets (retail, HORECA, public kitchens) adds to resilience if there is a disruption in the supply chain (supply or demand). At last, available statistics are insufficient in allowing for detailed mapping of Northern shrimp value chains.	
17		Nephrops	IRL	This CS analyses the Norway lobster post-harvest value chain in Ireland. This fishery is Ireland's second most valuable after mackerel, and is exploited by vessels in the polyvalent segment of the national fleet. In contrast to the other CS presented for Ireland (2, 6, 23) all of which consider pelagic species, Norway lobster are landed at all of Ireland's major fishing ports and form an extensive PH value chain that in many cases commences onboard the vessels while still at sea. Collectively these CSs (2, 5, 17, 21) represent 87% by volume and 75% by value of all quotas allocated to Ireland in 2020.	The model developed in this CS links Irish quotas, the national polyvalent fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the employment, GVA, wage bill etc of the PH value chain. It highlights, in particular, how the fleet has adapted to the changing demands of a market that demands the highest quality product by developing an extensive fleet equipped to undertake onboard freezing at sea. This innovation, and the additional (onboard, at sea, PH) employment opportunities it presents, demonstrate how the polyvalent fleet has adapted to increasing water temperature, created greater onboard added value, maintained the links with shore-based fishermen's cooperatives and increased its resilience to changes in the supply of this important species.	2

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
18		Imported tropical shrimp (frozen, fresh)	Global	The EU depends on the import of wild caught and farmed tropical shrimps, most of them coming from overseas areas that are already influenced by climate change effects such as rising sea levels, tropical storms, higher water temperatures, long distance transports. Beside needing huge volumes of "glazing water" (i.e., a protective layer of frozen water that helps preserve the freshness of the fish) to ship such fisheries globally, energy intensive processing (thawing, cooking, freezing) is used, as well as utilising retail packs which are environmentally unfriendly. CS18 covers frozen and refreshed, raw and cooked, Penaeus shrimps (White Tiger, Black Tiger) in Germany and Be-Ne-Lux: often head-off or peeled, partially value added: salads etc. CS19 covers cooked, raw, frozen and refreshed shrimps in France mostly head-on shell-on	The EU is importing most of their mid and large size shrimps from outside EU and the biggest share of it are Vannamei and Black Tiger Shrimps from East Asia and Latin America. After processing steps in the origin countries, the Shrimps get usually frozen and the shipped to the EU from overseas; the usual distances are more than 10.000 km. After the arrival in European Harbours the Shrimps are transported by truck to processing or to wholesale and retail. The transport is the main driver of GHG emissions. As there are no easy solutions to bring the shrimp origin closer to the EU an improvement field to lower the transport energy use and GHG emissions could be a better use of the transport capacities (use of container space) where currently often the containers are filled by 30% and more with frozen water and not with Shrimps.	1
19		Imported tropical shrimp (frozen, fresh)	Global		For the imported tropical shrimp PH chain, impacts of climate change are mainly about supply chain disruptions and the ability of the sector to source aquaculture products that may suffer from production areas that are facing important challenges (warmer temperatures, sea rise, floods). Stakeholders considered that existing business models were close to being optimised and that there would be a need for innovations to replace current cooking technologies for the sector to modify its practices.	2
20	Tunas	Tuna Bay of Biscay & imported tuna (cooked and canned)	ESP	This CS deals with the tuna canning industry within Spain, which includes utilising local tuna species fished in the Bay of Biscay as well as imported tuna. The tuna canning industry has adapted to the variability in raw material availability, formats, and market demand. After the market increase due to the	- The consulted stakeholders were very interested in sharing their experiences in the sector throughout their professional career, however, they refused to share more precise data when asked about financing or environmental projects.	2

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
				COVID19 pandemic crisis, the following future challenges could be highlighted: optimization of energy and water efficiency in conservation labours, reducing transport distances, finding alternatives to conventional energy sources, outdated and inefficient equipment, new packaging solutions or improving insulation systems.	- Few of the stakeholders knew their environmental footprint, and when asked for production data, or other aspects related to their environmental development, they were reluctant to share it. - The vast majority of GHG emissions within the canned tuna PH value chain come from primary packaging and energy (electricity and natural gas) consumed for heating and sterilization processes. Thus, increasing energy efficiency and finding alternative energy sources are relevant aspects to care about when intending to minimise GHG emissions. - Even though machinery providers constantly invest on improving equipment efficiencies there is a short room for achieving relevant breakthroughs on this field. This means that a great part of the companies' efficiency depends on operation and production strategies.	
21		Albacore tuna	IRL	The incidence of tuna and tuna-like species in Irish waters has shown signs of increase across the last 30 years. The CS will explore how the PH sector in Killybegs has adapted to these novel species and specifically the role they play (may play in the future) in helping the sector diversify its resource base, as well as improve adaptation and innovation, adding value to new species, and developing new markets and corresponding products. Note: this case study should be considered in conjunction with CS 2, 5, and 17.	The development of a fishery for albacore tuna off Ireland's south and west coasts is, for many in the sector, the best example of a fishery that has come about through climate change. And yet, almost 30 years after it first started this fishery is today landing most of its catch, not in Ireland, but directly in to France and Spain where it joins existing, local, PH value chains with little if any benefit to the Irish seafood sector. In this CS, the PH value chain for Ireland's albacore tuna fishery is successfully mapped including volumes and value. The model developed in the CS links Irish quotas, the Killybegs fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the	2

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
					employment, GVA, wage bill etc of the PH value chain. The CS then considers how management of the fishery a) saw the successful introduction of quotas including an Irish quota (in contrast to, for example, blue fin tuna, now also found in Irish waters), and, b) how the ban on the use of driftnets led to significant changes in how this fishery operates. This ban not only impacted the fishing gear used but also the boats involved and resulted, ultimately, in a move away from landing into Irish ports. With little or no fish now landed the potential to develop new PH activity is severely curtailed.	
22	Multiple	Various – concerns improved technology for GHG reduction	EU	Technology is an important aspect for the PH sector, yet how energy efficient or GHG-emission efficient the current technology used in this sector is, is currently difficult to estimate. This CS explored which technologies are being used and if these technologies are energy or GHG-emissions efficient. Furthermore, the incentives to use the current technologies will be investigated.	Most impactful activities (hotspots) were related to heating and drying for the feed producer, while thawing and (re)freezing for the seafood processor. High energy and water consumption were flagged as additional GHG hotspots as well as packaging for the seafood processor. The main incentive for technological or management changes appears to be financial gain. Sustainability is a secondary driver if investors make it a prerequisite of their financial investment. Gains on reducing GHG emission can still be made to tackle GHG production hotspots if huge financial investments are made or if an integrated legislation provides structural solution without destroying the financial benefits of the sector.	1
23	Multiple	Various – concerns structural and technological improvements for GHG reduction.	EU GBR	The seafood company at the centre of this CS is a wholesaler, processor, importer and exporter (both domestically within the UK and internationally). Their value chain covers locally (UK) caught species, including round fish, demersal, invertebrates, and small-pelagics, but also raw products bought on EU markets, with export to the EU as well as Asia.	The greatest contributor to the GHG emissions within this case study's postharvest value chain comes from the use and disposal of packaging, which accounts for 57-66 % of all associated GHG emissions. The largest contributor is polystyrene, despite measures in place to reduce this impact in the form of a polystyrene compactor that facilitates recycling. Other	2

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
				It is understood that there is a need for continual restructuring and technological advancement within post-harvest value chains in order to remain competitive, reduce costs and secure profitability. The aim of this CS was to better understand some of the mechanisms by which this can be achieved in the post-harvest value chain, the effect this has on GHG emissions and the driving forces behind these investments. To achieve this, the CS focused on understanding how the company structures its distribution chains for certain species, how the structure impacts GHG emissions, where and how GHG emissions could be reduced and what steps have been taken to try and reduce post-harvest related GHG emissions. Areas of the value chain found to contribute most significantly to GHG emissions are highlighted and reported. In addition, the use of new technologies within the company aiming at improving energy efficiency and reducing GHG emissions is also reported, including those that have not been successful and factors which are limiting implementation. Overall, there are several actions being taken by the processor in this case study to reduce their GHG emissions, both structural and technological. Many of these are easily replicable, but the main driving factor for change is cost savings, not a reduction in emissions.	methods for packaging have been trialled; however, alternative forms of packaging have not been successful because the trial packaging lacks either the structural integrity or the thermal properties required. The reuse of cleaned polystyrene boxes, which was common, has been reduced because of concerns raised at food hygiene inspections. Competing priorities such as these, between minimising food hygiene concerns and minimising GHG emissions, demonstrate some of the difficulties companies face when making business decisions that could affect post-harvest value chains and associated emissions. Reducing diesel use, identified as the second most GHG emitting aspect of the value chain within this case study, could be best achieved through a transition to electric vehicles for short distance transport (e.g., 100 km). This transition is now feasible due to technological advancement and changes to vehicle purchase cost and the rising cost of diesel. However, a global shortage of key components (e.g., microchips) is currently holding up this transition. Overall, there are several actions being taken by the processor in this case study to reduce their GHG emissions, both structural and technological. Many of these are easily replicable, but the main driving factor for change is cost savings, not a reduction in emissions. This could explain why, when asked which aspects of the business were most responsible for GHG emissions, only one of the answers given (diesel) was in the top three. Understanding and reducing GHG emissions, therefore, appears to be a question of priority and currently where there is no incentive to reduce their carbon footprint, outside of the associated reduction in	

Nr	Category	Species (type of processing between brackets)	Area	Narrative	Main Conclusions	Lot
					costs with reduced resource consumption, the likelihood of a business prioritising reducing emissions appears low.	

ANNEX 2. CASE STUDY REPORTS

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CASE STUDY 1: FISHMEAL/OIL – ATLANTIC HERRING (*CLUPEA HARENGUS)* AND EUROPEAN SPRAT (*SPRATTUS SPRATTUS)* – BALTIC SEA, SWEDEN, DENMARK, POLAND

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Photo credit: Peter Sjöholm

Sara Hornborg, Yannic Wocken, Marcin Rakowski and Adam Mytlewski

LIST OF ABBREVIATIONS

Term	Description
GHG	Greenhouse gas
HORECA	Hotels, Restaurants and Cafés
LCA	Life Cycle Assessment
LW	live weight
RSW	Refrigerated Sea Water
SwAM	Swedish Agency for Marine and Water Management
TAC	Total Allowable Catch
TRL	Technology Readiness Level
t*km	tonne kilometre, i.e., transport of one-ton material for one km

1 Background

Small-pelagic fisheries are generally associated with low greenhouse gas (GHG) emissions compared to other fisheries and seafood systems (Gephart et al., 2021). Pelagic species such as Atlantic herring *Clupea harengus* and European sprat *Sprattus sprattus* also represent highly nutritious seafood (Hallström et al., 2019). However, although the main global production volume is suitable for human consumption, landings of small-pelagics are often destined for fish oil/meal and bait (Cashion et al., 2017). Furthermore, if caught in certain areas of the Baltic Sea, fatty fish such as Atlantic herring may contain undesirable substances such as dioxins and dioxin-like polychlorinated biphenyls or PCBs ("dioxins"). Fatty fish from these areas thus have restrictions in dietary advice to consumers or require extra documentation concerning dioxin levels present before being sold at some markets. Hence, from a combination of market-related factors, the main production volume of Atlantic herring and European sprat from the Baltic Sea has increasingly been destined for fishmeal/oil and mink feed (in particular catches east of the island of Bornholm and further north in the Baltic Sea).

The total annual EU fishmeal and oil production has in the past decade (2010-2019) declined compared to previous 10-year period; ~474 000 tonnes meal and ~155 000 tonnes oil production is on average produced annually (EUMOFA, 2021a). The main drivers behind recent years decrease in production is increased utilization of some pelagic species for human consumption and a general decrease in quotas for industrial fisheries (i.e., fisheries targeting species for feed production) (Seafish, 2018). Although increased utilization for direct human consumption for important fishmeal and oil species may be favourable from a food security perspective (e.g., Majluf et al., 2017), current competition between fishmeal and oil production and direct human consumption in the EU is a challenge that requires more investigations. Today, the EU is a net importer of fishmeal and oil, even if the difference between supply/demand and imports is decreasing. However, out of the total production in the EU, 72 % of the fish oil and 39 % of the fishmeal was exported to Norway (EUMOFA, 2021a).

For current value chains of Atlantic herring and European sprat, there are a lot of uncertainties concerning volumes destined for human consumption verses other purposes due to complex trade routes and currently available statistics, complicating estimates of seafood consumption in e.g. Sweden (Hornborg et al., 2021). The Swedish value chain of small-pelagics from the Baltic Sea was disrupted by covid-19 with the closure of the Danish mink industry: fishmeal and oil were no longer needed for mink feed. This had an effect on the profitability of the company handling the largest landing volumes of European sprat and Atlantic herring from the Baltic Sea in Sweden. Meanwhile, there are a lot of ambitions in the Swedish food policy to improve utilization of small-pelagics for human consumption, to add to self-sufficiency. This is further supported by repeated calls by the UN to prioritize the pelagic fish resource for human consumption (Pihlajamäki et al., 2018). How this may be prioritized, and the potential implications on GHG emissions is yet to be resolved.

This case study (CS) focuses on Baltic Sea fishmeal and oil production based on Atlantic herring and European sprat. The overall aim is to map the supply chain and estimate current GHG emissions of fishmeal and oil production from the Baltic Sea with focus on Swedish, Danish and Polish value chains. One topic includes the effect on different transport scenarios of catches. Transporting by truck is cheaper than by sea, while the latter has lower GHG emissions for transporting a certain mass unit of goods a given distance. Furthermore, the CS intends to further the understanding of what happens when there is a sudden disruption in a supply chain, since this is likely to increasingly occur in the future as an indirect or direct effect of climate change (Cottrell et al., 2019), and explore opportunities and hindrances to increase utilization of resources for human consumption, including potential effect on GHG emissions.

2 Value Chain

2.1 Value chain description

Annual landings of European sprat from all waters in the EU are the second largest in volume of non-food use of fish resources between 2015-2019, decreasing from 391 000 tonnes to 255 000 tonnes, whereas Atlantic herring landings are the 4th largest in volume at around 131 000-197 000 tonnes annually, respectively (EUMOFA, 2021a). Contributions to these volumes from the Baltic Sea fisheries are not reported separately in the report and ICES landings from the areas includes both industrial fisheries and those for human consumption.

From the Baltic Sea (ICES subdivisions 22-31), catches of Atlantic herring varied over time and between stocks, but have been declining in most recent years for all stocks (ICES, 2022; Table 1). Atlantic herring fisheries for both human consumption and industrial purposes use primarily trawls with different mesh sizes (pelagic and demersal), but minor volumes are fished by purse seine, gillnets and traps. The Swedish, Finnish and Polish fishing fleets dominate the EU landings of Atlantic herring in the Baltic Sea. For European sprat from the Baltic Sea, catches have dramatically increased during the 1990s and have fluctuated between 250 000 – 300 000 tonnes in recent years (ICES, 2022; Table 2). Most of the European sprat catch is taken by pelagic trawls and is landed in Denmark by several EU fleets (96 % out of total landing volume in all areas; EUMOFA, 2021a).

The postharvest (PH) value chain of Atlantic herring and European sprat from the Baltic Sea starts at the point where first sales take place, after landings of fresh fish (Figures 1-2). The type of usage after landing is market-driven (Lassen, 2011; communication with actors around the Baltic Sea). There are no official data available on the overall share of human consumption for all fisheries of European sprat and Atlantic herring, specifically for the Baltic Sea; this requires investigations at Member State level. Trade flows are complicated and in their current format do not allow for reliable tracking of trade flows to use in seafood consumption mapping in e.g. Sweden (Borthwick et al., 2019; Hornborg et al., 2021). In the latest EU fish market report (EUMOFA, 2021b), some of the data related to both herring and sprat are even excluded due to confidentiality. However, the decrease seen in both per capita consumption of seafood and catches for human consumption in the EU are attributed to decreasing herring quotas in the Northeast Atlantic, including the Baltic Sea.

Stakeholders around the Baltic Sea describe that the PH destination is highly variable and differs between countries and stocks. Finland reports that for 2020, only 3 % of Atlantic herring landings from the Baltic Sea were destined for direct human consumption in Finland and 26 % were exported for human consumption; the rest was used for fishmeal and oil. In Poland, official data are not collected but based on the demand of the Polish processing industry it is estimated by NMFRI that about 30,000 tons of European sprat (around half of the landing volume) caught by the Polish fleet are used annually for human consumption. The remaining part of the catch (over 50 %) is used for non-consumption purposes, mainly fishmeal and oil, but also feed for fur animals. For Atlantic herring from the Baltic Sea, there are also no statistics on destination in Poland; part of the volume is landed abroad, some volumes are delivered to a cannery in Sassnitz (Germany). Part of herring landings used for non-consumption purposes is non-sorted catches mixed with sprat. In Sweden, which holds the second largest share of the Total Allowable Catch (TAC) for European sprat, the Swedish Agency for Marine and Water Management (SwAM) reports that on average 22 % of landing volumes of both species does not have information on if they are destined for human consumption or industrial applications; it is generally estimated that ~90 % of the Atlantic herring and over 95 % of the European sprat from the Baltic Sea is destined for industrial purposes such as production of fishmeal and oil. In Latvia, the utilization varies between stocks; all central herring (ICES SD 25–29 and 32, excluding the Gulf of Riga) is destined for direct human consumption due to limited fishing rights whereas only 40 % of the Gulf of Riga herring is destined for direct human consumption. Furthermore, 70 % of the sprat landings from Latvian fisheries in the Baltic Sea was destined for direct human consumption, the rest was used for fishmeal and oil production. In Lithuania (2019), 67 % of Atlantic herring landings from the Baltic Sea and 80 % of European sprat landings respectively were destined for fishmeal and oil production. Combined, the obtained information indicates that ~17 % of Atlantic herring volumes from the Baltic Sea is destined for direct human consumption on the domestic market or for export (based on data for 78 % of total landing volume) and ~28 % of the European sprat respectively (based on data for 72 % of total landing volume) (Figures 1-2). However, based on fishing area (including all landings except for those in 30-31 and 28.1), the share of Atlantic herring for direct human consumption is likely higher (<39 %). On a country level, the quota utilisation may however be considerably different in terms of share of human consumption versus industrial purposes.

After first-sale, landings are either processed directly in factories located in harbours or transported by truck (frozen or fresh) for further processing to fishmeal and oil or use as mink feed. Processing facilities include either fishmeal and oil processing plants (primarily in Denmark) that export to global feed markets (Table 1), or facilities around the Baltic Sea processing for direct human consumption (fresh or frozen fillets, whole frozen fish, canning, smoking). Volumes destined for direct human consumption comprise mainly of larger sizes of herring and are mainly from the southern part of the Baltic Sea. In Sweden, volumes destined for human consumption are distributed mainly as fresh or frozen fillets to retail and HORECA (Sundblad et al. 2020). Based on information from one Swedish company that processes Atlantic herring and European sprat for human consumption, 28 % of fresh fillets and 89 % of frozen fillets of Atlantic herring are exported to markets in Denmark, Finland and Italy whereas for European sprat, all is exported to the United Kingdom (UK), Poland, Latvia and Estonia.

One challenge in the supply chain is availability of harbours that can receive large vessels and handle large landing volumes. In Poland, only a few of the largest fishing harbours have infrastructure capable to land pelagic fishes on a large scale. Vacuum pumps for the vessels equipped with RSW (Refrigerated Sea Water) systems are owned by organizations or companies and are set up on quays in several ports. They enable industrial fish to be transported directly to trucks that transport the fish to meal and oil processing plants located outside the country (Denmark, Germany and Latvia are the main destinations). Trading companies and producer organizations also have sorting systems, which are used when part of the catch of a specific vessel is intended for sale for direct human consumption. Such operations cause increase of costs (about 0.02 EUR/kg), which influences shipowners' decisions to fish for non-consumption purposes.

Side streams from processing for human consumption are also used for feed production. In Sweden, these were in 2014 transported to fishmeal and oil production (57 %) in Denmark or used as mink feed (43 %) in Sweden or Denmark (Bergman, 2015). The fillet yield of European sprat is, according to EUMOFA, 37 % edible of live weight, but also whole fish is utilized for canning. The fillet yield of Atlantic herring from the Baltic Sea for human consumption varies in the Baltic, where there are less fat and smaller individuals compared to other fishing areas. Edible yield for larger Atlantic herring is in general around 52 % of live weight (EUMOFA), but according to industry the filleting yield may be as low as 20 % for smaller and less fat herring from the Baltic Sea (Figure 1). On a yearly basis, Atlantic herring from the southern parts of the Baltic Sea has a filleting yield between 30-35 %, but there is a large variability between fishing areas and seasons. When Atlantic herring from the Baltic Sea is used for fish oil and meal production (whole fish or trimmings), yield is 15.1-18.2 % for fishmeal and 6.3-8.3 % for fish oil respectively. Yield for whole fish or trimmings of European sprat from the Baltic Sea is 15.6-18.1 % for fishmeal and 6.3-8.1 % for fishmeal respectively.

After processing for fishmeal and oil, the destination has changed over time for the Danish processing industry, with a larger share currently being directed towards aquaculture. The fishmeal and oil have different markets, but the main volume is sent for production to compound feed in aquaculture. However, according to Seafish (2018), fish oil and meal from herring and sprat contributes to relatively small volumes out of total volume of raw marine material used by key aquaculture feed manufactures (Biomar, Skretting, EWOS). According to the Seafish report (2018), industrial fisheries for European sprat contribute with raw material for both fishmeal and oil whereas industrial fisheries for Atlantic herring only contributes to fish oil production; only trimmings of Atlantic herring are utilized for fishmeal. When there is information available on fishing area (summarized in Seafish, 2018), the total volumes of Atlantic herring and European sprat utilized only comprise of smaller shares caught in the Baltic Sea.

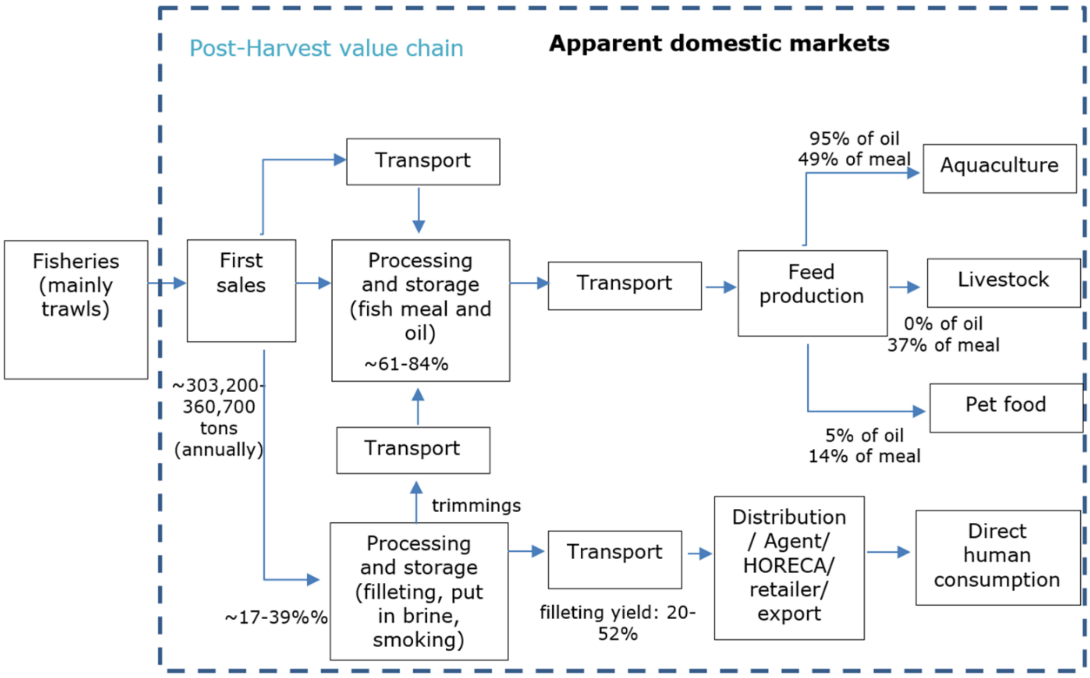

Figure 1 Postharvest value chain of Atlantic herring from ICES area 22-32 (2015-2019). Source: Industry data, EUMOFA.

Table 1. Numbers of the Postharvest value chain of Atlantic herring from ICES area 22-32 (2015-2019).

Main primary production	Top 5 EU countries (landing volume)[1]	Volume first sales (annually)[1]	TAC (quota) in 2021 (tonnes)(excl. Russia)[2]	Main first sales locations
Wild capture (mainly trawls)	1.Finland 2.Sweden 3.Poland 4.Estonia 5.Germany	303,200-360,700 tonnes	1.Finland (46 %) 2.Sweden (21 %) 3.Estonia (11 %) 4.Poland (10 %) 5.Latvia (9 %)	Skagen (DK) Norrsundet (SE) Västervik (SE) Kasnäs (FIN) Hel (POL) Kołobrzeg (POL)

Sources: [1]ICES, [2]European Commission

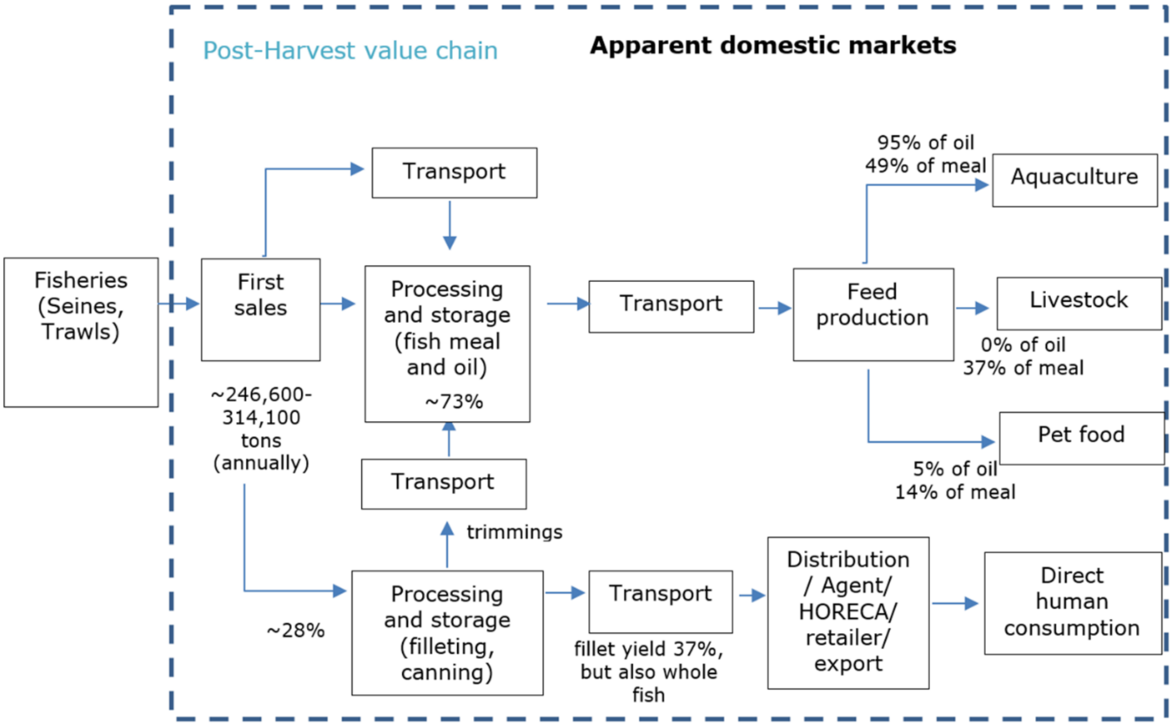

Figure 2. Postharvest value chain of European sprat from ICES area 22-32 (2015-2019). Source: Industry data, EUMOFA

Table 2. Numbers of the postharvest value chain of European sprat from ICES area 22-32 (2015-2019).

Main primary production	Top 5 EU countries (landing volume)[1]	Volume first sales (annually)[1]	TAC (quota) in 2021 (tonnes)(excl. Russia)[2]	Main first sales locations
Wild capture (pelagic trawl)	1.Poland 2.Sweden 3.Russia 4.Latvia 5.Estonia	246,600-314,142 tons	1.Poland (29 %) 2.Sweden (19 %) 3.Latvia (14 %) 4.Estonia (12 %) 5.Demark (10 %)	Skagen (DK) Västervik (SE) Hel (POL) Kołobrzeg (POL)

Sources: [1]ICES, [2]European Commission

3 Resilience

3.1 Physical and financial resilience

Most of the pelagic stocks used for fishmeal and oil production are believed to be affected by climate change according to EUMOFA (2021a); no specific reason is provided. In production of fishmeal and oils there is an international market and supply of fish and use of side streams from processing is flexible, depending on prices.

The yearly first-sale price of European sprat from all fishing areas was 0.19-0.28 EUR/kg during 2007-2020, whereas Atlantic herring prices varied between 0.38-0.73 EUR/kg respectively (EUMOFA, 2021a). There are no specific first-sale values reported by EUMOFA for the landings from the Baltic Sea area, but the prices are available on country basis. According to data from the Swedish Agency for Marine and Water Management, there is no large price difference in Sweden between sprat used as food or feed from the Baltic for Swedish fisheries (around 0.2 EUR for both); this difference is much larger for sprat from the North Sea (feed 0.3 EUR/kg and food 0.8 EUR/kg). For Atlantic herring in the Baltic, the feed is only worth 21 % of the food value (in EUR/kg), similar to the situation for herring from the North Sea. In Poland, there is a significant increase in cost of delivering landings for non-consumption purposes, because landings are lower.

In Sweden, there has in recent years been a strong public and political debate concerning the competition between Atlantic herring fisheries in the Baltic Sea for human consumption versus fishmeal and oil production, in particular in the more northern parts along the Swedish east coast. Finland takes the main volumes in the Bothnian sea (ICES areas 30-31), but the use of pelagic trawls in Swedish fisheries in coastal areas have increased in recent years. Although the stock is sustainably exploited according to the MSY-framework of the EU CFP, the proportion of larger sizes of fish have decreased. Size structure is not part of the MSY objectives, but larger sizes of fish are required for the human consumption market; there is thus a competition in current fisheries between different markets.

3.2 Major financial constraints and reliability

Climate change is expected to increase risks of outbreaks of zoonosis that may cause pandemics such as covid-19 (Carlson et al., 2022). EUMOFA (2021a) states that the initial negative impact on the global trade and logistics from the covid-19 pandemic was short lived for fishmeal and fish oil. This is correct, but one aspect not considered was other effects on the value chain supporting the fishmeal and oil industry. The value chain structure in Sweden was disrupted with the killing of minks in Denmark due to fear of zoonosis. Based on an interview with the major first-hand receiver of pelagic fish from the Baltic Sea in Sweden, this change was the end of their largest factory. Storage of frozen pelagic fish for on-demand delivery to mink feed in Denmark was an important extra income for the facility, even if they had already decided to end this production due to lower demand. However, factories handling Atlantic herring and European sprat from the Baltic Sea in Sweden currently need to be able to rely on keeping volumes for both non-consumption and direct human consumption to maintain freezing capacities and cover costs. After the decrease of the mink industry, demand for frozen, whole fish from the Baltic Sea is low (except for around 200 tonnes for cat feed) and landed volumes are instead directly transferred fresh by truck to fishmeal and oil producers in Denmark through new contracts. There was thus a positive effect on the availability of raw material for the fishmeal and oil producers, but it shut down the opportunities for factories to keep freezing capacity required to handle smaller volumes for human consumption.

In Sweden, a larger share of herring caught in the Baltic Sea was before used for direct human consumption. These volumes were mainly exported to markets in eastern Europe, in particular Ukraine and Russia. However, trade embargos and price competition between fishmeal and oil production in Denmark and purchasing power in eastern Europe have increasingly directed volumes towards non-consumption production (Sundblad et al., 2020). For the Swedish consumption market, the smaller sizes of fish and less fat content makes Atlantic herring from the northern Baltic Sea not suitable for pickling, an important product form for the Swedish market. However, in the southern Baltic Sea, Swedish industry processing European sprat and Atlantic herring for human consumption experience major lack of raw material. The trends of larger fishing vessels, larger landing volumes and reduced TACs for stocks in the southern Baltic Sea are driving a development towards increased utilization as fishmeal and oil due to Swedish harbour capacities in combination with quality needs for raw material for direct human consumption. According to Polish processors, with higher mechanization of production, Atlantic herring from the Baltic Sea is most suitable for canning, similar to sprat. For a lot of value-added products with high level of automatization such as breaded fillets, a larger share of herring from the North Sea is however imported in Poland. Despite this, Polish processing demand for Baltic herring for human consumption remains high.

3.3 Stakeholders' perceptions

In terms of climate driven effects affecting the value chain, representatives of the Danish fishmeal and oil industry report on increasing energy costs. Other issues of concern reported on are growing populations of seals (directly and indirectly affecting the resource) and increase in stickle back (Gasterosteidae) abundance (offering a potential new resource for fishmeal and oil); it is however not scientifically proven if climate change is a driver. At present, energy cost is seen as the most pressing issue. The issue with seals reported is mainly related to poor status of cod stocks (contributing with parasite spread to cod) and the spill-over effect on setting lower quotas for European sprat and Atlantic herring in the Baltic Sea to allow for rebuilding of cod stocks.

The main opportunities to cope with climate impacts and risks are, according to representatives of the Danish fishmeal and oil industry, the use of alternative energy sources and improving energy efficiency, but the main barrier is available infrastructure. There are no cables that can deliver the energy needed. With energy use now being based on coal and natural gas, the industry is vulnerable for effects such as seen now with the embargoes on Russia as a result from the military aggression against Ukraine. The processing industry may improve their efficiency by the fishing industry changing fishing patterns to seasons providing the highest yield (most oily); the dialogue on how to optimize per species is already ongoing. In this regard, the perception of the processing industry is that in the Baltic Sea, climate change has fewer effects on species and distribution than in the North Sea.

According to representatives of the Danish fishmeal production industry, the greatest impact on GHG emissions from their part of the value chain is the cooking process because this is likely the most energy demanding. Furthermore, they report that the main driver to take action on climate change is based on own initiatives. There is however a major challenge with public infrastructure not being available for using green energy; cables and capacity are not sufficient to support the processing industry where it is currently located. Dialogues with municipalities are ongoing, but changes in infrastructure are costly and require funding at higher level than the fishmeal and oil processing industry can support.

Overall, there are different issues affecting the value chain of fishmeal and oil from the Baltic Sea (Table 2). Some are more directly related to climate change whereas others are more of general concern (such as public perception of the fishmeal and oil industry). Strengths and opportunities for the value chain are the low GHG emissions, high nutritional value, increasing interest in environmental footprints and EU regulation initiatives to hinder deforestation which may provide market advantages for fishmeal and oil over imported soy.

Table 2 SWOT for fishmeal and oil production from European sprat and Atlantic herring caught in the Baltic Sea. Based on interviews with one producer organisation in Denmark, one producer organization in Poland, one trading company specialized in deliveries of raw material to plants in Denmark, one trading company with cold stores and processing of fishmeal attempt.

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	*Strengths* • Provides feed ingredients with low GHG emissions • High in nutritional value • Increased interest in product's environmental footprints where fish ingredients are more favourable than e.g. soy • Full utilization of catches through appropriate transportation or storage • Investments in green energy production in Poland (wind turbines, solar panels)	*Weaknesses* • Energy demanding to produce fishmeal and oil • Expensive to change to other energy sources and decrease energy use in Danish processing • Basing land transport on trucks
External origin (attributes of the environment)	*Opportunities* • Stickle-backs (Gasterosteidae) are increasing and may be a new resource for fishmeal and oil • EU regulation on deforestation is coming up, have to prove that e.g. soy doesn't cause deforestation, which will offer improved market opportunities for fishmeal and oil	*Threats* • Negative public perception and misunderstanding related to fishmeal and oil production (especially in the Baltic Sea) which may affect the political agenda and close fishing opportunities • High aggregation of fishing effort that puts pressure on the resource for economic reasons • Climate change is causing changes in fish spawning period, individual size, geographical distribution, as well as the mixing of fish stocks of different species, which makes sorting operations much more difficult

Another issue that was not brought up during the interviews but a common knowledge that is arguably affecting consumer market interest is that Atlantic herring and European sprat from the Baltic Sea are an important dietary source of undesirable substances in particular dioxins, although decreasing (Tuomisto et al. 2020). This situation is an opportunity for the fishmeal and oil processing industry that utilize a raw material of low consumer interest and have the ability to remove these substances from the final product. Furthermore, a weakness is that the availability of raw material cannot be scaled up because production is limited, and threats to the industry include potential overutilisation of stocks when quotas are set too high.

3.4 Role of management – lessons learned of adopted strategies

There are a lot of uncertainties in the stock assessments of Baltic Sea Atlantic herring and European sprat. One issue is the mixing of the species in catches, and that the relative share of the species reported in logbooks may not be accurate which complicates stock assessment (ICES, 2018). There is also a high degree of mixing of the defined Atlantic herring stocks, which is a compromise between populations defined on biological grounds versus practical fishery management units, which further complicates assessments. Prior estimates on fishing mortality and spawning stock biomass have had to be revised as new knowledge has emerged, and fishing pressure has been found to be higher and stock size smaller than previously assumed. This causes risks for effects from overfishing. Since the MSY-framework for managing fish stocks does not include objectives on size structure of the population, but only on biomass, a fishery may today be fished in line with MSY-objectives although the size structure may be skewed towards smaller individuals. This development has e.g. been seen for Atlantic herring stocks in the Baltic Sea, where e.g. the stock in the Gulf of Bothnia (ICES SD 30-31) has decreased from a mean size of around 20 cm to 14 cm between 2005 and 2017 (Sportfiskarna, 2020). This development causes increased tension between fishing segments in Sweden, where local fishermen require larger sizes of Atlantic herring for human consumption, as well as occurrence of fish in coastal waters; both have shown dramatic declines in recent years.

Polish fishermen indicated that fishing pressure in previously non-fished spawning areas is increasing. This has been made possible by adapting smaller vessels to pelagic fishing for non-consumption purpose. In their opinion, catch volume is most important factor; the price difference at first sales between landings for human and non-human consumption purposes is so small that saving on transport to fishing grounds is prioritized.

A separate issue lies in the structure of the value chain on land compared to fishery management objectives and fleet structure development. Through an introduction of individually transferable quotas in the pelagic fishery in Sweden, with one of the management objectives to make the fleet more efficient (SwAM, 2014), current sizes and thus catch capacity of vessels have increased (~700–800 tonnes). Based on an interview with one processor in Sweden, the largest facility to receive pelagic fish from the Baltic Sea in Sweden was built in 1997. It was adjusted to handle volumes from the common sizes of the fishing vessels at the time (a freezing capacity of ~200 tonnes/day). Landings could there be sorted by size and processed into fillets. Between 1997–2007, 10 000–20 000 tonnes were annually frozen for human consumption (50 % of landing volume), the rest was frozen for feed production. The part for direct human consumption was mainly exported to Estonia, Latvia, Russia and Ukraine. Around 2006-2007, the share destined for human consumption decreased down to 25 % of landing volume, and fully disappeared in 2014 with the embargo to sell fish to Russia. From year 2010 onwards, the size of fishing vessels increased, and with this development, the ambition has been to fish more efficiently (large volumes in short time). European sprat and Atlantic herring from the Baltic Sea are highly perishable, and to keep the quality needed for direct human consumption, the fishery needs another fishing patterns, with short hauls and smaller landing volumes. The catch needs to be stored in cold water onboard and should ideally be delivered to the processing facility within 24 hours. The current price and cost of production difference between fish landings for direct human consumption versus for feed production is not large enough to motivate this change in fishing pattern. If increasing utilization of Atlantic herring and European sprat from the Baltic Sea for human consumption would be the ambition, there currently is however a mismatch between vessel capacity and first-hand receiver on land in Sweden.

4 Greenhouse Gas Emissions

4.1 GHG emissions in the value chain

The functional unit of the European sprat and Atlantic herring value chain here is 1 kg of oil or meal at factory gate. The inventory is based on information from Danish processing plants, Swedish and Polish value chain actors, reports (mainly Winther et al., 2022) and secondary data from LCA databases. The data availability and variability for the different steps of the value chain is described below.

Fisheries

No published estimate on fuel use intensity (l/kg) is available for European sprat and Atlantic herring fisheries in the Baltic Sea. However, fisheries for Atlantic herring with pelagic trawls show small variation in available records and have on average a fuel use intensity of 0.1 litre/kg LW in Iceland, Scotland, Norway and western Atlantic (Byrne et al., 2021; Sandison et al., 2021; Winther et al., 2020; Driscoll & Tyedmers, 2010), which equals to roughly 0.38 kg CO_2e/kg LW. This estimate includes production and combustion of fuel and a generic value for non-fuel related emissions based on approach in Ziegler et al. (2021).

When fishing for human consumption versus for fishmeal and oil, the targeting pattern differs. As an example, in Poland, if catches are intended to be sold for non-consumption purpose, they fill the RSW tank 90 % fish and 10 % water. When the catch is intended for direct human consumption, fishermen protect the fish from being squished and the RSW tank is filled 50 % fish and 50 % water. There may thus be a lower catch per unit effort for fisheries for human consumption, possibly effecting fuel use intensity and thus GHG emissions; to which extent is unknown in Poland. Also, Swedish pelagic fisheries in the Baltic Sea exhibit great variability in targeting pattern, such as transport distance, fishing trip length and catch volume. However, on average, preliminary analysis of these fisheries based on data provided by the Swedish Pelagic Federation Producer Organisation indicates the same fuel use intensity for fisheries for human consumption versus fishmeal and oil, although it could be variable between fishing trips.

Processing for human consumption and trimmings

Most landings for non-consumption purposes are not sorted or stored. Shipowners choosing to fish for human consumption may sort landings, but smaller volumes are not frozen but instead just sent fresh by trucks to fishmeal and oil producers or mink feed production.

If destined for human consumption, 480–800 tonnes of trimmings are generated from 1000 tonne of Atlantic herring when filleted whereas for sprat, 630 tonnes are generated respectively. These trimmings are transported to fishmeal and oil factories fresh in tanks by trucks. According to Polish customs office data, exports of fish side streams from Poland was 89 500 tons in 2019 and 127 000 tons in 2020. The share sent to Denmark was 73 000 tons and to Germany 102 000 tons, respectively. These volumes are all reported as fish waste in official statistics (includes PH side streams and catches for non-human consumption), but it is not possible to separate data for fishing areas, nor separation between fish side streams (from processing for human consumption) and fish specially caught for non-consumption purposes.

Production of round-frozen (whole) Atlantic herring and European sprat for human consumption in an industrial processing plant requires approximately 216 kWh/ton LW for freezing, around 0.13 l fuel/ton (unspecified, assumption based on information from a salmon slaughter plant) and a municipal waste treatment process – combined ~19 kg CO_2e/ton fish processed (Winther et al., 2020). No data could be obtained on the GHG emissions from filleting of European sprat and herring, but a Norwegian report (SINTEF, 2006) has estimated a requirement of on average ~225 kWh/ton for processing of pelagic fish. This is equivalent to 99 CO_2e/ton (Ecoinvent data for average European grid mix). Sourcing raw material from trimmings is thus associated with slightly higher GHG emissions, i.e. emissions from processing and extra transport on top of emissions from fisheries, compared to sourcing directly from industrial fisheries. The degree of increase is however often marginal and depends on modelling choices in LCA, i.e., how emissions are allocated between main product (fillet) and side streams.

Transport

Most of the fish volume is landed directly on site of the fishmeal and oil factories in Denmark and thus does not require any further transportation than is included in the fishery. Fish sourced from more distant harbours is transported fresh in tanks by truck with eventual ferry journeys to shorten transport distance.

For the Danish fishmeal and oil processing industry, raw materials are predominantly landed directly at the fishmeal and oil factory. As a result, the average transport distance is comparatively short: 100–140 t*km truck transport and ~1 t*km ferry transport per ton raw material input depending on the factory and sourcing pattern.

However, transport distance can be highly variable in the supply chain. In Poland, transport to fishmeal and oil production comes directly from vessels landed at ports into tankers or tubs with a single capacity of 25 tonnes. The primary directions are Denmark (Skagen) and Germany (Cuxhaven), which, counting from the largest unloading port in Hel, gives a one-time distance of 1300 and 1000 km, respectively (for Kołobrzeg the distances are 250 km less). Chilled road transport process provides an emission of 0.248 kg CO_2e/t*km[5]. This includes the entire transport life cycle, but not the fact that some routes include roll-on-roll-off ferries which would lower the GHG emissions. Some examples of transport routes and associated GHG emissions are found in Table 3. Since the fisheries have a low fuel use intensity, with GHG emissions of 0.38 CO_2e/kg LW, different transport routes contribute to a larger share of total GHG emissions compare to more fuel intense fisheries; transports could have equal importance as the fishing phase if transported on road from distances over 1300 km.

Table 3 GHG emissions of different transport routes and modes.

Mode	Transport route	Distance (km)	kg CO_2e/t
Road	Poland (Gdynia) – Denmark (Skagen)	1200	298
Road	Sweden (Norrsundet) – Denmark (Skagen)	700	174
Road	Sweden (Västervik) – Denmark (Skagen)	450	112
Road	Hel (Poland) – Denmark (Skagen)	1300	322
Road	Hel (Poland) to Cuxhaven (Germany)	1000	248

Export of "fish waste" from Polish processing industry is considerable (Table 4) and has increased in recent years. This volume comprises of both trimmings from processing for human consumption and catches for non-consumption purpose. The increase in export seen is driven by the closure of the Eastern Baltic cod fishery (fishing moratorium), with as a result, more fishermen turning to pelagic species, in particular for non-human consumption purpose. According to information from interviews in Poland, one transport trip of "fish waste" can consume as much as 300 litres of diesel. In addition, most trucks return to Poland empty, which also burdens fish transport to the processing plant with GHG emissions. During the interviews of those involved in the process of supplying fishmeal processors, no answers on number of trips were obtained because of confidentiality issues. A rough estimation based on catch and consumption volumes for consumption purposes in Poland shows that about 800–1000 trips can be used to transport fish for fishmeal and oil production annually, resulting in diesel consumption of 240,000–300,000 l per year for these transport.

[5]16-32t Euro 5 at WLFDB 3.1/EU, AGRIBALYSE 3

Table 4. Export of "fish waste" in tonnes from Poland in years 2018-2019. Source: Eurostat

Country	2018	2019	2020
WORLD	69 116.48	89 459.63	126 982.96
DK	46 613.05	61 524.47	75 783.13
DE	11 668.37	11 955.10	26 081.41
LV	6 245.99	9 124.22	13 026.04
FR	1 770.82	2 367.86	4 594.64
GB	646.23	505.51	1 834.85
LT	414.51	489.93	1 707.18
CZ	3.19	33.46	1 133.44
US	1 263.62	1 107.65	1 126.86
AT	1.09	625.41	855.04
ES	106.84	96.77	469.64
HU	204.77	332.20	354.30
IT	22.35	5.70	8.04
BE	-	0.14	3.50
NL	23.80	25.68	1.79
SI	1.03	0.87	1.74
SE	18.55	0.02	1.37
FI	0.01	0.02	0.00

Processing into fishmeal and oil

Denmark is the main producer of fishmeal and oil in the EU with ~40–50 % of total production (EUMOFA, 2021a). The processing of raw material into fishmeal and oil separates solids (fat-free dry matter), oil and water in fully automatic closed systems (Figure 3).

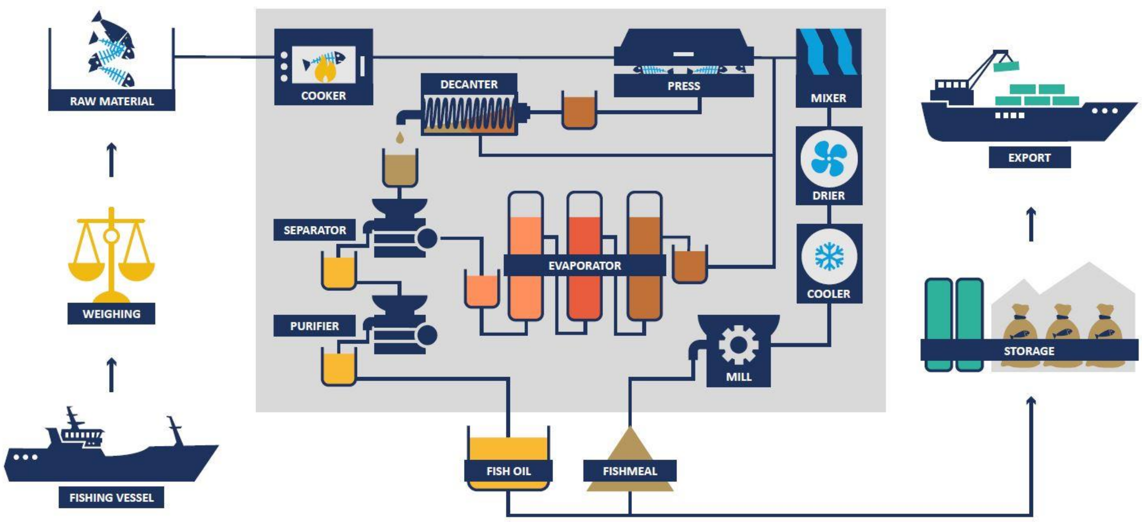

Figure 3 Processing scheme for fishmeal and oil in Denmark. Source: Provided by Marine Ingredients Denmark.

The production of fishmeal and oil comprises of many different steps (Table 5) but there are no detailed data on the energy requirements for the specific steps. During the different steps, it is best practise within the industry that vapours and air from the process are treated to reduce odour. According to representatives from the Danish fishmeal and oil processing industry, cooking is most likely the most energy demanding process.

For the general process of making fishmeal and oil out of raw material in processing plants in Denmark, the share of energy provided by electricity from the grid varies between plants but is restricted because available infrastructure does not allow for supplying the energy needed. A large share of the energy provisioning is therefore currently based on coal, natural gas and biogas. The mix of energy source varies between plants, with strong implications for GHG emissions, both in absolute numbers and relative contribution from processing to overall GHG emissions; an indicative value for greenhouse gas emissions from processing based on one of the factories is 0.44 kg CO_2e/kg fishmeal and oil.

Table 5. Steps during processing into fishmeal and oil

Process	Details
Raw material intake	Method differs depending on how the raw material arrives, could be by screw conveyers, lamella pumps, tipped from containers, bins, skips, bulkers or trucks or by pumping with water directly from the vessels. Common practice is that it is unloaded into enclosed hoppers or tanks.
Cooking	Raw material is stored in a buffer silo until it is fed into a cooker where it is heated to 90–95ºC. This sterilizes the fish, coagulates the proteins and disrupts the cell membranes, to facilitate the separation of the soluble and the oil from the dry matter.
Press & Decanting	The cooked raw material is fed to either a screw press, a 2-phase or 3-phase decanter, where much of the liquid is squeezed out to produce a liquid phase, a solid phase, and if there is a 3-phase decanter, there is an oil phase. Strainers are used before pressing to make optimal working conditions for the presses. Efficient pressing gives low fat levels in the product.
Separator	The press water is separated further in a decanter. The press water contains most of the oil from the fish and dissolved proteins, salts and fine particles. The liquid from the decanter is sent to separators, where the oil is removed and subsequently stored for export. A two-step separation is used for fish oil extraction: 1) Extraction of oil from soluble fraction by means of separator; and 2) Polishing of extracted fish oil by means of second separator. All solids separated by this process are recovered.
Evaporator	The liquid that remains after the removal of the oil (stickwater) is fed to evaporators, where it is concentrated before being blended with the press cake during the drying stage. The stickwater contains both dissolved and undissolved proteins, residual oil, minerals, and vitamins. To concentrate the stickwater and achieve a high concentration of dry matter, large quantities of water are removed by evaporation, which requires energy, and the resultant condensate has to be discharged. The industry currently uses various devices for evaporation; having an evaporator significantly reduces the environmental impacts of wastewater to the receiving environment.
Dryer	The wet mixture of presscake, decanter sludge and concentrated stickwater is converted into a dry fishmeal (moisture content below 12 %, enough to inhibit microbial activity). The material is heated to a temperature where the rate of evaporation of the water is considered satisfactory in order to avoid reduction of quality, especially of the protein. There is a diversity of drying processes that are used – indirect steam drying, vacuum drying, hot air drying and spray drying – and some factories use more than one drying process. Indirect steam drying is the most common practise throughout plants in Europe. Good practise applied to the drying process involves sealing of equipment to avoid uncontrolled excess air ingress, control/removal of vapour steam and maintaining equipment under vacuum.
Cooling	After drying the fishmeal is cooled by air.
Grinder/ Milling	The fishmeal is ground to a specific particle size using hammer mills. After the milling, the meal is stored for export either as meal or pelletized.
Oil purification	To reduce undesirable substances, the oil may pass through a carbon-filter press.
Scrubbing tower	The scrubbing tower collects air and surplus vapour from the dryers and the heat exchanger and air suction vapour from the processing plant.

Storage and distribution

After production, both fishmeal and oil are only stored for a limited time due to continuous high demand from feed producers and high production volumes. The fishmeal and oil are stored in containers/boxes at the processing plant with constant shipping out (mostly bulk ships but also trucks). Feed is distributed to producers predominately by ship directly from site. Smaller volumes are also transported by truck. Based on transportation data bases, distribution by ship is generally the more efficient transport method in terms of GHG emissions per tonne transported.

According to detailed information on destination provided by one Danish processing plant, 95 % of the fish oil is directed to aquaculture (the remaining 5 % to the pet feed industry) whereas only 49 % of the fishmeal is directed to the aquaculture industry; fishmeal is to a larger extent directed to livestock production (37 %) and the remaining to pet feed (14 %).

Overall GHG emissions

For fishmeal and oil produced in Danish plants, the largest contribution to GHG emissions per kg fishmeal comes from fuel use in fisheries. For PH, processing contributes with 23–35 % of total emissions (second largest for overall emissions). The most important factor influencing emissions from processing is the energy source other than electricity, with natural gas and biogas performing better than coal. GHG emissions from raw material transport only account for about 1 % of the Danish fishmeal or oil's cumulative emissions.

4.2 Alternative distribution systems

According to representatives of the Danish fishmeal and oil processing industry, there is little market interest for European sprat and smaller sizes of Atlantic herring from the Baltic Sea for human consumption; the fishmeal and oil industry takes what is of low interest for other uses. However, based on an interview with processors in Sweden, there is still demand for human consumption, such as the canning industry in Latvia but also other countries; the purchasing power may however be low. One option to increase utilization of the raw material is to redirect fish oil to human consumption as e.g. supplements, which would decrease EU dependence on imports of this market segment.

If switching to green energy could be enabled for the fishmeal and oil processing industry in Denmark, which would decrease GHG emissions. Furthermore, representatives of the Danish fishmeal and oil industry also reports that raw material quality may be better when use of electricity instead of gas and may thus add value.

4.3 Limitations for structural improvements in GHG emissions

Switching to green energy will be very expensive, and due to state aid rules for who can receive funding, private sectors such as the fishmeal and oil industry cannot receive fundings for this transition.

If the fish oil should be used for human consumption, the whole factory needs to be approved for food production. The raw material is food grade, and the fish oil is clean of unwanted substances such as dioxin. Current EU legislation on food production is thus a hinder today when food and feed cannot be produced in the same facility although both have food quality and production lines may be separated within a factory. According to representatives of the Danish fishmeal and oil industry, it has proven difficult to change these rules. Instead, a change in practise at the plants towards being food grade facilities and use side streams for feed needs to take place. This is associated with costs and may also affect the ability to receive raw material (that will always be generated) not suitable for human consumption.

In Poland, volumes of European sprat and Atlantic herring landed directly from fisheries in foreign ports (especially the island of Bornholm, Denmark) used to be around 12 to 20 thousand tonnes annually, but landings in foreign ports are decreasing. This is due to a combination of factors such as the development of infrastructure in Polish ports; fewer benefits related to taxes and subsidies affecting fuel prices in Bornholm, compared to Poland; fishermen's calculation of profits from deliveries directly to processing plants in Denmark versus Poland; and the most important factor is vessel operators saving time that could instead be spent on fishing. Climate change is perceived to lead to less fishing days with favourable fishing conditions and, as an effect, a reduction of the number of available fishing days. Combined, this results in increased fishing activity on fishing grounds closer to landing sites. This is a change in fishing pattern that may case risk for overfishing from increased fishing pressure in a certain area or time of year, depending on stock dynamics and possibility to account for this in stock assessments. But if sustainable fishing pressure can be assured, all actors in the Polish value chain may benefit from this: fishermen save time and money; producer organisations can act as traders; traders took the added value that was before left on Bornholm; and processors may get lower prices. Attempts are also being made to start processing of fishmeal and oil in Poland, but the existing value chain for fishmeal and oil is robust and optimized economically. This challenges opportunities for new establishments of plants, especially smaller ones, and requires relatively high level of investments in Poland at high financial risk.

5 Reducing GHG emissions by technical means

5.1 Trends in technological evolutions and industrial strategies

According to EUMOFA (2021a), fishmeal and oil production is projected to grow moderately the coming years with the growing aquaculture as a main driver. Because fishmeal and oil are limited resources, they are considered to rather be strategic ingredients used at lower concentrations in compound feed, whereas development of new raw materials (such as krill, algae and insects) and increased utilization of trimmings is expected to achieve growth in production. Parts of the volumes of Atlantic herring have been sent as frozen, whole fish to the tuna grow-out industry around the world. It is unknown to which extent this practice exists today. From a fish-in-fish-out perspective, i.e. how much fish raw material that is required relative to the output of the aquaculture production, processing into fishmeal and oil for production of compound feed offer better utilization of limited resources.

The growing aquaculture sector is intensively searching for raw materials to incorporate in compound feeds, driven by sustainability ambitions, supply and prices. Both replacement of fishmeal and oil (which are limited in availability) and plant protein sources with environmental challenges such as deforestation concerns (such as soy) are under development. In this effort, it is important to acknowledge the nutritional value of the new ingredient for optimized fish welfare and growth. Further, physical properties and availability of the new ingredient are important factors that need to be taken into consideration. Today, ingredients under development include those based on low-trophic level species, microbes, insects, plants, and animal by-products – each with different potential and challenges but all in need of accelerated development of new processing technologies to ensure commercial production (Albrektsen et al., 2022; Almås et al., 2020). Absolute values on GHG emissions from prior LCAs of these potential replacements cannot be directly compared without harmonization due to the strong influence on results from methodological choices in the modelling (Ziegler et al. 2022); furthermore, many ingredients do not have representative data yet for commercial scale production. For fish oil, a promising replacement based on nutritional value is algae oil, which has been shown to contribute to higher GHG emissions but comes with other environmental benefits such as reduced dependence on limited resources of fish (Bosch et al., 2018). For replacing fishmeal, different vegetable ingredients have been used so far, such as soy, which has also come with trade-off in terms of higher GHG emissions of feed production and often dominates feed related GHGs of aquaculture species (Hempel 2022; Ziegler et al., 2021). Hempel (2022) concludes that if GHG reduction is the goal, it is important to focus efforts on reducing inclusion of high-emission ingredients such as soy from countries with expanding agriculture, as well as micro-ingredients (in particular pigments) which have shown to be associated with high GHG emissions. Replacing fishmeal and oil with soy-protein concentrate results in an increase in GHGs and, in addition, increase the need to add feed additives to meet the nutrient requirements of the fish, but also to increase palatability, bioavailability or strengthen the health. There are other ingredients of interest at different Technology Readiness Level (TRL); one more novel feed ingredient of particular interest is different applications based on microbes that have fast growth rates and can be grown on different substrates including waste streams (e.g., Martínez-Córdova et al., 2017). Another marine-based ingredient that may be utilized more are blue mussels, which in Hempel (2022) were found to be associated with relatively low GHG emissions.

The current system of managing fish raw materials for non-consumptive purposes such as fishmeal and oil is based on large-scale processing plants. The number of fishmeal and oil plants has decreased in recent years, with Denmark alone seeing a reduction from twenty to three plants (EUMOFA, 2021a). Based on interviews in Poland, a few but large plants have created efficient and strong supply chain structures that are difficult to enter if smaller players want to get established; larger plants can also offer better prices. There has been an attempt to change such chains by building a fishmeal and oil plant closer to the point of landing, but this was not successful due to high competitiveness when entering the fishmeal and oil market, with low profit margin. It seems that the existing links between current processing plants and the customers of the fishmeal and oil, and the strong position of intermediaries (trading agents) that can offer higher prices to fishermen than small-scale processors, all contribute to Polish fishermen selling their catches to plants in Denmark (mainly) or Germany. A concentration of processing factories may require longer transport routes. In addition, if transport is conducted by trucks, it influences GHG emissions of fishmeal and oils; transport by sea is generally more efficient per tonne transported. In Poland, the current logistics associated with fishmeal and oil production resources is associated with relatively lower costs and greater cost-effectiveness of transporting it by land and at the same time keeping the vessel at sea – compared to the cost of time spent on direct transport by fishing vessels and landing at the port close to the plant.

Representatives of the Danish fishmeal and oil processing industry report on having internal strategies that include reduction of GHG/carbon emissions. This involves going through emissions and work on how to change energy supply. There are already EU regulations with binding agreements, EU Best Available Techniques reference documents (BREF, 2022), setting cuts in emission levels (including GHG emissions) based on five-year cycles and is seen as a very important document for the industry in general. Industry stakeholders also report that they have significantly decreased their overall freshwater usage during processing (no specific details were provided, processes that require water are found in Table 5 and currently use mainly seawater (90 % of the total).

For a long time, the Polish pelagic fleet used traditional methods of transport in boxes (25 kg, or 45 litres); later on, they changed to transporting in "big boxes" (containers). At this moment, those big boxes are not used frequently, after the introduction of Refrigerated Sea Water (RSW) tanks. The reason for having boxes was mainly due to the lack of infrastructure (vacuum pumps for the landing process) in Polish ports. Large quantities of fish for non-consumption purpose were landed in ports on the island of Bornholm, because of the possibility of obtaining a higher price. At the same time, Polish ship owners were modernizing their vessels by installing RSW-tanks instead of traditional storage. The launch of financial resources from operational programs for fisheries in Poland (the Sectoral Operational Program for Fishery during 2004-2006; the European Fisheries Fund (EFF) and European Maritime and Fisheries Fund (EMFF) Operational Programs in 2007-2013 and 2014-2020 respectively) was a driver for change. Suitable infrastructure on land came after the first vessels were equipped with RSW tanks, but by 2015, Polish ports and their surroundings were equipped with adequately landing, sorting and storage infrastructure, and most vessels were modified and equipped with RSW systems. At the same time, there were significant organizational changes in Polish fisheries. Producers' organizations (POs) were formed (usually based on fishermen's unions and associations) and became significant market players. Up until the 1990s, one state-owned company owned ports, vessels, processing and sale infrastructure. When this system collapsed, private owners (former captains of vessels) used to sign bilateral agreements with processors. Now, POs and a few large private traders dominate the market for the sale of pelagic catches, where the PO set rules that members should sell their catches trough their First Sale Center (owned by the PO). In practise, not all members of POs adhere to these rules, and the power of the PO is too small to enforce the terms. If cost of landing is higher in Polish harbours, they go to Bornholm. Vessel owners may also calculate the time needed for transport to different harbours compared to the earnings they can make if they spend the time on fishing instead and base their decision on that. In 2020, around 12 thousand tonnes of sprat and 4 thousand tonnes of herring were landed in foreign ports.

5.2 New processing and logistic techniques and their challenges

In the Norwegian report from 2006 (SINTEF, 2006), it was estimated that energy use for processing of pelagic fish could be reduced by 45 %. Reduction opportunities entailed optimization of all processes, such as utilizing the best lighting regimes, most effective process equipment, effective cooling and ventilation.

The wish to be able to use electricity in the processing plants in Denmark is hindered by cost, both from lack of suitable public infrastructure available and direct costs in transforming the operations in the plants. Representatives from the Danish fishmeal and oil processors also report that they pass on excess heating to municipalities but have to pay tax for that, and that they could otherwise be seen as energy producers.

In Poland, relatively modern processing and freezing infrastructure has been designed, with efficient and energy saving structure. One of the biggest freezing facilities is using a heat exchanger: during the freezing process, heat is released that was before wasted and considered a cost of the freezing process but is now instead used to heat the administrative areas such as offices.

Increased utilization of European sprat and Atlantic herring from the Baltic Sea for human consumption, and predominantly direct trimmings for fishmeal and oil production, comes with challenges. Use of trimmings may increase GHG emissions compared to use of raw material from dedicated fisheries for feed (reduction fisheries); to which extent depends on where the fishery trimmings originate from and LCA modelling choices related to how GHG emissions of co-products are calculated. Fisheries for direct human consumption in the Baltic Sea are both less efficient during the fishing phase (requires other quality of raw material and is fished at smaller volumes and other fishing patterns) and requires more processing steps and transports (must also go through a processing facility). Another challenge is related to the mismatch between vessel size, harbour capacity and the different quality needs for fishmeal and oil production compared to direct human consumption. According to information from one Swedish processor for human consumption, they depend on smaller volumes (ideally 10–50 tons) delivered continuously; quality assurance is challenging with erratic volumes of 1000 tons. Atlantic herring and European sprat are also seen as nutritious and affordable food – with current increase in production prices (packaging prices three-fold increase; transport prices doubled), the production marginals decrease. They also see national allocation of fishing opportunities for the agreed TAC – today split into an overall 'big' part, regional and coastal quota respectively – not fulfilling its purpose in securing regional fishing opportunities. This because the smaller regional and coastal parts of the TAC is smaller and not prioritized, but cut the same, when TAC is cut.

6 Conclusions

- The industry reports on challenges today that are categorized as indirect effects of climate change and are thus expected to increase (increasing costs of energy and fuel, changes in the sea affecting raw material).
- To reduce GHG emissions in the fishmeal and oil processing industry in Denmark, there is a need for investments in infrastructure for the industry to be able to use electricity from the grid.
- Concentration of processing facilities adds to transport distances.
- Choice of transportation mode of raw material (road or sea) affects PH GHG emissions, as seen in Poland, but the largest raw material volume is landed directly at the plants in Denmark.
- Existing supply chain is optimized economically, and even if GHG emissions may be reduced by cutting transports in Poland it may prove difficult to change; if transport costs are lower than production costs of smaller processing plants closer to landings there is little incentive to change.
- Use of trimmings instead of whole fish may slightly add to GHG emissions but is important for optimizing resource use.
- The market for fishmeal and oil versus human consumption is complex and sometimes in conflict from various reasons (e.g., trade embargos, costs, fleet structure).
- Mandatory reporting of post-landing destination of catches (direct human consumption or industrial applications) would facilitate PH mapping which is today difficult for European sprat and Atlantic herring from the Baltic Sea.

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CASE STUDY 2: FISHMEAL/OIL – BLUE WHITING (*MICROMESISTIUS POUTASSOU*) AND BOARFISH (*CAPROS APER*) – IRELAND

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Michael Keatinge

LIST OF ABBREVIATIONS

Term	Description
BII	Bio-marine Ingredients Ireland (BII)
BIM	Bord Iasciagh Mhara
FOB	Freight on Board
FTE	Full Time Equivalent
GVA	Gross Value Added (GVA)
IFPEA	Irish Fish Processors & Exporters Association
IFPO	Irish Fish Producers Organisation
ISEFPO	Irish South & East Fish Producers Organisation
ISWFPO	Irish South & West Fish Producers Organisation
SWOT	Strengths, Weaknesses, Opportunities and Threats
UFI	United Fish Industries (UFI)

1 General Introduction

In the 2021 review of Ireland's seafood sector, Bord Iascaigh Mhara (BIM) estimate that PH activities in the fisheries and aquaculture value chain comprise 3,873 FTE (full time equivalent) jobs in processing, along with a further 7,942 FTEs jobs in indirect employment. The present CS focuses on one of the top 10 fisheries species in Ireland (blue whiting, *Micromesistius poutassou*), as well as boarfish (*Capros aper*), an important commercial catch within Ireland. Blue whiting is one of the top three pelagic quota species within Ireland, with a landing value of EUR9 million (data from 2020), and with the other pelagic landed species in Ireland (Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*) and albacore tuna (*Thunnus alalunga*)) represent 82 % by volume and 43 % by value of Ireland's quotas. These species are caught primarily by vessels registered in the pelagic/RSW fleet, as well as to a lesser extent in the polyvalent segment of the national fleet.

Ireland's Sea Fisheries Protection Authority[6] estimates that in 2020 the port of Killybegs handled 231,774 tonnes of fish worth some EUR110.9 million at first point of sale. These include landings by Irish and non-Irish vessels and represent 71 % by weight and 32 % by value of all the seafood landed at Irish ports. Of the 231,774 tonnes, 228,632 tonnes were pelagic species. This was 91 % of all the pelagic fish landed nationally, and included 100 % of the blue whiting and 87 % of boarfish.

The seafood sector in Killybegs (processing, fishmeal plant, bio-marine ingredients plant, PH downstream indirect economy) has been extensively studied, including detailed studies carried out in 2010 (European Commission Fish/2006/09)[7] and 2019 (The Economic Impact of the Seafood Sector: Killybegs. BIM & Oxford economics), as well as analysis of key metrics (employment, seafood economy etc) updated annually by BIM in the Business of Seafood. These reports provide a detailed breakdown of the PH value chain and a baseline against which to estimate the impact(s), if any, of climate change within the Irish PH industry.

Killybegs is home to Ireland's main pelagic fleet of 23 RSW tank boats[8]. These state-of-the-art vessels specialise in pelagic mid-water trawling and many are vertically integrated with the local processing sector; either owned by the same owner/company, or operating in close cooperation with a particular processor. All pelagic species landed within Killybegs are handled by the port's processors, fishmeal plant and Ireland's only bio-marine ingredients plant that, collectively, represent a major PH value chain.

Based within Killybegs, the United Fish Industries (UFI) Fishmeal and Fish Oil Plant was established in 1957 and extensively redeveloped in 2016. Today the plant employs approximately 36 people on site, as well as 100 ancillary employees, and houses a state-of-the-art steam generation production process, waste heat evaporative capacity, computer control systems and environmental control systems. Along with blue whiting and boarfish the plant also processes trimmings from local processors and the wider seafood industry in Ireland and can process up to 1,200 tonnes a day. Most of the fishmeal and fish oil produced in the plant goes to Scotland's three main aquafeed producers, Biomar, Skretting and EWOS.

In addition to the fishmeal plant, Killybegs also supplies Irelands only bio-marine ingredients plant. Bio-marine Ingredients Ireland (BII) is a marine bio-tech company

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6 https://www.sfpa.ie/Statistics/Annual-statistics/Annual-Statistics/2020-Statistics

7 Macfadyen, G., Keatinge, M., O Donoghue, S., and Kavanagh, A. (2010). Assessment of the status, development and diversification of fisheries-dependent communities: Killybegs Case Study Report.

8 The performance of this fleet segment is reported on annually in the Annual Economic Report (AER) of STECF.

located in County Monaghan that produces high quality marine ingredients utilising blue whiting supplied by the pelagic processors in Killybegs. The combination of an integrated supply chain and state-of-the-art production facilities means BII is a leader in the supply of marine-based proteins, lipids and calcium to the international marketplace.

1.1 Blue whiting

This species is widely distributed in the eastern part of the North Atlantic. Globally, in 2020 1.495 million tonnes of blue whiting was landed. The multinational fleet targeting blue whiting consisted of several types of vessels from 16 countries. The bulk of the catch is caught with large pelagic trawlers, some with capacity to process or freeze on board, while the remainder is caught by RSW vessels.

Blue whiting is the most important species landed within Killybegs by volume (54 %) but accounts for just 22 % by value at first point of sale. This rises to 30 % at final export value, reflecting the greater Gross Value Added (GVA) for this species. TACs for blue whiting were introduced in 1988 and quotas for this species in 2001. Based on 2021 landing data, Killybegs currently lands 100 % of the national quota for blue whiting. This species is used for three different products, fishmeal, fish oil and sold as whole round blue whiting (Sizes: 20cm+, 23cm+, 25cm+, Packed in 20kg cartons)

1.2 Boarfish

Exploratory fishing for boarfish by Irish vessels began in the late 1980s, when commercial quantities were encountered during the spring horse mackerel and mackerel fishery in northern Biscay. The first commercial landings were reported in 2001 (120 tonnes), but these remained relatively small during the early 2000s (<700 tonnes per year). From 2001 to 2006 only Ireland reported landings of boarfish. It was not until 2006 that a directed fishery developed, with landings rising to 137,503 tonnes in 2010. Since 2018 following annual ICES advice, the catch covering ICES Subareas 6, 7 and 8 has been set to 20,000 tonnes, with catches 11,300 to 15,650 tonnes.

The small body size of boarfish means little edible flesh, with the unusual shape making filleting difficult. Therefore, boarfish had been ignored as a commercial fish and those large enough to be caught in trawls were often discarded as bycatch or used to bait crab and lobster pots. However, boarfish are now targeted for fishmeal in the pelagic trawl fishery to the southwest of Ireland, with catches within ICES Areas 7 and 8 (data from 2020) totalling 4,176 and 5,336 tonnes, respectively.

1.3 Postharvest value chain for blue whiting and boarfish

In terms of the PH value chain, the volume and value of blue whiting and boarfish entering the value chain along with the volume and value of these species utilised by the processing sector is provided (Figure 1). In this respect, Ireland exported 72,000 tonnes of blue whiting for human consumption in 2021 (100 % of blue whiting exports), while Ireland also exported 15,400 tonnes of fishmeal and 5,100 tonnes of fish fats and oils. With a nominal yield of 48 % these account for a further 42,760 tonnes of blue whiting and boarfish (Table 1).

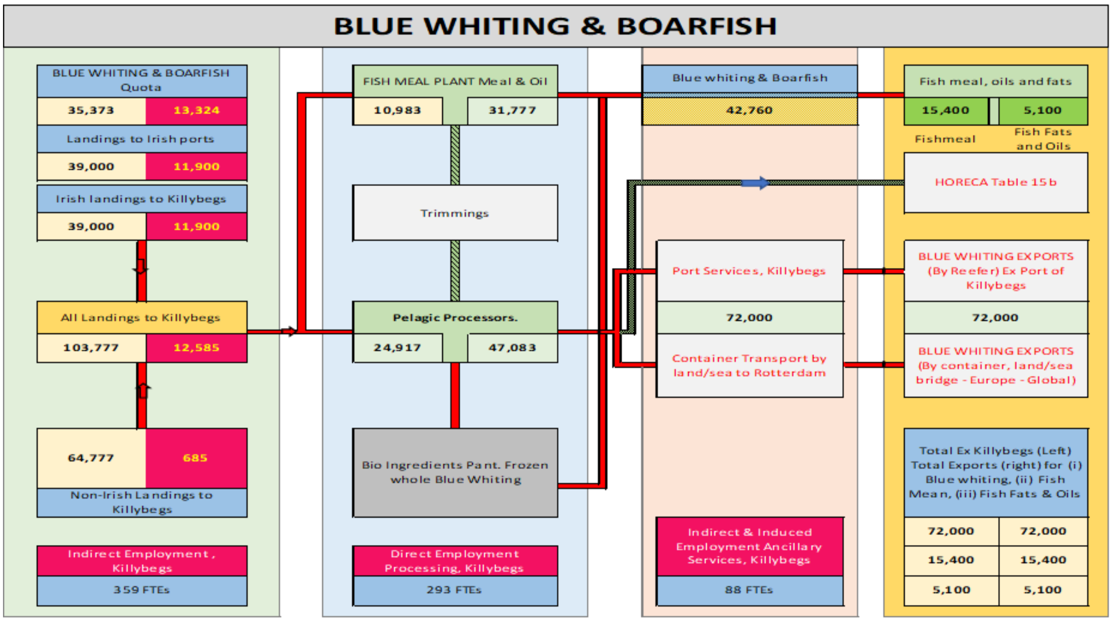


Figure 1 Pelagic postharvest value chain, Killybegs.(Figures are tonnes of blue whiting 35,373 and boarfish 13,324).

Note: Red channel: main flow of blue whiting and boarfish for either fishmeal or for human consumption. Other channels, of less importance: trimmings ex processing to fishmeal; blue whiting from processor to bioingredients (and other secondary processing entities)

2 Postharvest Value chains – focus on Killybegs

To understand the structure and resilience of the PH value chain for both blue whiting and boarfish, this CS now focuses on describing in detail the PH industry within Killybegs (encompassing all species), the segments that comprise the value chain for this local industry, as well as the factors which may enhance, but also impact on the sustainability of this industry.

Within Killybegs, sales note data show that the top four companies handled quantities of fish varying from 12 to 21 thousand tonnes and valued at between EUR 10 and EUR20 million. Across these processors, typically mackerel accounts for 50 % of fish processed with horse mackerel and blue whiting making up the bulk of the rest. Much smaller quantities of boarfish are recorded on average.

Table 1. Postharvest, pelagic, value chain, Killybegs, 2021. Note: EUR/tonne indicates final export price.

Species	€/tonne	VOLUME (tonnes)					VALUE €'million			
		Post harvest Value Chain (Processors)	Other processing, Fish Meal, Bio Ingredients etc	Total	Ireland's Total Exports	% of total exports from this value chain	Proccessors	Other	Total	Exports
		A	B	C	D	E	A	B	C	D
Blue whitingfor Human Consumption	€486	72,000		72,000	72,000	100%	€35		€35	€35
Boarfish for Human Consumption	€0	1,602		1,602		NA	€0	€0	€0	€0
Blue whiting & Boarfish for Fishmeal	€1,561		42,760	42,760	15,400	100% of exports. (Yield 47.942%)	€0	€29.3	€29.3	€22.0
Blue whiting & Boarfish for Fish Fats and Oils	€24,917				5,100					€7.0

2.1 Transport

Postharvest transport to market from Killybegs is generally either by land and sea in 40-foot containers, or by sea in refrigerated vessels ('reefers') directly from the ports of Killybegs and Sligo. In the past (prior to 2022) container transport typically cost EUR600 Freight on Board (FOB) from Killybegs to a port on Ireland's east coast (e.g., Dublin or Rosslare etc); EUR600 Ireland to Rotterdam or other European hub; and EUR1,200 by container ship to far east. In 2018, for example, almost 4,000 containers were contracted by the seafood sector. Containers typically hold up to 24 tonnes of fish and the 4,000 used in 2018 provided a total capacity of up to 96 thousand tonnes (4,000 containers x 24 tonnes x 100 % utilisation). Assuming a lower utilization (90 %), then these containers were sufficient to carry approximately 50 % of the processed fish and fish products produced in Killybegs.

With the significantly increased cost of container transport in 2022 the option to use other, less expensive, ways of getting product to market has increased, specifically refrigerated ship from Sligo or Killybegs port. This is particularly true for blue whiting (for human consumption) to Africa.

2.2 Employment

As an integrated seafood port, Killybegs is the single biggest seafood employer in Ireland. In their report, The Economic Impact of the Seafood Sector: Killybegs[9], BIM and Oxford Economics estimated that that the sector directly generated EUR254 million in turnover, EUR150 million in GVA, while also supporting 1,835 jobs and providing EUR61 million in wages in 2018. Fish processing is the largest of the three seafood sub-sectors, generating an estimated EUR163 million in turnover (64 %), followed by commercial fishing, EUR73 million (29 %), and aquaculture, EUR19 million (7 %). When translated into GVA, the seafood sector directly contributes an estimated EUR94 million to the local port economy.

Seafood businesses operating in Killybegs are typically well-established, have operated for more than 10 years and, generally, have relatively stable year-on-year turnover. These businesses typically invest more in capital (relative to the other ports in Ireland) and their workforce tends to originate from the local area. Furthermore, over three quarters of the fish processing carried out locally is for the export market.

Within the Killybegs port economy, commercial fishing, aquaculture and fish processing are estimated to represent 21 % of workplace employment. Furthermore, fishing and aquaculture represent nearly all of the local agriculture, forestry and fishing related employment, while fish processing accounts for 40 % of local manufacturing, mining and utilities jobs. In this respect, of the 1,835 full time employees (FTE) identified as 'seafood - Killybegs' by the BIM, Oxford Economics study, 1,005 FTEs were directly employed. This included 380 (38 %) in fishing, 145 (14 %) in aquaculture and 480 (48 %) in fish processing. It is these latter 480 FTE jobs that are considered direct employment in the PH value chain. In total the fish processing sub-sector supports an estimated 1,225 jobs, of which an estimated 595 are sustained along the supply chain, while a further 145 are as a result of spending supported by this employment. Included are:

- 495 FTEs are identified as Manufacturing (i.e. processing).
- 520 FTEs are identified as Agriculture, forestry & fishing.
- 210 FTEs identified from other areas including, wholesale/retail (60), Transportation & storage (20) etc.

[9] 9427 BIM Economic Impact of Seafood Sector report - Killybegs.indd

2.3 Apportioning employment across the different processing sectors

The PH value chain in Killybegs is estimated to employ a total of 1,225 FTEs of which 485 are directly employed in processing (Table 2). Of these 293 direct jobs are associated with blue whiting, including 181 FTEs preparing blue whiting for human consumption and 112 FTEs employed in the fishmeal plant the bioingredients plant and other secondary processors.

Table 2 Employment by species.

Species	Landings - ALL, by volume		Direct	Indirect	Induced	Total
	Tonnes	Share	485	595	145	1,225
Mackerel	54,829	28%	138	169	41	348
Horse mackerel	20,331	11%	51	63	15	129
Herring	1,264	1%	3	4	1	8
Blue whiting (Human Consumption)	72,000	37%	181	222	54	458
Blue Whiting & Boarfish (Fish Meal, Fats, Oils)	44,362	23%	112	137	33	282
	192,785	**100%**	**485**	**595**	**145**	**1,225**

2.4 Management interventions to mitigate impacts of climate change within the postharvest industry

To understand the climate mitigated factors which may impact the PH value chain within the Killybegs, key stakeholder in the local seafood industry were interviewed either one-to-one or in group sessions. Stakeholders included producer organisations, processors (bio ingredients plant), support services and fisheries scientists attached to Ireland's Marine Institute (Table 3). In addition, a semi-quantitative questionnaire was used to determine stakeholder views across a wind range of climate change related impacts and possible outcomes.

Table 3: Key Stakeholders interviewed as part of CS (Blue whiting and boarfish, postharvest value chain)

CS number	SH category	Stakeholder type	Country	Name of company/ organisation
2	Bio-Marine Ingredients,	Tertiary Processing - Bio-Ingredients	Ireland	Biomarine Ingredients Ireland
2	Transport logistics	Transport logistics	Ireland	Sinbad Marine Ltd
2	Fisherman's co-op/Trader	Fisherman's co-op/Trader	Ireland	Castletownbere Fisherman's Co-op Ltd
2	Producer Organisation	Producer Organization	Ireland	Killybegs Fishermans Organisation

Stakeholders were asked to identify climate change related events that had impacted their business in the recent past and to give their view on how and where in their business model these impacts had occurred. Respondents were allowed identify up to three separate climate change impacts. To help standardise the responses, and following consultation with stakeholders, five general impact categories were identified for use in this study: Weather Events (floods, droughts, heat waves, blizzards); wind events (prolonged periods of high winds); ocean characteristics and chemistry; rising sea temperature; and energy costs and security.

Table 4 Categorization of Climate Change impacts used in CS

	EVENT	1		2		3		4		5	
A	**Weather Events: Floods, droughts, heat waves, blizzards..**	**A1:** Drought: reduced **water supply** and/or cost of water increases		**A2:** High Intensity Rainfall events resulting in reduced **water quality**		**A3:** Heat Waves – **High Air Temperature** and increased **energy usage/costs** in cold stores		**A4:** Colder winters/hotter summers - increased energy usage/costs of heating or cooling workplace		**A5:** Increased frequency of winter storms/blizzards - Work patterns disrupted - **staff** problems getting to work	
		Inceased variable costs for processors. (For service sector possible opportunity to supply fresh water, other equipment to increase energy efficiency, conrol temperature, replace damaged equipment, property and other services etc). (Value Chain)									
		DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY
B	**Wind Events Prolonged periods of high winds (storm intensity)**	**B1: Transport** problems, Roads closed, Ferry cancelled. Time delays getting to factory, market, loss of shelf life		**B2: Trade patterns disrupted** by severe weather events.		**B3:** Extreme wind events, **damage to YOUR property or equipment**.		**B4:** Impact fleet activity leading to **lost days at sea**		**B5:** Impact fleet activity, **lower catch** per unit effort	
		Inceased variable costs (Value Chain)				Inceased capital costs		Reduced catch/raw material for processing / Reduced demand for your services / Reduced Turnover (Value Chain)			
		DIRECT	VALUE CHAIN	DIRECT	VALUE CHAIN	DIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY
C	**Ocean characteristics & Chemistry**	**C1:** Sea Surges leading to delays at discharge or outward transport		**C2:** Sea Level Rise; damage to YOUR property or equipment.		**C3:** Change to Ocean Currents - New species in Irelands EEZ		**C4:** Ocean Acidification		**C5:** Algal Bloom and Invasive Species	
		Increased variable costs		Inceased capital costs		Increased R&D, equipment, marketing costs.		Reduced catch/raw material for processing / Reduced demand for your services / Reduced Turnover			
		DIRECT	VALUE CHAIN	DIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY
D	**Rising Sea Temperature**	**D1:** Increased **parasite** intensity		**D2:** Impact on **fish quality**		**D3: species** in Irelands EEZ		**D4:** Impact on stocks **distribution**		**D5: Impact on TAC / Quotas** because of reduced fecundity, growth etc	
		Increased processing costs/reduced final value: Inceased variable costs for processors.				Increased R&D, equipment, marketing costs.		Reduced catch/raw material for processing / Reduced demand for your services / Reduced Turnover			
		DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY
E	**Energy Costs & Security**	**E1:** Increased demand (data centres) + climate change related reduced generation (peat power stations shut down) leading to **power outages**		**E2:** Extreme wind events - damage to transmission lines - **power outages**		**E3:** Higher **fuel prices** resulting in increased **operating costs**		**E4:** Higher **fuel prices** resulting in increased cost of raw material from boats		**E5:** Higher fuel prices resulting in increased cost of transport	
		Processing activity curtailed/Reduced Turnover. (For service sector possible opportunity to supply equipment and services etc).				Increased variable costs					
		DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY	DIRECT	CORE ACTIVITY	INDIRECT	CORE ACTIVITY	INDIRECT	VALUE CHAIN

Across all results from the questionnaire (n = 15), 40 % of respondents identified energy costs and security as the most relevant climate change related impact on their business followed by wind events (27 %) and weather events (20 %) (Figure 2).

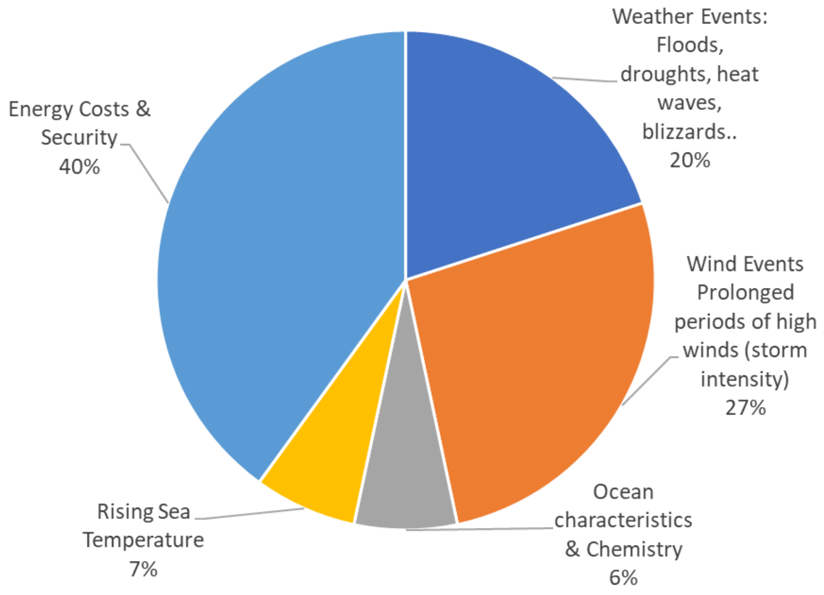


Figure 2: Major event categories impacting postharvest vale chain (case studies 2 and 5 combined).

To provide deeper understanding of climate change impacts, each of the five major event categories was further divided into five subcategories of related impacts. For example, energy costs and security is divided as shown below, with E1 and E2 focussing on energy security (power outages) while E3-E5 focus on energy costs (higher prices).

- E1: Energy: Increased demand + climate change related reduced generation leading to power outages
- E2: Energy: Extreme wind events - damage to transmission lines - power outages
- E3: Energy: Higher fuel prices resulting in increased operating costs
- E4: Energy: Higher fuel prices resulting in increased cost of raw material from boats
- E5: Energy: Higher fuel prices resulting in increased cost of transport

This work showed that the sector considers energy costs/higher fuel prices as the most important factor impacting their business at every stage from raw material supply, to production and post production transport (Figure 3). Whether this be E4: higher fuel prices resulting in increased cost of raw material from boats (50 %), E3: higher fuel prices resulting in increased operating costs (33 %), or E5: higher fuel prices resulting in increased cost of transport (17 %). Of the impacts identified, 67 % affect variable costs, 20 % capital costs and only 13 % turnover.

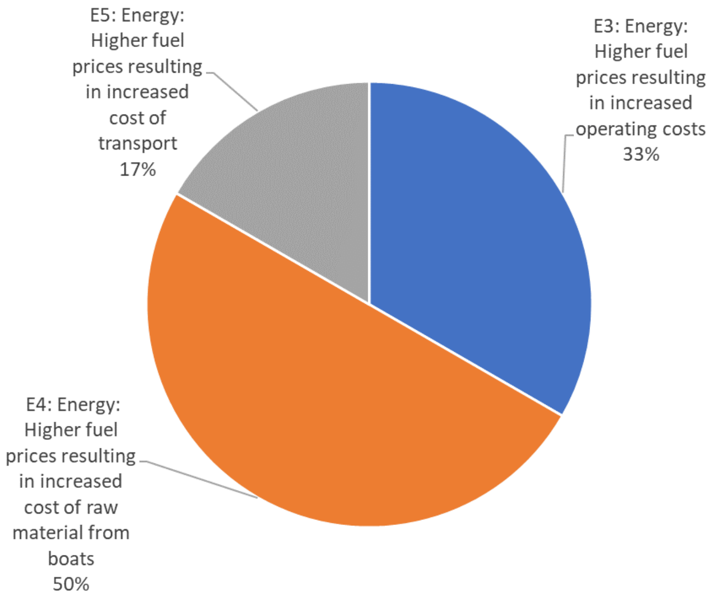


Figure 3: Detailed event categories (E: Energy costs & security) impacting postharvest value chain, Killybegs (CS 2 & 5).

Respondents were then asked about the legacy of recent climate change events, by indicating the duration of an identified climate change impact on business performance. This was measured as either a day, a week, a month, 6 months or 1 year. Of the respondents, 70 % believe that recent climate change events, if any, impacted their business for less than 1 month or in 3 cases for a year or more. The latter are related to the longer term (> 1 year) impacts of quota reductions.

Table 5: Legacy (duration) of climate change impact on postharvest value chain, Killybegs (CS 2 & 5 combined).

A day	A week	A month	Six Months	A year or longer
1	4	2	0	3
10%	40%	20%	0%	30%

Respondents were then asked to estimate the intensity of the event by indicating, were a similar event to happen again, how many times in a 12-month period would it need to happen to put the business into financial jeopardy? While 60 % of respondents believe that an event would have to happen 3 or more times in a year for it to have any long-term impact on their business, 40 % believe it would take just two or less events to impact their business.

Table 6: Intensity (frequency) of climate change impact on postharvest value chain, Killybegs (CS 2 & 5 combined).

1 time	2 times	3 times	4 times	5 times or greater
1	3	3	2	1
10%	30%	30%	20%	10%

Finally, respondents were asked to provide their own estimate of the current risk level to their business of possible future climate change impacts. Surprisingly none of the respondents believe their business is fully resilient to the impacts of climate change: 45 % believe their business is partly at risk, while a further 36 % believe their business is at risk.

Table 7: Stakeholder perceptions of the current risk level of climate change impacts, Killybegs (CS 2 & 5 combined).

Fully	Partly	At Risk	Unsure
0	5	4	2
0%	45%	36%	18%

The CS questionnaire also considered possible future impacts of climate change with respondents, once again, asked to select from the 5 main climate change impact categories (A-E), each with 5 sub classifications (1-5) and to consider possible impacts 1-year, 5-years and 10-years in the future. Of the 26 responses received, energy costs and security, again received the highest number of responses (42 %). In detail, the impact of higher fuel prices on operating costs (46 %) and on the cost of raw material (36 %) were seen as the single biggest future threats to the industry, while energy security and the possibility of power outages impacting business in the future was also highlighted.

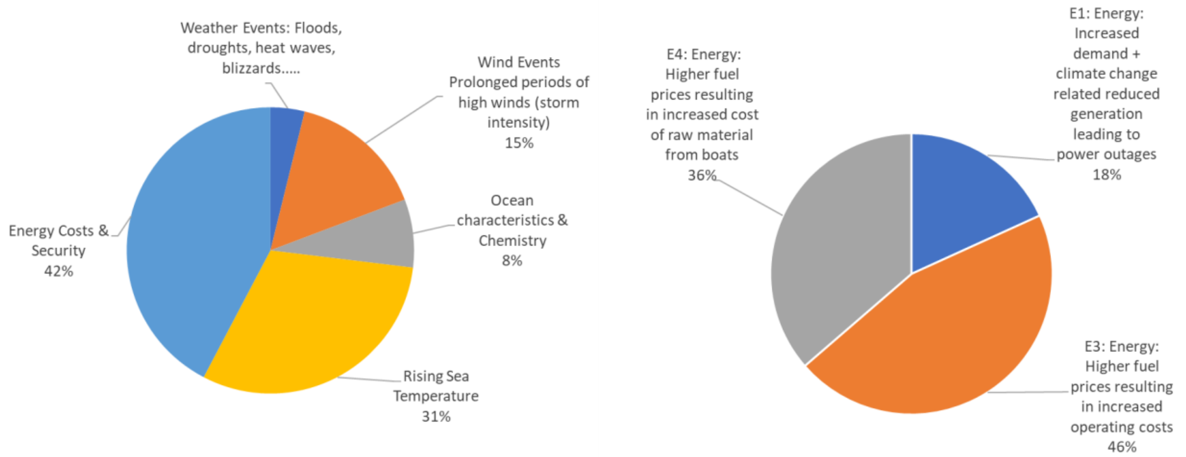


Figure 4 Major event categories potentially impacting postharvest vale chain in the future with a breakdown of the energy impacts. (case studies 2 and 5 combined).

Unlike the previous results (past impacts), when asked to consider future impacts 31 % of respondents identified rising sea temperature as the second most likely potential impact, including rising sea temperature which will lead to new species in Ireland's Exclusive Economic Zone (EEZ), increased temperature impacting stock distribution, as well as impacting quotas as a result of reduced fecundity, growth of commercially important fishes.

3. Strengths, Weaknesses, Opportunities, and Threats

The stakeholder questionnaire also asked respondents to undertake a strengths, weaknesses, opportunities and threats (SWOT) analysis of their current business circumstances (Table 8). Interestingly, and perhaps not surprisingly, the PH industry within Killybeg focused on excellent port facilities and an extensive array of local services within the port area as strengths. Conversely, distance to market was seen as a key weakness along with the continued reliance of the sector on fossil fuels and, perhaps not surprisingly, quota restrictions. Opportunities and threats ranged widely with new markets, species and fuels all seen as opportunities, but offset by an expectation of higher energy, labour and transport costs, along with reduced quotas, quality, catch and demand.

Table 8: SWOT ANALYSIS

Strengths	Count	Percentage
Port facilities	4	31%
Proximity to fishing grounds	3	23%
Marine cluster - excellent local services	2	15%
Other	4	31%
	13	100%

Opportunities	Count	Percentage
New Markets	2	20%
New fuels (e.g. hydrogen) locally sourced	2	20%
New Species	1	10%
Security of Supply (new stocks/opportunities)	1	10%
Customer Demand	1	10%
Reduced Costs (innovation and new business practices)	1	10%
Competitive Advantage over other producers / processors	1	10%
New business opportunities (renewables and other services)	1	10%
	10	100%

Weakness	Count	Percentage
Reliance on fossil fuels	3	38%
Quota restrictions limit turnover	2	25%
Distance 2 markets, transport costs, Energy usage, Limited added value	3	38%
	8	100%

Threats	Count	Percentage
Higher Energy Costs	3	19%
Reduced quota because of climate change	3	19%
Reduced demand for your services	2	13%
Reduced catch/raw material for processing	2	13%
Reduced quality of fish for processing (fat content, size)	2	13%
Higher labour costs	2	13%
Higher Transport Costs	1	6%
Key species disappear	1	6%
	16	100%

4. Conclusions

The PH value chain for industrial fisheries in Killybegs is successfully mapped including volumes and value of blue whiting and boarfish as they pass through the traditional processing sector, the fishmeal and bioingredients plants and onward to export. The model developed in the CS links Irish quotas, the Killybegs fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the employment, GVA, wage bill etc of the PH value chain in the town.

While clearly demonstrating resilience to the current impacts of climate change, the PH sector has also demonstrated its ability to adapt and add value. For example, an important finding shows how blue whiting, once primarily intended for fishmeal is now being utilized more by the traditional small pelagic processors and exported to Africa for human consumption. This generates greater added value and has attracted additional landings of blue whiting to the port.

CASE STUDY 3: SMALL-PELAGICS – HERRING (*CLUPEA HARENGUS)*, MACKEREL (*SCOMBER SCOMBRUS)* – NETHERLANDS, GERMANY, UNITED KINGDOM, DENMARK, NORWAY

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Atlantic herring (*Clupea harengus*). Photo credit: Oscar Bos, WUR.

Mackerel (*Scomber scombrus*). Photo credit: Oscar Bos, WUR.

Hoekstra, G., Deetman, B., Turenhout, M., Van den Burg, S., Vernooij, V., Broeze, J. & Guo, X.

1 Background

The small-pelagic PH chain could be divided into two differing supply flows:

1) The supply chain for frozen small-pelagics, like herring and mackerel, as whole fish in particular for the West-African market.
2) The supply chain consisting of mass flows with defrosted and chilled herring and mackerel. Fillets of herring are known as soused herring or new season Dutch herring (*Hollandse Nieuwe*). Mackerel is landed both fresh and frozen. The fresh landed mackerel and the 'Hollandse Nieuwe' herring are both destined for the European retail (supermarkets and fishmongers). Mackerel is often smoked as a whole gutted fish while 'Hollandse Nieuwe' herring is defrosted and chilled processed into fillets/flaps to consume.

Three processors of herring and mackerel and one representative from the Pelagic Freezer-trawler Association were interviewed. A representative from the retail suppliers was consulted via a questionnaire.

Within this CS the primary focus is on the PH chain of frozen pelagics as whole fish. However, the PH chain of defrosted and chilled 'Hollandse Nieuwe' herring fillets is relevant as well. The trade of it is dominated by Dutch companies for centuries.

1.1 Frozen, whole fish

The PH chain for frozen small-pelagics as whole fish from the Netherlands, is dominated by three pelagic freezing trawler enterprises. These, originally fisheries, enterprises are vertically integrated and possess the entire supply chain from catch to distribution to end-consumer-market channels like retail and foodservice. Within the EU, the pelagic freezing trawlers are organized in the Pelagic Freezer-trawler Association (PFA), representing the interest of 9 European pelagic companies which fish for human consumption. The association currently has members in France, Germany, Lithuania, the Netherlands and the UK. The PFA consists of 23 pelagic vessels. Small-pelagic species such as herring, mackerel, blue whiting, sardine and horse mackerel are targeted by the vessels. The fish are processed onboard, where the small-pelagic species are frozen as a whole and packed in ~20-kilogram cardboard boxes. After landing and frozen storage within EU or African coastal countries, these cardboard boxes are distributed via reefers (refrigerated cargo ship) to especially the local African markets such as Nigeria (Figure 1), Egypt and Ghana. Out of the exported volume, 90 % is destined for this African market. The other 10 % is often aimed for the Asian market. In Africa these small-pelagic frozen as a whole species are one of the scarce low price affordable protein sources for the local communities. Internationally and even within EU, the Netherlands is a major player in terms of export value of frozen, whole, herring (Figure 2a) and mackerel (Figure 2b).

1.2 Defrosted and chilled herring and mackerel

The 'Hollandse Nieuwe' known as soused herring used to be mainly caught by Dutch and German vessels. According to the consulted stakeholders, since the end of the 1960s/early 1970s, the fishery is mainly carried out by Danish and Norwegian pelagic vessels. They state that climate change effects were not the main reason for the 'Hollandse Nieuwe' fishing fleet moving away from the Dutch coast to Scottish, Norwegian and Danish waters. The main reason was a political one. Between 1977 and 1982 the European Union decided to ban the herring fishery in the North Sea by regulation due to concerns about the sustainability (deteriorated biomass) of the herring. The Norwegian and Danish herring fisheries did not have restrictions to catch herring within their own coastal waters. Since then, the Scandinavian countries dominated the herring fisheries while the Dutch salesmen hold their position as traders of the '*Hollandse Nieuwe'* renowned as '*Matjes'* (in German) during the month of June in Germany as the fatty acid percentage does have the highest quality by nature in this month.

Mackerel is widely caught in European fishing areas at sea. For the mackerel sold by Dutch processors and wholesalers, mackerel is often caught in Scottish waters by pelagic freezer trawlers or trawlers with life tanks aboard known as Refrigerated Sea Water/Chilled Sea Water (RSW/CSW). In the North Sea, purse seiners also land mackerel as by-catch in large industrial fisheries. The pelagic freezer trawler land frozen whole mackerel. The RSW and CSW trawlers land the mackerel as fresh fish. After landing of the fresh mackerel, these are often smoked as major processing activity by the PH chain destined for the EU retail channels. The majority (around 80 % of total export value) of the exported mackerel by the Netherlands is frozen and comes from pelagic freezer trawlers (Dutch Fish Federation, 2020).

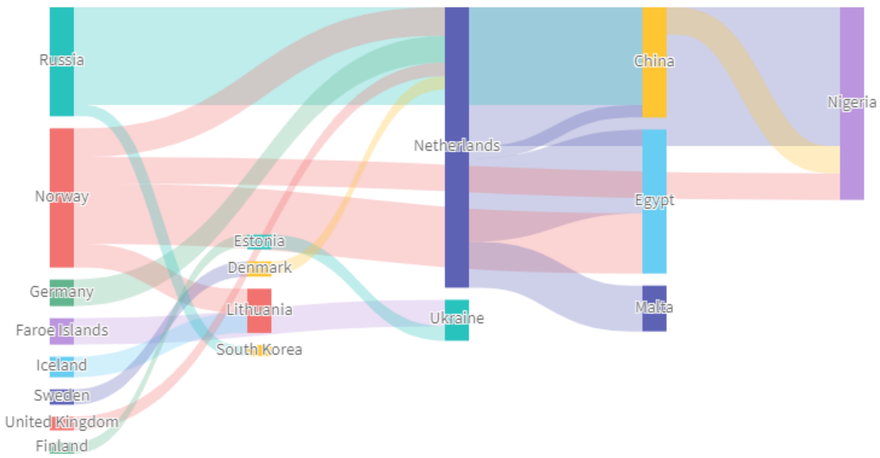


Figure 1. Quantitative comparison of top export flows (in value, 2020) for both PH chains: frozen herring as a whole destined for African market and the 'Hollandse Nieuwe' herring. (https://www.tridge.com/intelligences/pacific-herring/export).

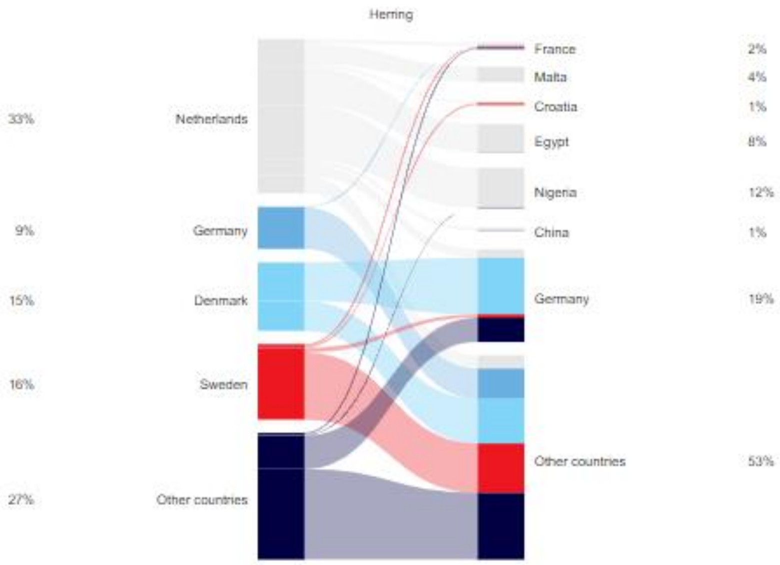


Figure 2a. Quantitative comparison of top export flows (in value, 2020) of herring among EU member states (left side) and the imported markets (right side) (Dutch Fish Federation, 2020). This trade flows are for both PH chains: frozen herring as a whole destined for African market and the 'Hollandse Nieuwe' herring.

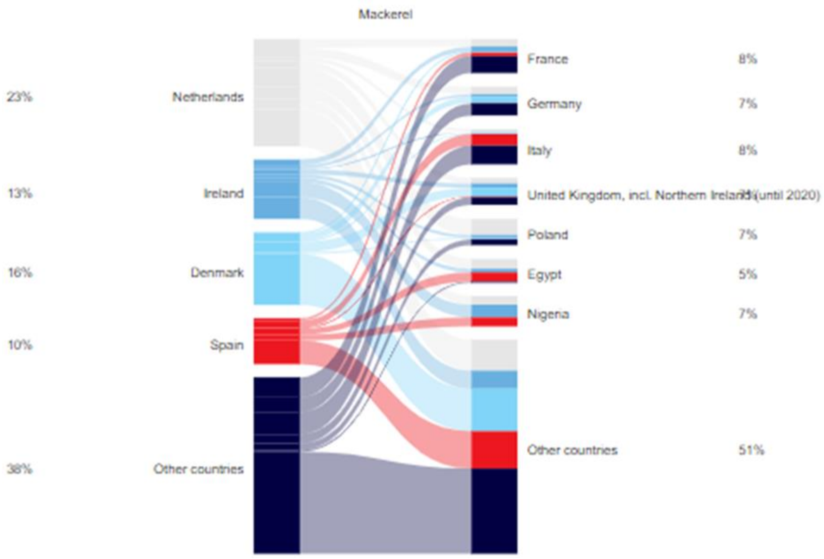


Figure 2b. Quantitative comparison of top export flows (in value, 2020) of mackerel among EU member states (left side) and the imported markets (right side) (Dutch Fish Federation, 2020). This trade flows are for frozen and fresh mackerel.

2 Value Chain

2.1 Value chain description

Dutch pelagic trawlers catch between 200 to 350 metric tonnes fish per year[10]. The five main EU Member States (MS) targeting North Sea herring were, in order of value (in Euro): Denmark, UK, the Netherlands, Germany and Sweden. The value chain for Dutch pelagic fisheries, serving the market in Africa, is represented in Figure 3. The largest share of the catch is processed (frozen) onboard and subsequently landed in Europe and shipped through reefer ships to Africa. The other share of the catch is directly landed in Africa. In both cases, the (frozen) transport to Africa is the dominant PH activity. The distribution chain in Africa is out of the geographical scope of this EU study. According to the consulted stakeholders in the Netherlands and Germany, the herring is imported by African importers that trade and distribute to food consumer markets in metropoles or cities close to the countryside.

10 FAOSTAT and agrimatie (https://www.agrimatie.nl/ThemaResultaat.aspx?subpubID=2232&themaID=2286&indicatorID=2880&sectorID=2860)

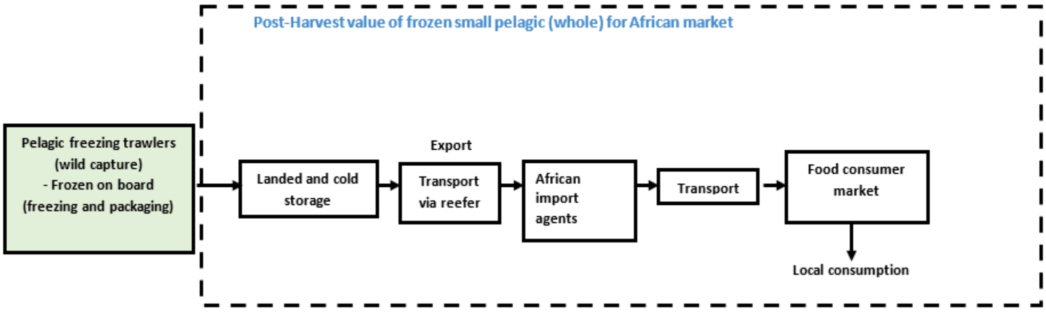


Figure 3. Value chain for small-pelagics caught by Dutch fisheries for African markets.

Contrary to the herring caught by pelagic freezer trawlers and sold to the Northern Eurpean market, the 'Hollands Nieuwe' is caught by Norwegian and Danish vessels. Subsequently these fresh landed herring is processed (gutted and frozen) often in Denmark, transported in brine to the Netherlands where the herring is mainly filleted via machines, checked by hand and traded to European retailers: in particular supermarkets and fishmongers. The largest market for 'Hollands Nieuwe' is Germany.

3 Resilience

3.1 Physical and financial resilience

In literature there are forecasts and projections that herring and mackerel fishing stocks in the North Sea are affected by climate change driven events. For herring it is expected that plankton will shift due to climate change in the North Sea; this results in less feed for herring larvae. Another effect is the rising sea water temperature close to spawning grounds that likely has a negative effect on the vitality of herring larvae (CERES, 2020a). For herring, the changes observed in the analyses of abundance and presence is most likely linked to changes in stock biomass and composition (ICES, 2016). Herring (Clupea harengus) reacts strongly and quickly to climate change, by shifting north as sea water temperature rises, because of its physiological limits and potential for fast population growth (Rose, 2005). Within the CERES project (2020a), there are projections that under all scenarios there is potential for a change in total abundance of over 25 % by 2050 and 50 % or more by end of the century for herring (Peck et al, 2020).

For mackerel, it is expected that due to rising sea water temperatures there will be higher abundance of mackerel in the North Sea (CERES, 2020b). Geographical expansion was measured during the summer feeding season in Nordic Seas driven by increasing mackerel stock size and constrained by availability of preferred temperature and abundance of mesozooplankton (Olafsdottir, 2018). Mackerel is becoming smaller in length and size mainly due to food competition within the North Sea with other predators like other small-pelagics or demersal species that have earlier spawning seasons (Olafsdottir et al., 2016).

These changes of the fishing stocks do marginally affect the PH chain according to consulted stakeholders. However, if future landings of mackerel consist of large shares of small mackerel it could become problematic for the PH chain. According to consulted stakeholders from the small-pelagic industry, no major climate-driven events are currently known to affect the PH chain of herring and mackerel. For the coming five years, the PH supply of herring and mackerel is not expected to be disturbed by climate change according to consulted stakeholders. However, for future scenarios (ten years or more from now) it is unknown for the consulted stakeholders what impact climate change could have on the fishing stocks. Since mackerel is globally abundant, there is less risk for the PH chain if climate change effects do impact the biomass in the North Sea. Looking at the fishing areas for herring, there are hardly any changes in position compared to 16th and

17th century as the trawlers are still fishing at the east of Shetland Islands according to two interviewed herring processors from the Netherlands.

3.2 Major financial constraints and reliability

There is no literature found that describes major financial constraints related to climate driven events for the herring and mackerel PH chain. Only literature is found that predicts and projects changing fishing stocks of herring and mackerel by climate change.

3.3 Stakeholders' perceptions

Out of the challenges and impacts that were described by consulted industry stakeholders the majority were rather more political or market related than climate change driven.

Trends and developments perceived by consulted stakeholders that are related to climate change:

- Mackerel is migrating more northward than herring. TAC and quota division for the North Sea is not aligned with migrating fish species.
- Sardine is a new bycatch species in the herring and mackerel fisheries in the North Sea. These sardines could increase unselective catches, resulting into higher sorting costs for the PH chain as processors purchase the landed small-pelagics to process for human consumption. The increasing landings by fisheries of sardines in North Sea is due to climate change (rising water temperature) according to interviewees.
- A side effect of climate change is the accelerated construction of offshore wind farms (OWFs). Some of these OWFs are built on spawning areas of for instance herring. What is the effect of OWFs on the reproduction of herring? Due to the stakeholders little is known about the effect and building continues.

Trends and developments perceived by consulted stakeholders that are more political or market related than climate change driven:

- In order to act upon EU policy and consumers' needs to decrease employ of single used plastics, EU retail increasingly requires more sustainable alternatives of plastic packaging. According to herring processors, decreasing the thickness of plastic packaging or replacing it by bio-plastics can negatively affect food safety (e.g. oxygen passes through) and shelf life of perishable fish products.
- Processing plants install solar panels to generate renewable power to reduce electricity costs, but also to improve their sustainability and self-sufficiency for energy consumption.
- Technical innovation (machinal processing instead of manually fileting) to process herring could enable increased local production and reduced amounts of international transporting movements to lower-cost producers abroad and back to the market of consumption. This could substantially decrease transporting distances compared to the current situation, where raw materials are transported to other continents for low wage processing. Shorter supply chains or logistics could reduce emissions and energy consumption. The COVID-19 pandemic showed the importance of resilient and preferably shorter supply chains. During the pandemic logistics of globally connected PH chains were vulnerable due to disruptions in one country or one part of the PH chain.
- Vertically integrated pelagic companies and international joint ventures are more resilient compared to non-vertically integrated individual companies in the PH chain. Vertically integrated companies can optimize efficiencies in the PH chain by predictions of supply flows between harvest and PH activities. These vertical integrated companies and international joint ventures could shift or relocate their physical PH activities to another production location if climate change driven events are negatively affecting the resilience of one location. Also, larger companies have the advantage that they can

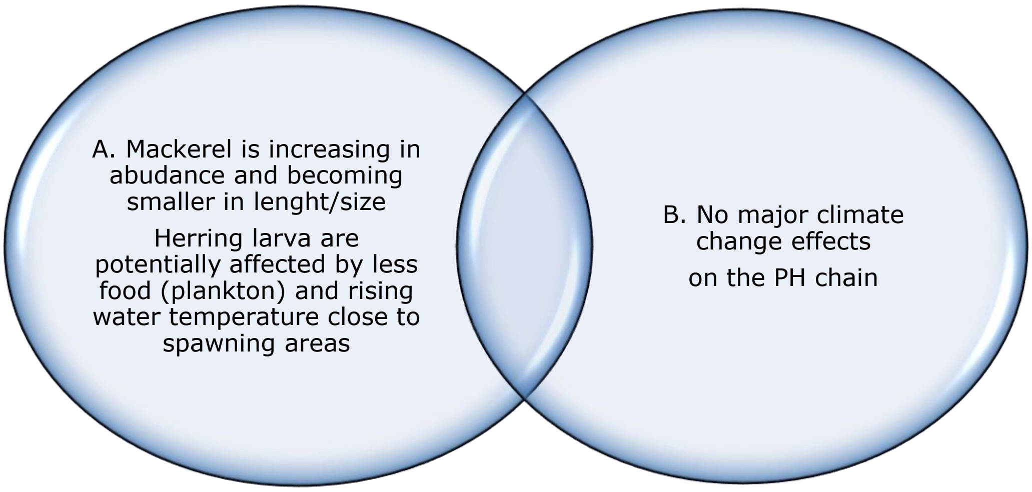
reduce purchasing costs of raw materials (unprocessed herring and mackerel) by their buying power (scale advantages).

- EU Green Deal and other legislations to reduce GHG emissions stimulate PH industry stakeholders to take action. For instance, herring processors from the Netherlands are exploring ways to substitute their petrol-driven trucks by electrical driven trucks. More and more EU cities have low-emissions zones: certain vehicles are not allowed to enter to improve air quality. According to the consulted stakeholders there are two reasons that demotivates investments into electric trucks:
  - Information about requirements from EU policy or legislation for nearby future (long run and short term) to reduce GHG emission for trucks is lacking.
  - There are no financial incentives for shifting from petrol-driven trucks to electrical trucks
- Prices of sea freight container transport strongly increased: in 2019 transport prices including hiring the sea freight container were 2.500 US Dollars per trip; and in 2022, prices increased up to 18.000 US Dollars. Most of these cost inflations are passed on to purchasing customers such as importers or wholesales.
- A challenge for Dutch herring processors is the globally scarcity of raw materials of fish to process. Due to increasing prices of fishmeal (e.g. for the salmon aquaculture) landed herring in Denmark is competing with the fishmeal industry. The fishmeal industry would ordinarily purchase lower priced fish species than herring to process as fishmeal. However, with the international scarcity of fish raw materials and increasing fishmeal prices the Dutch herring importers are competing with fishmeal producers nowadays for landed herring.

	Helpful	Harmful
Internal origin (attributes of the organizations)	Strengths • Vertical integration and international joint ventures strengthen the resilience of PH processors of small-pelagics as they could operate in different locations despite climate driven events at one production location. • Technical innovation (machinal filleting locally instead of manually in lower-cost producers abroad) has led to increased efficiency in local processing and reduces costs and unnecessary transportation miles (and as a result into reduction of energy use and emissions by transport).	Weaknesses • Alternative plastic packaging required by supermarkets to act upon EU policy and by consumers' needs, could affect food safety and shell lifetime of fish products.
External origin (attributes of the environment)	Opportunities • Reducing fossil fuel use by implementing electrical trucks and installing solar panels.	Threats • More bycatch of new species in the North Sea such as sardine. Non-selective fisheries affect the PH purchasing prices due to more sorting activity and less net volume of raw materials of herring as target species landed. • Cost inflations due to high sea freight container prices, energy prices and scarcity of materials could discourage consumers to purchase higher priced herring or mackerel products. • Migrating mackerel stocks in future due to climate change are not aligned with annually TAC and quota divisions between countries.

	Helpful	Harmful

3.4 (Mis)Fits between literature review and stakeholders' perceptions



A. = From literature review
B. = From stakeholders' perception
C. = Overlapping as found both in literature and stakeholders' consultation

3.5 Role of management – lessons learned of adopted strategies

Vertically integrated PH companies and joint ventures could strengthen the physical resilience (specialization and outsourcing activity close to place of landing and processing and distribution) and financial resilience (buying power for materials, predictability of supply flows etc.). Furthermore, investing into renewable energy or reducing GHG emissions in an early phase of transition could help to get in line with upcoming environmental legislation. For instance, consulted herring processors explained they are exploring new ways to implement electrical trucks instead of current petrol driven trucks as they expect that petrol-driven trucks will be no longer be allowed in city centres in the nearby future. Another example is investing in technical innovation to be able to locally process the fish using machines. In the past, Dutch herring companies have outsourced the manually filleting to Polish processing companies with a production rate of 120 herring fillets per hour. Nowadays, semi-automatic processing provides a productivity up to 300 fillets per hour. This mechanization improved productivity and reduced transport costs and emissions (food miles). Another side-effect of this transition to more locally machine filleting is shorter and closer supply chain loops that reduce risks of disrupted logistic global supply chains as experiences during the COVID-19 pandemic.

4 Greenhouse Gas Emissions

GHG emissions in the post-harvest chain are related to transportation (fuel use), processing and refrigeration (mainly energy use; with phasing out refrigerants with high GHG impact the contributions from leaking refrigerants is marginalized) and packaging. Also, food losses (indirectly) induce additional GHG emissions since losses induce extra demand for catch and related post-harvest chain emissions. The GHG emissions are estimated for typical post-harvest chains for the products of this case study: typical transportation distances, refrigerated storage durations and packaging solutions. Chains for mackerel and herring are separately described. For herring, we describe herring products for African market (around 70% of the volume), another substantial product group (soused herring) and a niche product (pickled herring).

4.1 GHG emissions in a typical PH chain frozen herring for African market

Approximately 70% (expert estimate) of caught herring is frozen and packed in cartons on-board and traded as whole fish for the African market and other continents. Most of this is first landed in Europe. For this product, main contributions of GHG emissions are related to energy use for frozen storage and fuel use in export (in reefer containers) to Africa. The distribution chains in the other continents are very diverse and beyond scope of this study.

Frozen storage

Since no data on energy use for refrigerated/frozen stored were or could be provided by interviewees, we use typical values from a trusted secondary source: from Evans et al. (2014) electricity use for frozen storage in large warehouses is estimated at 1 kWh eq. per ton per day. Most of the stored herring is sold and exported within a year. For a typical storage period of 4 month, the frozen storage induces 0.03 kg CO2-eq per kg fish[11].

Supply transport

Herring exported from Europe are transported (frozen) by reefer container ships to the African market. Emissions of further activities along the post-harvest chain in Africa are out-of-scope for this study.

Typical transportation distances (only transport in Europe and sea transport is considered): 50 km road transport and 6000 km reefer container transport.

Based on data from www.ecotransit.org, EcoInvent and IMO (2020), GHG emissions associated to transport are estimated at 0.20 kg CO2-eq, per ton product per km for road transport and 0.02 kg CO2-eq, per ton product per km for container ship transport (both for frozen transport). This results in total transport-induced GHG emissions of 0.13 kg CO2-eq. per kg fish.

Summary of climate impact

Table 1. Summary of climate impact of described post-harvest chain: frozen herring for African market

[11] In this study we use European average GHG emission intensity: 0.23 kg CO2-eq. per kWh (European Energy Agency)

Chain stage	Frozen herring supplied to Africa climate impact (kg CO2-eq. per kg fresh fish equivalent)
freezing, bulk packaging	on-board; out-of-scope for the PH chain
frozen storage (4 months)	0.03
international supply transport	0.13
TOTAL post-harvest up to delivery in Africa	**0.16**

4.2 GHG emissions in a typical PH chain for soused herring

For soused herring ("Hollandse Nieuwe") nowadays fresh whole herring are landed in Denmark. The fish are gutted and/or deheaded, brined and frozen on land (Denmark). The frozen fish (in brine) is transported to The Netherlands, and defrosted and filleted there. An increasing fraction of the fillets is packaged in consumer-packages (2 to 4 pieces per package).

Losses along the PH chain induce extra demand for catching, packaging, etc. In order estimate GHG emission effects of losses it is also essential to have an estimate of emissions associated to catching.

Processing and frozen storage

The fish are gutted and/or deheaded, brined and frozen on land (e.g. Denmark) with around 10% weight loss. Emissions associated to the brine are negligible.

Brining/ripening is done in plastic packages, with plastic use 0.014 kg plastic per kg herring. GHG emissions related to plastic are estimated around 3 kg CO2-eq/kg (ETC-WMGE, 2021). Thus, the net climate impact of plastic use in brining is estimated at 0.04 kg CO2-eq. per kg fish.

Energy use for freezing and processing is estimated at 216 kWh electricity plus 0.13 litre fuel per ton fish (Winther et al., 2020: the electricity use is quite comparable to energy use related to freezing meat). This induces around 0.05 kg CO2-eq. GHG per kg gutted fish.

The product is kept in frozen storage for a short period (max. few days). This will add relatively little extra emissions, typically around 0.0002 kg CO2-eq per kg fish; this is neglected compared to above 0.05.

Supply transport: from Scandinavia to The Netherlands

Assuming typical road transport distance of 800 km, the transport-induced GHG emissions are estimated at 0.16 kg CO2-eq. per kg fish.

Further processing and packaging

Before processing, the frozen product can be kept in frozen storage (up to a year). Based on typical electricity use for refrigerated storage follows climate impact of storage up to 0.09 kg CO2-eq. per kg fish. One of the interviewees mentioned that 20% was produced locally through solar panels. This is an example how companies reduce GHG emissions.

In processing, the herring is defrosted (substantially lower energy use than for instance the freezing step) and filleted (at the processor or seller). The yield from whole fish to gutted and/or deheaded fish is around 84-83%. From gutted and/or fillet it is around the product ends with around 50%.

Soused herring are increasingly packaged in consumer packages, typically around 80 gram plastic per kg product. This induces 0.24 kg CO2-eq per kg fish fillet.

Distribution transport

Based on typical total transport from processor to end-market of 200km the transport-induced GHG emissions are estimated at 0.04 kg CO2-eq. per kg fish fillet.

Energy use for refrigeration in the retail display cabinet

(Electricity use of refrigerated retail shelves were estimated at typically 0.06kWh per kg per day from a set of direct measurements for various product categories; the actual value however will largely depend on technical design, loading degree and operational use).

Assuming typical shelf period of 3 days follows total refrigeration electricity use of 0.2kWh per kg gross product, which induces 0.05kg CO2-eq. per kg.

Effects of losses in retail

Product losses in retail are estimated at 7.5% (retail interview). Emissions associated to catching (0.20 CO2-eq. per kg fish, Byrne et al., 2021), processing and transporting these lost products are allocated to the actually sold products. Based on above data, the emissions of all activities upstream along the supply chain are estimated at 1.2 kg CO2-eq. per kg fish fillet. Consequently, the contribution due to the 7.5% is 0.09 extra CO2-eq. per kg fish fillet.

Summary of climate impact

Table 2. Summary of climate impact of described post-harvest chain configuration for soused herring

Chain stage	Fresh and gutted herring (kg CO2-eq. per kg fresh fish equivalent)	Soused herring (in plastic package) (kg CO2-eq. per kg fish fillet)
processing: gutting, brining packaging and freezing	0.09	0.09/0.56=0.16
international supply transport	0.16	0.16/0.56=0.29
frozen storage up to 1 year	0.09	≤0.09/0.56=0.16
filleting		(relatively small)
packaging		0.24
distribution transport		0.04
energy use in retail		0.05
effects due to losses		0.10
TOTAL post-harvest		**1.0**

4.3 GHG emissions in a typical PH chain for pickled herring (niche product)

Pickled herring ("zure haring") is a niche product, mainly sold in glass jars in the Netherlands. The product's PH climate impact mainly deviates from soused herring because of the consumer package. Furthermore, the average shelf life is longer and consequently the average shelf period will be lower as well as losses in retail.

Final product processing and packaging

A common packaging solution for pickled herring is a glass jar: 200 g fish in 380 ml jar (package weight ~ 220 g) and 300 g fish in 550 ml jar (weight ~ 300g). Average 1 kg glass per kg fish fillet. Based on a GHG emission factor of 0.6 kg CO2-eq per kg glass (Schmitz, 2011), follows a climate impact of 0.6 kg CO2-eq per kg fish fillet.

Distribution transport

Assuming typical road transport distance of 200 km, with 2 kg brine + jar per kg fish fillet the transport-induced GHG emissions are estimated at 0.12 kg CO2-eq. per kg fish fillet.

Energy use for refrigeration in the retail display cabinet

Assuming typical shelf period of 10 days follows total refrigeration electricity use of 0.6kWh per kg gross product, which induces 0.14kg CO2-eq. per kg. Taking into consideration that only one third of the product including packaging is fish fillet, this means 0.4 kg CO2-eq. per kg fish.

Effects of losses in retail

Product losses in retail are expected lower than for products with short shelf life; here we assume 2.5%. Based on above data, the emissions of all activities upstream along the supply chain are estimated at 2.0 kg CO2-eq. per kg fish fillet. Consequently, the contribution due to the 2.5% is 0.05 extra CO2-eq. per kg fish fillet.

Summary of climate impact

Table 3. Summary of climate impact of described post-harvest chains for pickled herring

Chain stage	Fresh and gutted herring (kg CO2-eq. per kg fresh fish equivalent)	Pickled herring ("zure haring") (in glass jar) (kg CO2-eq. per kg fish fillet)
processing: gutting, brining packaging and freezing	0.09	0.16
international supply transport	0.16	0.29
frozen storage up to 1 year	0.09	≤0.16
packaging		0.6
distribution transport		0.12
energy use in retail		0.4
effects due to losses		0.05
TOTAL post-harvest		**1.7**

4.4 GHG emissions in a typical PH chain for mackerel

A large part of the mackerel is sold for smoking in the EU. A large part is frozen on-board and directly transported to the processing company (smokery) and there packed in final package.

Fisheries

Based on results presented by Byrne et al., 2021 an average estimate of 0.2 kg CO2-eq. per kg landed mackerel is derived. From fuel use figures in Agrimate (www.visserijincijfers) for small pelagic fisheries somewhat higher emissions are estimated, 0.54 kg CO2-eq. per kg landed fish. In this study the average of these values is used: 0.37 kg CO2-eq. per kg landed fish. This estimate includes production and combustion of fuel and a generic value for non-fuel related emissions based on approach in Ziegler et al. (2021).

Supply transport to processor

Assuming typical road transport distance of 50 km, the transport-induced GHG emissions are estimated at 0.01 kg CO2-eq. per kg fish.

Frozen storage and processing

Before processing, the frozen product can be kept in frozen storage; here 2 months is assumed. Based on typical electricity use for refrigerated storage follows climate impact of storage up to 0.02 kg CO2-eq. per kg fish.

In processing, the mackerel is defrosted (no substantial energy use), gutted (typical yield 90%), salted and smoked (with yield of salting + smoking around 80%, see Rybicka et al., 2022). The combined yield from whole fish to smoked product is estimated at 72%. Traditional smoking is based on wood, to which only low climate impact is associated.

Consumer packaging of mackerel is mostly plastic (vacuum) packaging, sometimes combined with paper board. Typical GHG emissions 0.1 to 0.2 kg CO2-eq per kg mackerel.

Distribution transport

Based on typical total transport from processor to end-market of 200km the transport-induced GHG emissions are estimated at 0.04 kg CO2-eq. per kg fish fillet.

Energy use for refrigeration in the retail display cabinet

(Electricity use of refrigerated retail shelves were estimated at typically 0.06kWh per kg per day from a set of direct measurements for various product categories; the actual value however will largely depend on technical design, loading degree and operational use).

Assuming typical shelf period of 5 days follows total refrigeration electricity use of 0.3kWh per kg gross product, which induces 0.07kg CO2-eq. per kg.

Effects of losses in retail

Product losses in retail are estimated at 7.5% (retail interview). Emissions associated to catching/landing, processing and transporting these lost products are allocated to the actually sold products. Based on above data, the emissions of all activities upstream along the supply chain are estimated at 0.8 kg CO2-eq. per kg smoked mackerel. Consequently, the contribution due to the 7.5% is 0.06 extra CO2-eq. per kg fish fillet.

Summary of climate impact

Table 4. Summary of GHG emissions in a typical PH chain for mackerel

Chain stage	Supplied frozen fish (kg CO2-eq. per kg whole fish equivalent)	Smoked mackerel equivalent (kg CO2-eq. per kg smoked mackerel)
supply transport	0.01	0.01/0.72 ≈ 0.01
storage (2 months)	0.02	0.02/0.72 ≈ 0.03
processing + packaging		0.15
distribution transport		0.04
energy use in retail		0.07
effects due to losses		0.06
TOTAL post-harvest		**0.36**

5 Conclusions

Herring and mackerel are two species that are only coming from fisheries. The most likely climate change effects for the three PH chains of frozen herring as a whole (African market), herring filets and mackerel (EU market) are changes in the fishing stocks. Changes are projected by literature such as displacement, higher abundance (in case of mackerel) due to rising sea water temperature, decreasing recruitment due to less feed of plankton for herring larvae and smaller sized mackerel. For the nearby future (5-10 years) there are no major threats foreseen for the financial or physical resilience of the PH chains of these small-pelagic species by the consulted stakeholders. However, first steps are taken by the industry to reduce their footprint and costs, in order to act upon EU climate change policy (e.g. Green Deal) and to meet the increasing need from customers to become more sustainable throughout the entire PH value chain. First steps are for instance:

- Machinal processing (filleting machines) locally (Netherlands) instead of manual processing by workers in lower-cost producing countries abroad (e.g. Poland). This saves not only costs and processing time (machinal filleting is more efficient) but also reduces unnecessary transportation between processing locations and the following activities in the PH chain. Therefore, energy costs and GHG emissions could be further reduced.
- Electrification of transporting trucks that currently use fossil fuel.
- Solar panels on roofs of factory building to generate renewable energy.

Management interventions that appeared to be successful to become more resilient to climate driven events, are vertical integration and joint ventures by the PH chain of small-pelagics. The advantage of vertical integrated companies and joint ventures within the PH chain are specialization and the ability of outsourcing activities close to place of landing and processing and distribution. Also, multiple production locations worldwide make it easier to remove production activities and increases the physical resilience of a PH chain. Financial resilience is high for vertical integrated companies by increased buying power for materials and predictability of supply flows due to scale advantages.

The case studies show significant different GHG emissions in PH chains. PH emissions of chains that export frozen herring to Africa are limited to energy use in frozen storage and transport-related emissions, in total typically 0.16 kg CO2-eq. per kg fish.
For fish marketed in Europe, other categories relatively significantly contribute to total GHG emissions of PH activities: freezing, international transport, packaging and retail shelf (refrigeration energy use + effects of losses). For soused herring total GHG emissions of PH phase was estimated at 1.1kg CO2-eq. per kg fillet. For pickled herring (a niche product) a significantly higher GHG emission value was found: 1.6kg CO_2-eq. per kg fillet; the difference with soused herring is mainly related to the impact of glass production for the jar.

For mackerel PH chain (smoked mackerel) the post-harvest chain is simpler than for herring. This is reflected in the lower GHG emissions in the PH chain for mackerel, which is estimated at 0.36 kg CO2-eq. per kg smoked fish.

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CASE STUDY 4: SMALL-PELAGICS – SARDINE *(SARDINA PILCHARDUS),* ATLANTIC HORSE MACKEREL *(TRACHURUS TRACHURUS),* ATLANTIC CHUB MACKEREL *(SCOMBER COLIAS)* – PORTUGAL

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Narcisa Bandarra, Carlos Cardoso & Cláudia Afonso

LIST OF ABBREVIATIONS

Term	Description
ANICP	Associação Nacional dos Industriais de Conservas de Peixe
ANOPCERCO	Associação Nacional das Organizações de Produtores da Pesca do Cerco
EUMOFA	European Market Observatory for Fisheries and Aquaculture
FAO	Food and Agriculture Organization
GHG	Green House Gas
ICES	International Council for the Exploration of the Sea
INE	Instituto Nacional de Estatística
LCA	Life Cycle Assessment

1 Background

This CS examines the impact of global ocean warming amid a changing climate on small pelagic fishes within temperate Atlantic European waters, focusing on sardine (*Sardina pilchardus*), Atlantic chub mackerel (*Scomber colias*), and Atlantic horse mackerel (*Trachurus trachurus*) in Portuguese waters. These three species represent a substantial share of the seafood consumed within Portugal; upwards of 50 kg per year, per capita of each species are nationally consumed. In this respect, these three species are both economically and socially important within Portugal.

Sardine (also termed European pilchard), belongs to the family Clupeidae, is a small coastal pelagic species, and is a vital national seafood in both Portugal and Spain (Almeida et al., 2014; 2015). Fished stocks are found in Portuguese water, mostly in the Western Continental Shelf of Mainland Portugal. Fresh sardines are consumed mainly in the summer months (June to early October), when their fat content, taste and aroma are improved, while canned sardines are also eaten in other times of the year. However, these stocks show large natural fluctuations (due to variation in planctonic richness, which, in turn, is related to upwelling phenomena and sea temperatures), but also now are showing signs of overexploitation. Such issues with availability of stocks have resulted in fishing moratoria being implemented for sardine stock off the coast of Portugal and Galicia (Spain), as well as other measures (e.g., control of landed quantities) to limit capture. With such changes in the availability of sardine, other small pelagic species (Atlantic chub mackerel, Atlantic mackerel, and Atlantic horse mackerel), are now popular alternatives.Regarding quantities and flows, for instance, in 2020, sardine landings totalled 14,526 tons, being only 3,893 tons imported, and 9,091 tons exported (4,932 tons of fresh sardine and 4,159 tons of frozen sardine) (INE, 2020). Within these flows, the canned sardine, for its importance, may be highlighted, with a production of 8,645 tons, the import of 1,714 tons, and the export of 10,243 tons. This yields an apparent consumption of just 116 tons of canned sardine. This was also the assessment of EUMOFA (EUMOFA, 2021), but it may be distorted by statistical imprecision and the inclusion of other sardine-like species besides *Sardina pilchardus*.

Atlantic chub mackerel, which belongs to the family Scombridae, is a small coastal-pelagic species widely distributed in the warm and temperate waters of the Atlantic Ocean and surrounding areas, found between 25 to 300 m depths (Velasco et al., 2011). This species is globally important, with Portuguese landings increasing from 15,000 tons up to 33,000 tons in the past decade (ICES, 2020). Such increased landings have been associated with increased local stock biomass amid lowered local landings of sardine. According to INE (2020), the landings of this small pelagic fish species were 23,666 tons, imports reached 7,366 tons, and exports were 23,537 tons (4,813 tons of fresh chub mackerel and 18,724 tons of frozen chub mackerel). For this species, canning is also very important. In fact, canned chub mackerel production has reached lastly 2,609 tons (INE, 2020).

Atlantic horse mackerel, the third important small pelagic species within Portugal, belongs to the Carangidae family. This species is abundant in temperate Atlantic European waters, congregating in large shoals in rocky coastal waters, eating smaller fish, crustaceans, and squid (Vázquez-Rowe et al., 2010). Atlantic horse mackerel are fished all year round, with the best quality individuals sold fresh and whole in markets. Two thirds of Atlantic horse mackerel landings occur between late spring and summer, with reduced landings during the winter months; part of the landings within the winter months are used for fishmeal production or canning. This species is popular within the region, with both Portuguese and Spanish households buying Atlantic horse mackerel regularly.The landings of Atlantic horse mackerel in Portuguese harbours have been variable, but have remained in the range of the 10,000 to 20,000 tons per year, for instance, reaching 14,609 tons in 2020 (INE, 2020).

The fishing industry associated with all three species is likely to be substantially impacted by both external environmental changes as well as internal economic changes. Firstly, all three small pelagic species populations show sensitivity to warming waters. In this respect, there is the potential for stock biomass between 35° and 45° N latitude (southwest European Atlantic coast, encapsulating Portugal, Spain and France western coastlines) declining if waters become warmer. The contemporary decline in sardine landings within Portugal and Spain may already reflect increased localised warming. Secondly, sardine and chub mackerel are vitally important in the Portuguese canning industry, comprising 17 % and 5 % of the canning undertaken within the country, respectively (INE, 2020). However, such importance belies the role of this industry in consuming high levels of energy, with a substantial proportion of such energy utilised within the cooking process. This high reliance on energy in turn may render part of the PH chain for all three species highly susceptible to taxes on fuel and CO_2 emissions.

2 Value Chain

2.1 Value chain description

All three of the CS species are wild caught, with no commercially significant aquaculture production within Portugal. The majority of the individuals entering the PH chain are caught in Iberian waters, with the Portuguese market mostly supplied by Portuguese fishermen using vessels (e.g., trawlers) throughout the Portuguese coastline. An overview of the PH value chain for all three CS species in Portugal is illustrated in Figure 1.

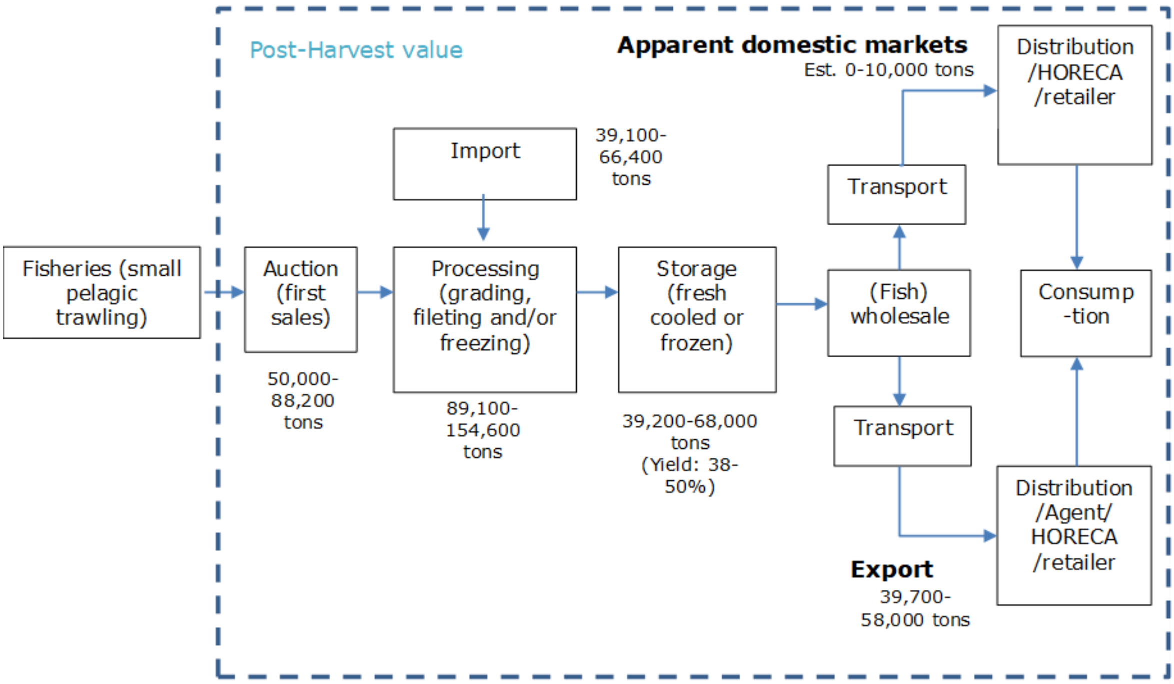


Figure 1. Postharvest value chain of small pelagic fish species in Portugal. Source: EUMOFA

Figure 1 enables a general overview of the small pelagic fish in Portugal and their various flows, which entail transport between different locations.

Since most transport of fish products between landing sites, processing units, and markets is done by medium-heavy duty trucks, the specific total CO_2 emissions of this transport medium must be considered: 340 g CO_2 equivalent/tonne-km (Nahlik et al., 2015). Admitting average distances between landing sites, processing units, and markets of approximately 100 km in Portugal, it can be estimated a CO_2 contribution of transport of 34 kg CO_2 equivalent/tonne of fish product in the links from auction to processing and then in the transport to the domestic market. For imported raw materials, taking into account that Morocco and Spain are key suppliers of such small pelagic fish to Portugal (Paquotte and Lem, 2008), an average distance of 1000 km may be assumed, yielding a CO_2 contribution of transport of 340 kg CO_2 equivalent/tonne of fish product. Furthermore, for export of small pelagic fish, canned fish is very important, being sent to all over the world. However, the largest share is sold to EU partners. Being Portugal an EU country in the European periphery and main consumption markets in Central Europe, most export travel (mainly by road) can involve approximate distances of 2,000 to 3,000 km. Assuming the worst-case scenario, this yields approximately 1,020 kg CO_2 equivalent/tonne of exported fish product.

Within the processing part of the chain, it should be remarked that canning is very important. It is one of the most common and prized ways to preserve seafood, since it maintains the nutritional value and food safety without additives or preservatives (Lyon and Kiney, 2013). Canned seafood products are eaten and exported all over the world, travelling large distances and being stored for long times (Vázquez-Rowe et al., 2012). In the canning industry, processing starts with storage of sardines that are often landed in high quantities and stored chilled or frozen (Aubourg, 2001). The cooking step, to reduce moisture and inactivate endogenous enzyme activity, can be done in two different ways: the raw pack method, where sardines are cooked in the can (modern method), or, alternatively, the sardines can be cooked before being packed into cans (traditional method) (Warne, 1988). The energy consumption of such cooking procedures (with temperatures of 121 °C) is large and typically is provided by an internal factory utility that consumes fuel oil, thereby representing a dependency of a non-renewable resource and also releasing of very significant amounts of CO_2 to the atmosphere. Any supply difficulty, including a price increase of the fuel conditioned by a higher CO_2 taxation or a higher cost of the fish itself —given the substantial CO_2 release associated to their production, varying between 600 and 1,200 kg CO_2 equivalent/tonne for small pelagic fish, such as chub mackerel, horse mackerel, and sardine (Iribarren et al., 2010)—, can be a serious threat to the business sustainability of this PH sector. Again, assuming a worst-case scenario leads to adopting the highest value of the range, 1,200 kg CO_2 equivalent/tonne of processed fish. Though not all small pelagic fish is directed to canning and subjected to energy-expensive thermal treatments, the other processes energy and CO_2 emission budgets can be rounded up to 1,200 kg CO_2 equivalent/tonne of processed fish.

After transport and thermal processes, a third major item in the energy/CO_2 budgeting is cool and frozen storage, sometimes for long spans of time. This expenditure of energy mainly concerns the transport of raw materials to factories and storage facilities, their storage until being used for production, storage of intermediate and final products (not in the case of canned products, which can be stored at room temperature), and transport of the final products from factory to wholesale point and, further downstream, to retailer (and its storage in each of these points of the PH chain). Taking into account the estimates made by specialists in the area of seafood and food in general (Tan and Culaba, 2009; Trapp et al., 2017), each month in refrigeration entails a CO_2 emission of 6.5 kg CO_2 equivalent/tonne of stored seafood and an equal time in frozen storage (at approximately -18 °C) causes an approximate CO_2 emission of 60 kg CO_2 equivalent/tonne of stored seafood. The time elapsing from fish capture until its processing can be up to close 1 year, but, in average, may be estimated to be 6 months. The time spans for the frozen storage of intermediate and final products may also add up to near 1 year in the case of small pelagic fish. In the most unfavourable scenario, this would translate into 1,440 kg CO_2 equivalent/tonne of fish.

If all main items described above are put together, a maximal value of 3,660 kg CO_2 equivalent/tonne of fish may be estimated. However, distinctions have to be made between small pelagic fish processed into canned products and those slightly processed as well as between imported and locally fished raw materials and also between products consumed in Portugal and those exported (mostly to the EU). An overall picture and rough estimates of the situation concerning specifically sardine, chub mackerel, and horse mackerel, with emphasis on the canning industry (given its GHG implications) and only considering fish landed in Portugal and processed in Portugal, are shown in Figure 2.

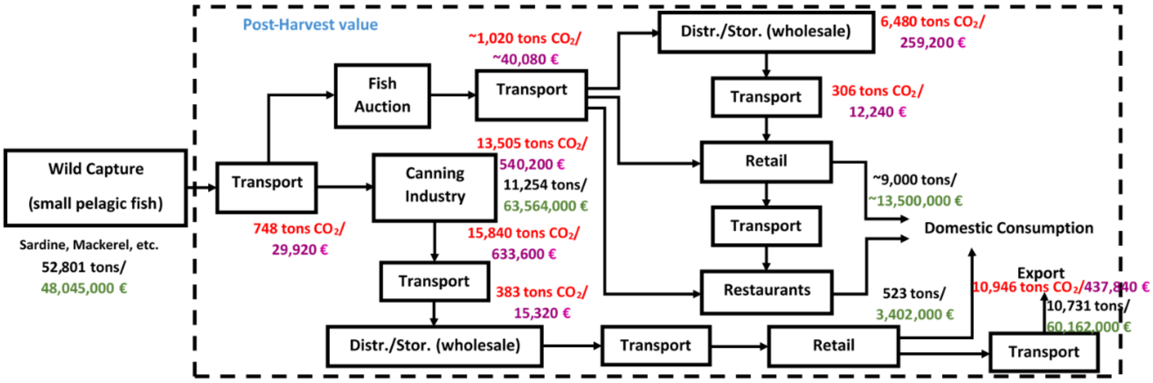


Figure 2. The GHG and economic aspects of the postharvest value chain of small pelagic fish species in Portugal for fish landed in Portuguese ports and processed in Portuguese factories. Source: EUMOFA, INE (black figures correspond to production, export, and consumption quantities; green figures correspond to economic value of production and flows; red figures correspond to CO_2 emissions; and purple figures correspond to the estimated CO_2 associated costs).

The overview provided by Figure 2 is necessarily incomplete, since there is data scarcity, especially concerning specific products prepared from a given fish species as well as the overall efficiency/yield of the processing operations. There were several assumptions. Namely, that canning had an overall yield of 0.5 tonne of canned product per tonne of raw fish and that storage up to a year in freezing rooms was applied in the canning industry to the raw material and to the other products prior to their distribution to the retail handlers. There is an estimated grand total of about 50,000 tonnes of CO_2 that are emitted as a result of the activities within the Portuguese small pelagic fish PH chain.

3 Resilience

3.1 Physical and financial resilience

Atlantic chub mackerel, horse mackerel, and sardine are excellent case studies for assessing the sensitivity/robustness of the PH sector to climate change, given the environmental and economic aspects that may make the industry prone to reduction. In this respect, the small pelagic fish fishery is emblematic of the range of challenges impacting the PH seafood sector within Portugal.

While Atlantic chub mackerel's landings have been increasing and this species is currently the most important one in terms of sheer quantity of landings (23,666 tons corresponding to 9,348,000 EUR according to INE (2020)), sardine is the most important species in terms of economic value landed in Portugal (14,526 tons corresponding to 22,087,000 EUR according to INE (2020)). Horse mackerel is also an important fish species with 14,609 tons of landings corresponding to an economic value of 16,610,000 EUR. Regarding the fate of these small pelagic fish species in the overall PH, there are also differences among them. Indeed, whereas almost half of the sardine landed is consumed fresh by the

Portuguese population and approximately 40 % go to factories of which the main part (78 %) goes to the canning industry (the remainder is used as agricultural feed), chub mackerel is mainly consumed as a canned product (Almeida et al., 2015; INE, 2020). On the other hand, horse mackerel is mainly consumed whole and unprocessed, being most of it consumed fresh. In Portugal, there are 20 fish canning plants producing approximately 44,000 tonnes of canned products annually (Almeida et al., 2015), being tuna a major raw material followed by sardine and chub mackerel.

It has been estimated that wasted sardine biomass may be up to 38 % of the raw material (Almeida et al., 2015). For chub mackerel, though information is lacking, it may be assumed similar percentage of waste of the raw material. This is an area where improvements could be achieved, though limited by the difficulty of using some materials, for instance, fins are totally inedible and must find other adequate and updated applications. Nonetheless, a better management of stocks and improved care in handling these small pelagic fish species beginning in the fishing vessels themselves can be helpful in reducing this high percentage of waste or its suboptimal utilization as feed, such as fishmeal (Almeida et al., 2015). A more physically resilient PH sector would have to deal with these shortcomings in the future.

Canning has advantages and problems of its own that affect the whole resilience of the PH sector for the small pelagic fish. Canning, whereby the food within the can is cooked at high temperatures, is one of the most common and prized ways to preserve seafood, since it maintains the nutritional value and food safety without additives or preservatives (Lyon and Kiney, 2013). In this respect, canned seafood products are eaten globally, as they can stored for a long time and are able to be consumed straight from the can (Vázquez-Rowe et al., 2012). In regards to both mackerels and sardines, the canning process starts with individuals being chilled or frozen (as they are often landed in high quantities) (Aubourg, 2001). The cooking step, to reduce moisture and inactivate endogenous enzyme activity, can be done in two different ways: the raw pack method, where fish are cooked in the can (modern method), or alternatively the fish can be cooked before being packed into cans (traditional method) (Warne, 1988). The environmental aspects of these cooking options are not sufficiently considered unless in a purely energetic/economic perspective.

Precisely, despite canning being a vital form of preserving and storing the two small pelagic fish species used in canning for domestic and international use (and also for horse mackerel, despite its scarce consumption as canned food in Portugal), the energy consumption is substantial. For the species used in canning, individuals are cooked in temperatures which can range up to 121 °C. Energy for this process is typically provided by an internal factory utility that consumes fuel oil, thereby being wholly dependent on a non-renewable resource and, also, releasing significant amounts of CO_2 to the atmosphere. It is estimated a value of up to 1,200 kg CO_2 equivalent/tonne of processed fish, which is substantial albeit not much higher than the carbon footprint for a truck transport across half Europe or 12-18 months in frozen storage (Iribarren et al., 2010; Paquotte and Lem, 2008; Tan and Culaba, 2009; Trapp et al., 2017).

Regarding the financial aspects to the sector, its whole picture and CO_2 emissions and concomitant economic impacts must be considered (Figure 2). If the costs associated to the CO_2 emissions —calculated assuming 40 EUR/tonne of CO_2, which is higher than the traded price, but is fairer, since it appraises environmental costs in a more thorough way (Choi, 2019) — are compared to the economic value of the manufactured, sold internally, and exported products, their economic importance seems to be limited with the exception of the canning industry (especially if its large export branch is considered), which may generate CO_2 with a cost of roughly 1,600,000 EUR (i.e. approximately 140 EUR/tonne of exported canned fish) in an export market worth approximately 60,000,000 EUR, that is, around 2.5-3.0 %. This may be significant when compared with operating margins and profitability of the sector.

Any supply difficulty, including a price increase of the fuel conditioned by a higher CO_2 taxation or a higher cost of the fish itself —given the substantial CO_2 release associated to their production, varying between 600 and 1,200 kg CO_2 equivalent/tonne for small pelagic fish, such as chub mackerel, horse mackerel, and sardine (Iribarren et al., 2010)—, can be a serious threat to the business sustainability of this PH sector. The transport by truck and the estimate of 340 kg CO_2 equivalent/tonne of fish product in a trip of 1,000 km (or 1,020 kg CO_2 equivalent/tonne of fish product for a driving distance of around 3,000 km, as would be in a continental export from Lisbon to Berlin) also involve direct large fuel consumption levels. In this context, the increase of energy prices, particularly of diesel prices, as a result of the Ukraine war in 2022 represents a good exercise and test to the sector. Taking diesel prices, these have increased from an average of 1.50 EUR/l in previous years to 2.00 EUR/l after war broke out (AHDB, 2022). The underlying crude oil variation was steeper, but government intervention reduced the impact of the price increase in the world wholesale markets. The 40,000 tonnes of released CO_2 correspond to a minimum of 14,000 tonnes of fuel, which would cost previously 21,000,000 EUR and in June 2022 around 28,000,000 EUR in a rough estimate, which again compares against an export market worth approximately 60,000,000 EUR (whole internal and export market – 80,200,000 EUR, i.e. 75 % of exports). This means that the current price shock in energy prices can have an impact worth 10 % of the sales volume of the export sector. This highlights the existence of a serious vulnerability.

Another major risk is the reduction or even disappearance of the fish stocks. Global warming of the oceans may lead species, such as sardine and mackerel, to migrate to northern latitudes, thereby disappearing from the Portuguese Coast. As a consequence, the sector companies would have to import all raw material. This could involve CO_2 emissions and associated costs comparable to those estimated for the export flow, that is, in a magnitude near 1,000 kg CO_2/tonne of fish or 40 EUR/tonne of fish. The associated fuel consumption would be, at least, 350 kg, that is, 700 EUR/tonne of fish. For the canning industry, this would add another 15 % of costs to those already mentioned. Given the competition in this sector and relatively low operational margins, this would lead to severe losses in relative competitiveness of these companies. Hence, unless new fish species suitable for canning would become abundant in Portuguese waters, even a very flexible sector with capacity to import large quantities of raw material as this would have serious difficulties in coping under such a scenario.

3.2 Major financial constraints and reliability

The various financial aspects of the fishing and fish processing (namely canning) sectors in Portugal and in neighbouring Spain have not been much studied. Nonetheless, the studies by Amigo-Dobaño et al. (2008) and Bjørndal et al. (2015) are worth mentioning as well as the general perspectives for stewardship in the seafood industry as discussed by Blasiak et al. (2021).

The Portuguese companies are relatively small in an international comparison and, as Amigo-Dobaño et al. (2008) have stressed, data analysis shows the importance the size of the company has on their financial results and capacity. This is not so much a matter of profitability, but of significant differences in cash flow levels. According to Amigo-Dobaño et al. (2008), is observable a direct and positive relation between the size of the companies and the cash flow and a close link between levels of borrowing and company size, with the small and medium-sized companies having higher levels of borrowing. This imposes financial constraints on the fish processing companies in their effort to adapt to the effects of climate change, especially given the higher operational costs that could evolve from higher fuel prices and a proper taxing/pricing of CO_2 emissions, as explained previously.

Any management strategy to reduce GHG or to mitigate through contingency preventive measures the impact of climate change on the business model (from lower fish stocks to natural catastrophes) are necessarily expensive in terms of both capital investment and augmented operational costs for the companies. Namely, replacing old equipment by novel environmentally-friendly one, changes in insulation materials or the renewal/electrification of the transport fleet can pose major challenges to companies, especially the smaller ones with less access to credit provided under favourable conditions. Moreover, the additional operational costs associated with environmental ameliorations tend to accumulate and compound themselves along the production chain, being often translated to large increases in the final product prices, which, in turn, reduces its competition to other sectors (e.g. meat sector). Therefore, new approaches must be taken by the industry (especially, the canning industry), being the utilization of environmental labelling an alternative, which is still absent from the Portuguese market.

3.3 Stakeholders' perceptions

The questionnaires were sent to the ANICP ('Associação Nacional dos Industriais de Conservas de Peixe', i.e., National Association of the Canned Fish Entrepreneurs), ANOPCERCO ('Associação Nacional das Organizações de Produtores da Pesca do Cerco', i.e., National Association of the Seine Fishery Producers), and other stakeholders involved in different paths of the PH processing chain of small pelagic fish. In particular, ANICP is a large association, representing a grand total of thirty associates, all companies dedicated to processing sardine and/or mackerel and producing canned products. ANOPCERCO comprises producers that also transport and sell their product in local markets. The received answers representing the majority of these industrialists/processors delivered a relevant overview of the sector with additional data and insight into the problems of the sector.

From the conducted interviews and received responses to the previously prepared questionnaires, it can be considered that, at least, among the consulted stakeholders no special care or concern is attached to GHG emissions and the consequences of climate change. Moreover, these stakeholders had a strong propensity to evaluate the effects of climate changes on their sector and business as limited or modest, including the possibility of declining stocks (imports are considered a viable and relatively cheap solutions).

Hence, despite problems with fluctuations and an overall declining trend in Portuguese sardine stocks, fish processors did not report a problem of decreasing turnover and profits, especially because they state that price increases and the valorisation of fish as a healthy food in the last pair of decades has offset any reduction in production volumes. They also did not find any evidence until now of a loss of quality of the raw materials and claim to have been able to maintain the quality standards of the final products or even enhancing such quality standards.

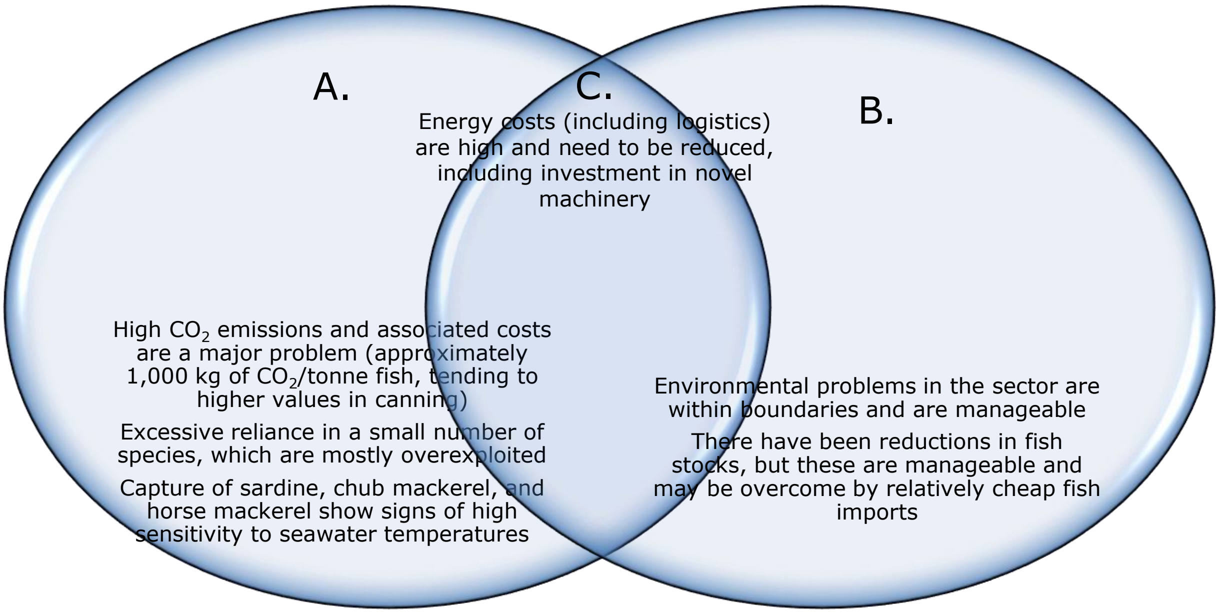
The major concern in the current context is connected to the increasing costs of energy, especially because the processors of small pelagic fish (with emphasis on the canneries) are very dependent on energy for most of their processes (emphasis on cooking and sterilization of canned products). There have been efforts by the stakeholders with key management positions in reducing energy costs, taking into account the weight of these costs in the overall costs (even in times of relatively cheap energy). However, there are physical ceilings to the amount of energy that can be spared and each extra spared kWh may require an excessive and unacceptable cost in terms of capital equipment investment. Furthermore, the canning industry association has promoted some projects for limiting the ecological footprint by fostering circularity and has stimulated their associates to invest in reforestation initiatives that should contribute to carbon neutrality in the sector.

The stakeholders have reported an overall trend to acquire fish raw materials for their industries in foreign markets, thus reducing their dependence on Portuguese fish stocks. However, they acknowledge that this also harbours risks, given the sensitivity of such a strategy to energy price increases. In any case, they claim that acquisition costs of import fish are still low enough to remain competitive in comparison to fish landed in Portuguese auctions. In spite of rising transport costs, the situation is still regarded as favourable to the development of fish imports in the next years. Of course, all this approach enhances the importance of the logistics aspects in the sector with a clear bearing upon the whole PH chain. This may be related to the tendency of the sector to outsource services for auxiliary and transport/logistics activities, which causes a change of perception in the managers who are prone to view logistics difficulties and other problems as exterior to their business.

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	***Strengths*** • Small pelagic fish are healthy foods, being the sole main source of long-chain omega-3 polyunsaturated fatty acids; • Most processing units are near the Coast easily accessible by marine transport and enabling rapid access to export ports; • The canning sector has been investing in innovation and added-value products in the last two decades.	***Weaknesses*** • Overreliance in imported fish, especially whenever national fish stocks fluctuate in an unfavourable way; • Transport of imported fish is particularly sensitive to the price of energy; • Dependence on energy-intensive processes for key processes in the transformation of small pelagic fish into staple products (such as canned sardine or canned mackerel); • Small companies with old equipment that need to be replaced by modern machinery with a more positive environmental balance.
External origin (attributes of the environment)	***Opportunities*** • There is a culture of consumption of sardine and, to a lesser extent, of horse mackerel in Portugal and Southern Europe that may cause consumers to accept higher prices and added-value products; • There is an increasing environmental awareness by Portuguese (and European) consumers.	***Threats*** • Reduction (or wide fluctuations) of the small pelagic fish stocks in the Portuguese Coast (and elsewhere); • The increasing trend of energy costs as a result of more demanding environmental protection norms (and, also, geopolitical problems) and CO_2 emission pricing; • Increasingly longer supply chains more subject to high transport costs and geopolitical problems; • Market trend for associating less processed products to healthier food.

3.4 (Mis)Fits between literature review and stakeholders' perceptions

There is an innate divergence between the main findings of the literature review and the attained stakeholders' perceptions that results from the eminently academic nature of the revised publications. Moreover, the point of view of the authors of these publications is eminently environmental and that of the stakeholders is mainly commercial. Several published papers involved Life Cycle Assessment (LCA) studies. Though an LCA analysis is more holistic, it still imparts a strong environmentalist character to the revised papers. These differences underlie a significant misfit between literature review and the sector actors. These clearly undervalue the importance and urgency of several issues raised in the literature.



A. = From literature review
B. = From stakeholders' perception
C. = Overlapping as found both in literature and stakeholders' consultation

3.5 Role of management – lessons learned of adopted strategies

The pace of climate change has been increasing in the last decades and the associated problems and its anthropogenic origin have been increasingly highlighted. Of course, this has been acknowledged by more and more extensive layers of the society and it has reached and appraised by various managers. However, this appraisal has been circumscribed to the energy cost problems, including possible future costs of CO_2 taxing. Accordingly, management has brought some progress as far as some investments were made in novel equipment for achieving a more rational organization of logistics inside and outside companies as well as in reaching lower levels of waste and effluents. Within this context, energy-sparing approaches and technical solutions have been adopted, thereby leading to a modest reduction of the carbon footprint. Nonetheless, practical advances are slow and more information and benchmarking of processes in an environmental-friendly way are still much needed.

4 Conclusions

The case-study on the PH chain of small pelagic fish highlighted the importance of fish processing to many industries, such as the canned fish industry, and the potential sensitivity of such PH chain to disruptions as well as long-term evolutions brought forth by climate change. The data gleaned from the literature, public institutions, stakeholders, and other sources enabled to conclude that there are several environmentally critical aspects and significant GHG by the industries in the sector. In particular, the canning industry generated plenty of GHG and was sensitive to any increase of the energy costs, given the fact that it encompasses energy-intensive transformation processes and logistics. Three main areas in the operation of this PH sector contribute to GHG emissions (directly or indirectly) and are more critically affected by increases in energy expenditure: transport; thermal processes (essentially in the canning industry); cold and frozen storage as well as room cooling in general (low temperatures are also required for the processing of fish). If all main items described above are put together, a maximal value of 3,660 kg CO_2 equivalent/tonne of fish may be estimated. However, distinctions must to be done between small pelagic fish processed into canned products and those slightly processed as well as between imported and locally fished raw materials and also between products consumed in Portugal and those exported, since impacts and carbon budgets may differ significantly when such aspects differ.

Regarding questionnaires and the input from the sector's stakeholders, it should be remarked that stakeholders were not very concerned with the environmental issues involving their companies, at least, in what regards their own direct and indirect GHG emissions as well as knew their vulnerability to the multiple incidences of climate change. Moreover, they had only a faint notion of the environmental footprint of their industries. Nevertheless, they acknowledged the energy cost problems and the associated GHG emissions and estimable CO_2 equivalent costs. In accordance with this concern, stakeholders were looking into ways to increase energy efficiency and exploit alternative energy sources. Being mostly small companies, they manifested their difficulty in performing investments in equipment with better energy efficiency and reduced GHG emissions or in advancing towards a full electrification of the transport fleet.

In any case, this was all within a conservative framework that did not leave much margin for truly alternative approaches to the management of resources within each company. The preparation of contingency plans for future developments issuing from climate change impacts (e.g. disruption in the supply of raw materials) was much underdeveloped, being concerns again mostly devoted to scenarios of even higher energy costs.

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CASE STUDY 5: SMALL-PELAGICS – ATLANTIC MACKEREL (*SCOMBER SCOMBRUS*), ATLANTIC HORSE MACKEREL (*TRACHURUS TRACHURUS*) AND ATLANTIC HERRING (*CLUPEA HARENGUS*) - KILLYBEGS, IRELAND

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Michael Keatinge

LIST OF ABBREVIATIONS

Term	Description
BIM	Bord Iasciagh Mhara
IFPO	Irish Fish Producers Organisation
IFPEA	Irish Fish Processors & Exporters Association
ISWFPO	Irish South & West Fish Producers Organisation
ISEFPO	Irish South & East Fish Producers Organisation

1 Background

Within Ireland, mackerel (landed value EUR80 million in 2020) and horse mackerel (landed value EUR12 million in 2020) are two of the top five species landed by value. Both species are caught primarily by vessels registered in the pelagic/RSW fleet, and to a lesser extent in the polyvalent segment of the national fleet, with significant quantities landed in Killybegs (see more details regarding Killybeg in CS2).

Killybegs pelagic species are handled by the ports processors, fishmeal plant and Ireland's only bio marine ingredients plant that, collectively, represent a major local PH value chain. In 2020, 63 % by volume and 48 % by value of all seafood landed in Ireland by Irish registered fishing vessels was landed in Killybegs. There are currently seven main pelagic seafood processors in Killybegs (Table 1) all of whom handle Atlantic mackerel, Atlantic horse mackerel and Atlantic herring. Products range from whole frozen (all species) to more sophisticated products like headed and gutted, fillets, and flaps in the case of mackerel and herring (Table 2)

Table 1: Pelagic processors, Killybegs

Arctic Fish Processing Ltd.	Killybegs Seafoods Ltd.	Gallagher Bros. (Fish Merchants) Ltd.
ROSHINE ROAD, KILLYBEGS , CO. DONEGAL	CONLIN ROAD, KILLYBEGS , CO. DONEGAL	DONEGAL ROAD, KILLYBEGS , CO. DONEGAL
karl@atlantic-dawn.com	jmg@killybegsseafoods.com	fish@gallagherbros.ie
+353 74 9731225	+353 74 9731028	+353 74 9731004
http://www.atlantic-dawn.com	http://www.killybegsseafoods.com	http://www.gallagherbros.ie
Karl McHugh	John McGuinness	Anne/Michael Gallagher

Island Seafoods Ltd.	Premier Fish Products	Norfish Ltd.
CARRICKNAMOHILL, KILLYBEGS , CO. DONEGAL	KINCASSLAGH, DUNGLOE , CO. DONEGAL	THE GLEBE, KILLYBEGS , CO. DONEGAL
info@islandseafoodsltd.ie	info@premierfish.ie	info@norfishltd.com
+353 74 9731216	+353 74 9543118	+353 74 9731146
http://www.islandseafoodsltd.ie	http://www.premierfish.ie	http://www.norfishltd.com
Mick O'Donnell	Martin Meehan	Tony Byrne

Sean Ward (Fish Exports) Ltd.
ROSHINE ROAD, KILLYBEGS , CO. DONEGAL
info@wardfish.ie
+353 74 9731613
www.wardfish.com
Sean Ward

Table 2. Postharvest Value Chain – product summary for Atlantic mackerel, Atlantic horse mackerel and Atlantic herring

	Mackerel	Horse Mackerel	Herring
Latin name	*Scomber scombrus*	*Trachurus trachurus*	*Clupea Harengus*
Catching Area	FAO 27, in the Northeast Atlantic		
Season	Jan-Mar & Oct-Nov	Jan-Feb & Oct-Dec	Jan-Feb & Sep-Nov
Fat Content	Jan-Mar: 16%-22% Oct-Nov: 21%-25%	10%-20%	Jan-Feb: 8%-12% Oct-Nov: 10%-16%
Products	• Whole Round Mackerel • Headed and Gutted Mackerel • Hand Gutted Mackerel: 20kg cartons. Scramble packed or hand-laid • Hand-cut Mackerel Fillets, suitable for smoking: 10kg or 20kg cartons, hand-laid • Butterfly Mackerel flaps, suitable for canning. Packed in 20kg polybags	• Whole Round Horse Mackerel: Packed in 20kg cartons	• Whole Round Herring • Butterfly Herring flaps • Skinless Herring fillets

Within Killybegs, the RSW fleet currently target all three CS species. However, by far the most important species are Atlantic mackerel and Atlantic horse mackerel. Under national quota management rules 84.5 % of Ireland's Atlantic mackerel quota is allocated to the RSW fleet; 15 % to the polyvalent fleet (a number of which are now also fitted with RSW tanks) and a further 400 tonnes (0.7 % in 2021) set aside annually for hand lines operated from inshore vessels. All of the Atlantic horse mackerel[12] is also allocated to the pelagic RSW fleet. While Atlantic horse mackerel fisheries had been subject to TACs from 1983, member states quotas were only introduced in 1993.

As of 2021, Killybegs lands 96 % of the Atlantic mackerel landed at Ireland's top 10 ports, as well as 97 % of the Atlantic horse mackerel and 81 % of the Atlantic herring. Of this, 80 % of Atlantic mackerel catches are taken by the biggest RSW vessels (≥ 40 metres[13]) and a further 17 Atlantic % by vessels 24 – 40 metres in length (overall LOA) which are a mix of RSW and polyvalent vessels. In terms of Atlantic horse mackerel, 75.4 % of catches are taken by the biggest (≥ 40 metres) RSW vessels and a further 22.3 % by vessels 24 – 40 metres in length (overall LOA), which are a mix of RSW and polyvalent vessels. For herring, only 24 % of catches are taken by the largest (≥ 40 metres) RSW vessels. Conversely, 43 % of catches are taken by medium sized (24 – 40 metres) RSW and larger polyvalent vessels and a further 20 % by polyvalent vessels 18 – 24 metres in length. These vessels also target Celtic Sea herring and total landings to Killybegs, at 81 %, are significantly less than Atlantic mackerel (96 %) or Atlantic horse mackerel (97 %).

[12] While horse mackerel fisheries had been subject to TACs from 1983, member states quotas were only introduced in 1993

[13] There are no polyvalent vessels over 40 metres on the Irish register.

2 Share of European TAC – Atlantic mackerel, Atlantic horse mackerel, Atlantic herring

With a total EU share of 420,097 tonnes valued at more than EUR565 million in 2021, Atlantic mackerel is one of the most important species fished by Irish fleets and supports a significant number of jobs in the catching, processing, and ancillary sectors. However, Brexit with reduced share of the European TAC of Atlantic mackerel, as well as shifting populations associated with increasingly warming waters surrounding Ireland has seen the share of the TAC for this species substantially reduce, from 57.7 % between 2000-2009, falling to 42.6 % between 2016 – 2020 and 23 % by 2021.

With a total EU share of almost 83,000 tonnes valued at more than EUR62 million in 2021, horse mackerel is the 7th largest EU stock by volume and the 14th by value. Along with mackerel and herring it is a vital part of the pelagic catching sector (> 600 vessels) and supports a significant number of jobs (> 6,000 in EU) in the catching, processing, and ancillary sectors. Currently the EU share of the horse mackerel TAC is 87 %. In 2021 for example, the TAC2021 was 95,385 tonnes of which the EU was allocated 82,980 tonnes (87 %); Ireland has a quota of 17,891 tonnes, 21.6 % of the EU share. Following Brexit, this quota will increase (in the UK and Union waters of 4b, 4c and 7d) from 11.35 % in 2020 to 40 % in 2025, with no change in its share other stocks.

With a total Union share of almost 256,000 tonnes valued at more than EUR109 million in 2021, herring is the 2nd largest EU stock by volume and the 8th by value. Along with mackerel and horse mackerel it is an important species for the pelagic catching sector and supports a significant number of jobs in the catching, processing, and ancillary sectors. While very significant for Ireland in the past, today, with dwindling stocks and a total quota of just 6,642 tonnes across 5 management units in 2021, herring is of relatively minor importance.

In 2021, the total TAC2021 for herring was 1.77 million tonnes of which the EU was allocated 255,594 tonnes (14.4 %) and Ireland 6,642 (2.6 % of the EU share).

3 Value Chain

3.1 Value chain description

In both 2020 and 2021 Killybegs accounted for 98 % of landings for the 5 pelagic species of interest (Table 3). This included 96 % of all mackerel landed in Ireland, 97 % of the Horse mackerel, 70-80 % of the Herring.

Table 3 Landings to Killybegs by species; 2020 and 2021

		Mackerel	Horse mackerel	Herring	Blue whiting	Boarfish	Total
Killybegs	2021	54,829	20,331	1,264	103,777	12,585	192,786
National Total		56,820	21,025	1,565	103,843	13,589	196,842
% Killybegs		96%	97%	81%	100%	93%	98%
Killybegs	2020	73,871	22,048	2,439	119,875	8,005	228,632
National Total		77,318	22,790	3,555	119,875	9,231	232,769
% Killybegs		96%	97%	69%	100%	87%	98%

3.2 Volume and value of fish purchased for processing.

To better understand the volume and value of the three CS species typically purchased by pelagic processors, sales note data for the top ten processors were obtained from the Sea Fisheries Protection Authority. The top four companies handled between eight to 13 thousand tonnes of Atlantic mackerel, between two and approximately four thousand tonnes of Atlantic horse mackerel and between approximately 630 and 150 tonnes of Atlantic herring. Across these processors, typically, Atlantic mackerel accounts for 50 % of fish processed as well as Atlantic horse mackerel, with much smaller quantities of Atlantic herring (likely associated with its scarcity, with quotas having been falling for some time).

3.3 Pelagic postharvest value chain

For Ireland's quotas of the three CS species in 2021, they have a first point of sale value of EUR103.5 million (Table 4). These are being fished primarily by the RSW fleet operating from Killybegs, with additional landings from non-Irish vessels. As an example, Ireland's 2021 quota for Atlantic mackerel was 60,847 tonnes. Of this, 60,700 tonnes were landed at Irish ports by Irish vessels with 54,829 tonnes landed to Killybegs of which 46,926 tonnes were utilized by the pelagic processors in Killybegs and a further of which approximately 17 % (7,903 tonnes) went for fishmeal by way of trimmings.

Excluding the fishmeal and bioingredients plants and some secondary processing, pelagic processors handle some 90,067 tonnes of fish supplied by Irish vessels and 47,083 tonnes supplied by non-Irish vessels. These have a nominal value (FPOS - first point of sale/price to the boat) of EUR111 million.

Table 4. Postharvest value chain, Killybegs. Note: EUR/tonne indicates price at First Point of Sale (FPOS)

			Quota and Landings				Utilization in Post harvest Value Chain			
Species	€/tonne	Irish Quota (tonnes)	(1) Landings to Irish ports	Landings to Killybegs	Landings to Killybegs	(2) Landings to Killybegs	Pelagic Processors		Fish Meal, Bio Ingredients, other secondary processing	Total
			Irish Vessels	Irish Vessels	Non-Irish Vessels	All Vessels	Irish Vessels	Non-Irish Vessels		
		A	B	C	D	E	F	G	H	I
Mackerel	€1,203	60,847	60,700	54,829		54,829	46,926		7,903	54,829
Horse mackerel	€847	17,891	18,900	18,900	1,431	20,331	15,062	0	5,269	20,331
Herring	€545	6,642	5,500	1,264		1,264	1,561			1,264
Blue whiting	€231	35,373	39,000	39,000	64,777	103,777	24,917	47,083	31,777	103,777
Boarfish	€252	13,324	11,900	11,900	685	12,585	1,602		10,983	12,585
Total Landed Volume		134,077	136,000	125,893	66,893	192,786	90,067	47,083	55,635	192,785
Total Landed Value (FPOS)		€103.5	€104.0	€94.6	€16.3	€111.0	€76.2	€10.9	€23.9	€111.0

Table 5 gives details of the PH volume and value chain by each of the processing subsectors. Column A includes traditional pelagic processor while column B includes secondary processing and the fishmeal and bioingredients plants. These have a combined value of EUR180.7 million. For comparison column D provides the volume and value of Irish exports by species.

Table 5. Postharvest, pelagic, value chain, Killybegs, 2021. Note: EUR/tonne indicates final export price.

Species	€/tonne	VOLUME (tonnes)					VALUE €'million			
		Post harvest Value Chain (Processors)	Other processing, Fish Meal, Bio Ingredients etc	Total	Ireland's Total Exports	% of total exports from this value chain	Proccessors	Other	Total	Exports
		A	B	C	D	E	A	B	C	D
Mackerel	€1,566	46,926	7,903	54,829	69,600	67% - 79%	€73.5	€12.4	€85.9	€109.0
Horse mackerel	€1,374	15,062	5,269	20,331	21,100	71% - 96%	€20.7	€7.2	€27.9	€29.0
Herring	€2,051	1,561	-297	1,264	3,900	32%	€3.2	-€0.6	€2.6	€8.0
Blue whiting	€486	72,000		72,000	72,000	100%	€35.0	€0.0	€35.0	€35.0
Boarfish		1,602		1,602	0	NA				
Fishmeal	€1,429		42,760	42,760	15,400	100% of exports. (Yield 47.942%)	€0.0	€29.3	€29.3	€22.0
Fish Fats and Oils	€1,373				5,100					€7.0
Total Export Volume		137,150	55,635	192,785	187,100	103%	€132.4	€48.3	€180.7	€210.0
Total Export Value (€ millions)		€132.4	€48.3	€180.7	€210.0	86%				

In their 2018 report The Economic Impact of the Seafood Sector: Killybegs, BIM and Oxford Economics[14] considered the destinations of seafood sales ex Killybegs. The Killybegs commercial fishing sector (primarily the RSW fleet) sold 92 % of their produce in the port hinterland (to the processing sector) and had no exports. The fish processing sector, however, sold 77 % of their produce in export markets.

There are a number of key markets for Irish pelagic exports (Table). For example, of the 54,829 tonnes of Atlantic mackerel landed to Killybegs, 46,926 tonnes were utilized by the pelagic processors in Killybegs. This represents 79 % of the total mackerel exported from Ireland (69,600 tonnes) that year (67 % if the 7,903 tonnes used in secondary processing, trimmings etc are discounted). Of this, 31,084 tonnes (45 %) went to the main markets in China (8,939 tonnes), Egypt (7,918 tonnes), Nigeria (6,794 tonnes) and Japan (6,321 tonnes).

Table 6 Postharvest, pelagic, value chain, Killybegs, 2021. Part C: Main Markets.

Species	€/tonne	Exports (tonnes)	Nigeria	Japan	China	Egypt	Poland	Germany	Other
Mackerel	€1,566	69,600	6,794	6,321	8,939	7,918	5,147	3,397	31,084
Horse mackerel	€1,374	21,100	2,488	3,405	0	0	0	0	15,207
Herring	€2,051	3,900		878			507	819	1,697
Blue whiting	€486	72,000	49,248	0	0	0	0	0	22,752
Total Export Volume		166,600	58,530	10,604	8,939	7,918	5,654	4,216	70,739
Total Export Value (€ millions)		€181.0	€38.0	€16.4	€14.0	€12.4	€9.1	€7.0	€84.1
Market Share (By value €)			21%	9%	8%	7%	5%	4%	46%

[14] The Economic Impact of the Seafood Sector: Killybegs. BIM & Oxford economics, August 2019 9427 BIM Economic Impact of Seafood Sector report - Killybegs.indd

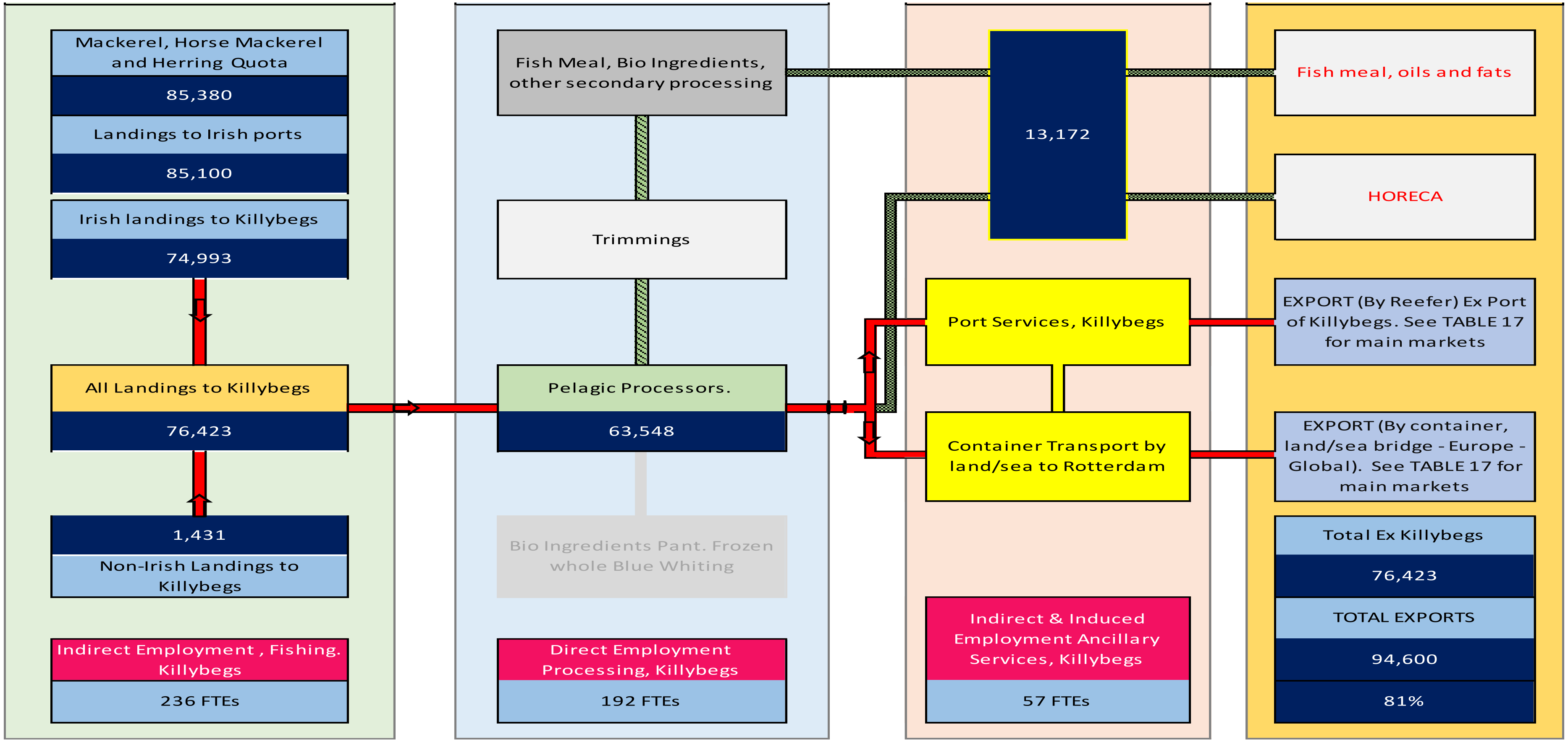

Figure 1 Pelagic postharvest value chain, Killybegs.

Note: Red channel: main flow of Mackerel, Horse mackerel, Herring, and (part of) Blue whiting for human consumption. Yellow channel: flow of services including port and ancillary services. Other channels, of less importance: trimmings ex processing to fishmeal; blue whiting from processor to bioingredients (and other secondary processing entities)

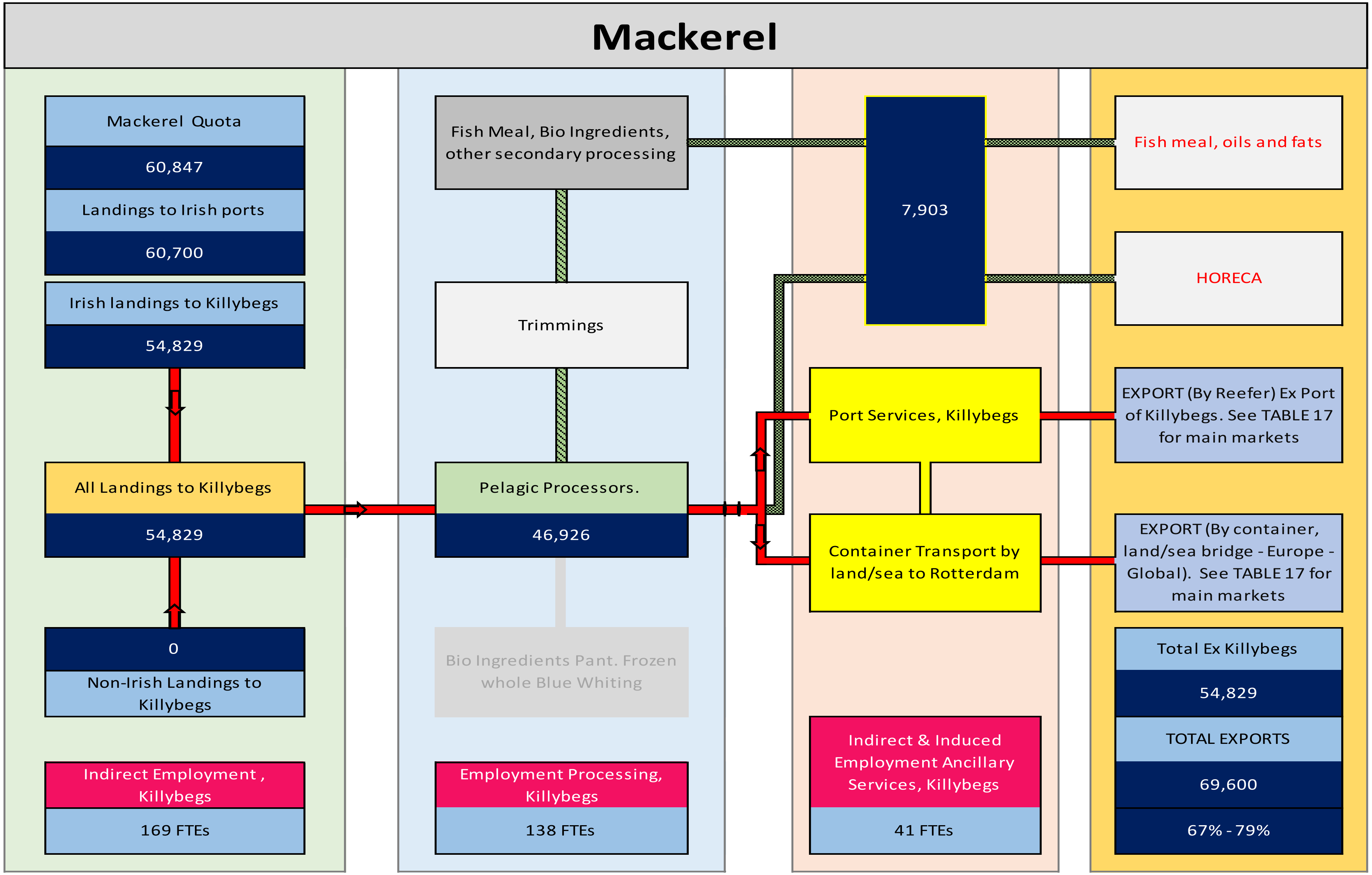

Figure 2 Mackerel Postharvest Value Chain. All figures shown are tonnes.

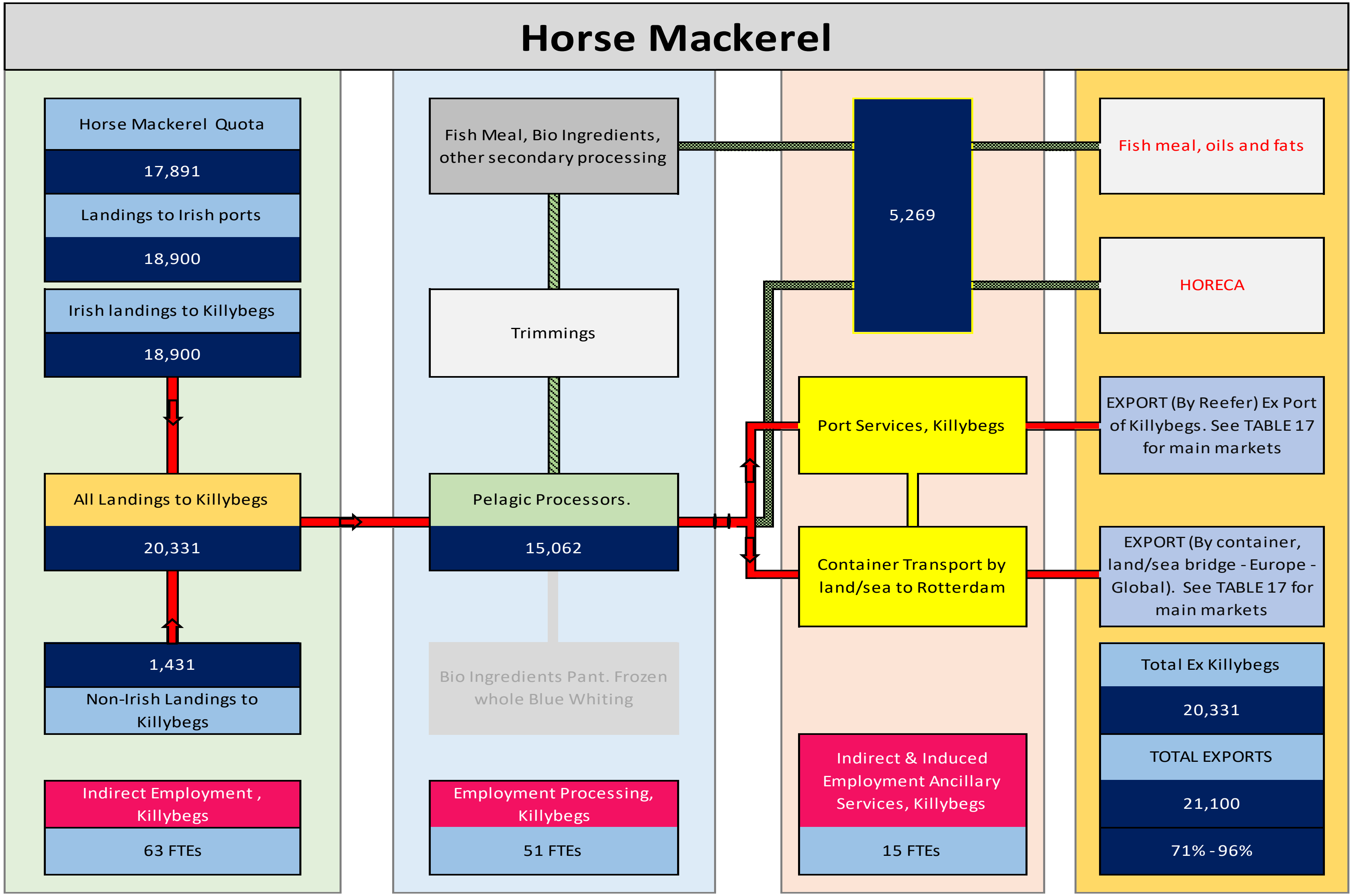

Figure 3 Horse mackerel Postharvest Value Chain. All figures shown are tonnes.

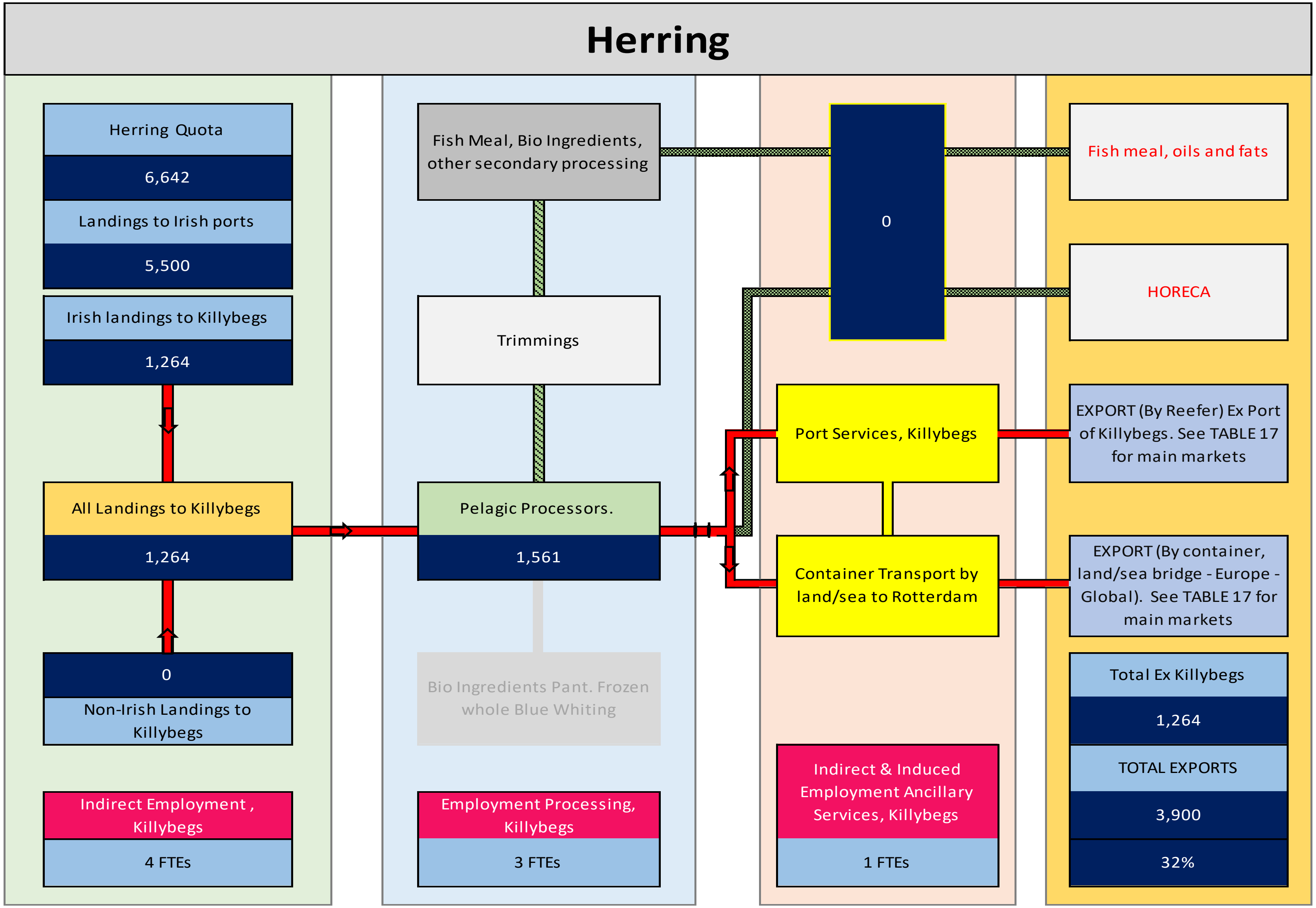

Figure 4 Herring Postharvest Value Chain. All figures shown are tonnes

[Catalogue number]

CASE STUDY 6: ROUNDFISH – ATLANTIC SALMON *(SALMO SALAR)*

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Atlantic Salmon *(Salmo salar)*

Source: Shutterstock (property rights purchased by WUR)

Alexander Wever, AWF Consulting

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LIST OF ABBREVIATIONS

Term	Description
EPS	expanded polystyrene (Styrofoam)
EU27	The 27 countries of the European Union
GHG	Green House Gas
HOG	Head on gutted
MAP	Modified atmosphere packaging
RAS	Recirculated Aquaculture System

1 Background

This CS focuses on the PH value chain for Atlantic Salmon. The outcomes are based on about 10 interviews with stakeholders in the PH sector for Atlantic Salmon and on expert judgement. The interview partners include Atlantic Salmon importers and traders, seafood wholesalers, salmon smokers, salmon portion suppliers to retail, retail chains, fishmongers and seafood journalists with operations in Germany, Denmark, Poland and France.

The Atlantic Salmon (*Salmo salar*) is a species of ray-finned fish in the family Salmonidae. Atlantic Salmon are found in the northern Atlantic Ocean and in rivers that flow into this ocean. Most populations of this fish species are anadromous, hatching in streams and rivers but moving out to sea as they grow where they mature, after which the adult fish seasonally move upstream again to spawn. Wild Atlantic salmon are found in the North Atlantic on both European (Portugal to Russia) and North American (Cape Cod to Labrador) sides. Atlantic salmon, whose PH sector is considered in this CS, originates from net-cage aquacultures in the North Atlantic, primarily Norway, Scotland, Faroe and Ireland, and from aquacultures in the South Pacific off Chile’s coast. In the PH sector value chain, whole gutted salmon is used to produce various fresh salmon products, frozen salmon products and smoked salmon products at different locations within the EU. For this purpose, large quantities of salmon are transported across Europe before – after various stops for processing and resale – they end up on the consumer’s plate.

As Atlantic salmon is one of the most popular and best-selling seafood products in almost all EU countries, and its processing and resale require a high degree of specialization in some cases, it has a kind of special role within the European fishing industry, also because it cannot be easily substituted by other species.

1.1 Salmon aquaculture

(Source: FAO Fisheries and Aquaculture)

Atlantic salmon Sea cage culture was first used in the 1960s in Norway to raise Atlantic salmon to marketable size. The early successes in Norway prompted the development of salmon culture in Scotland, and latterly Ireland, the Faroe Islands, Canada, the North-eastern seaboard of the USA, Chile and Australia (Tasmania). All of the major production areas lie within latitudes 40-70º in the Northern Hemisphere, and 40-50º in the Southern Hemisphere.

When the juveniles weight just under 100 grams, they are big enough to be reared as food fish. This requires keeping salmon in seawater or brackish water. Then the fish are placed in net pens, such as those often found in Norwegian fjords and off the Chilean coast. Modern farms have up to a million fish at a time distributed among several nets anchored to the seabed. The location of the farms plays a major role. To avoid local contamination of the water with waste materials, they must be placed in locations with a steady flow and sufficient depth. A constant water temperature, which must not be too high, is advantageous. Recently, salmon have also been reared in closed recirculation systems.

Current worldwide production of farmed Atlantic salmon exceeds 1,7 Million tonnes. Farmed Atlantic salmon constitute >90 percent of the farmed salmon market, and >50 percent of the total global salmon market. The major markets for farmed Atlantic salmon are Japan, the European Union, and North America. The major products remain fresh (whole, steaked, filleted), frozen, and smoked (mainly for the European market). A small but increasing per-centage is on-processed to supply value-added products into the market.

1.2 Major trade flows for Salmon of selected countries

The role of Salmon for an EU country can be very different in the PH sector. This becomes clear by looking at trade flows (Table 1 & 2). There are pure transit countries such as Sweden, transit countries with processing such as Denmark, processing countries such as Poland, high consumption countries with rather low domestic processing such as Germany and high consumption countries where most of the processing is done in the country itself such as France.

1.3 Importance of farmed Atlantic Salmon for EU postharvest sector

Between 2015–2020, the 27 countries in the European Union (EU27) imported on average nearly 850.000 tonnes of Salmon products per year from outside the EU (Table 1 & 2: EU Extra imports) with a value of almost 5,5 billion Euros on import price level. By far the most important country of origin is Norway, followed by Scotland and Chile (frozen products). When this Salmon reaches the consumer plates after a journey through Europe and several processing and trade steps it represents a value of far more than 10 billion Euros.

Atlantic salmon is purchased by almost all EU countries, although not every country buys directly at origin, but many countries are supplied via intermediate stations. The added value of salmon products in the form of processing (filleting, portioning, packaging, smoking, canning) takes place in many EU countries, of which Poland, France, Germany, Denmark and the Netherlands are the most important.

Farmed Atlantic Salmon is probably the most traded and consumed seafood species in EU27 and also the one that is most widely spread within EU.

Table 1. Trade-flows for salmon in the EU, expressed in value (euros) First panel shows the extra imports; second panel the intra imports; third panel the extra exports; and fourth panel the intra exports. More detailed information can be found in Supplementary 1.

- EU Extra Imports: EU country importing from a country outside EU
- EU Intra Import: EU country importing from a country inside EU
- EU Extra Export: EU country exporting to a country outside EU
- EU Intra Export: EU country exporting to another EU country

Value	EU Extra Imports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	4.589.903.726 €	50.947.329 €	744.564.274 €	66.093.714 €
Denmark	927.612.512 €	12.512.216 €	136.062.248 €	2.728.661 €
Germany	110.379.200 €	4.415.161 €	27.824.581 €	12.870.304 €
France	206.553.489 €	744.135 €	38.033.105 €	13.666.271 €
Netherlands	80.107.266 €	1.380.263 €	102.776.065 €	639.591 €
Poland	245.024.374 €	2.578.668 €	138.867.411 €	148.165 €
Sweden	2.777.029.370 €	9.532.229 €	211.376.905 €	5.250.706 €

Value	EU Intra Imports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	2.533.611.069 €	117.025.196 €	657.164.259 €	1.186.350.857 €
Denmark	12.772.716 €	29.742.673 €	9.305.371 €	35.800.559 €
Germany	274.820.955 €	11.449.336 €	158.684.691 €	527.380.925 €
France	547.534.642 €	5.137.758 €	109.412.217 €	108.635.627 €
Netherlands	61.610.917 €	1.482.134 €	23.005.433 €	32.923.264 €
Poland	582.826.977 €	10.584.481 €	62.432.986 €	14.820.243 €
Sweden	2.362.889 €	2.817.818 €	12.594.468 €	12.865.661 €

Value	EU Extra Exports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	436.937.066 €	12.676.305 €	151.733.164 €	235.617.151 €
Denmark	101.120.760 €	1.662.763 €	34.368.898 €	43.625.134 €
Germany	11.113.456 €	175.966 €	51.031.764 €	59.585.622 €
France	7.623.373 €	1.008.485 €	15.554.765 €	16.316.953 €
Netherlands	11.825.222 €	1.421.588 €	31.229.757 €	65.441.920 €
Poland	396.613 €	1.396.898 €	3.224.583 €	22.847.839 €
Sweden	278.582.896 €	421.983 €	12.161.557 €	5.383.498 €

Value	EU Intra Exports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	3.424.431.996 €	79.310.966 €	744.564.274 €	1.328.385.996 €
Denmark	606.822.092 €	43.557.473 €	136.062.248 €	70.935.987 €
Germany	85.386.942 €	1.761.362 €	27.824.581 €	153.627.604 €
France	23.962.909 €	1.143.869 €	38.033.105 €	43.785.652 €
Netherlands	49.869.980 €	5.772.692 €	102.776.065 €	25.015.787 €
Poland	12.242.212 €	5.958.601 €	138.867.411 €	657.159.056 €
Sweden	2.444.522.478 €	8.526.008 €	211.376.905 €	7.775.078 €

Table 2. Trade-flows for salmon in the EU, expressed in volume (tonnes). First panel shows the extra imports; second panel the intra imports; third panel the extra exports; and fourth panel the intra exports.

Volume	**EU Extra Imports main Salmon categories**			
in tons	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	776.022	12.232	45.590	13.824
Denmark	157.575	2.221	5.651	2.770
Germany	18.003	859	1.497	3.553
France	31.188	114	1.774	759
Netherlands	13.235	251	178	3.506
Poland	41.129	602	1.004	1.460
Sweden	473.365	2.945	32.375	342

Volume	**EU Intra Imports main Salmon categories**			
in tons	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	413.785	19.899	70.021	86.629
Denmark	1.920	5.199	1.130	3.178
Germany	43.349	1.625	16.141	38.599
France	87.964	775	12.096	7.856
Netherlands	9.659	175	1.738	2.294
Poland	102.055	1.900	8.352	1.178
Sweden	318	337	1.371	858

Volume	**EU Extra Exports main Salmon categories**			
in tons	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	70.234	8.439	13.178	13.824
Denmark	16.256	7.860	3.079	2.770
Germany	1.750	323	4.409	3.553
France	830	6.924	1.062	759
Netherlands	1.289	2.714	2.661	3.506
Poland	59	6.113	369	1.460
Sweden	45.811	1.642	1.238	342

Volume	**EU Intra Exports main Salmon categories**			
in tons	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	561.070	15.042	74.651	93.654
Denmark	100.455	7.354	13.870	5.744
Germany	13.332	272	2.872	10.725
France	3.602	421	3.185	2.306
Netherlands	7.627	946	9.288	1.607
Poland	1.476	918	13.560	47.056
Sweden	405.227	2.528	24.170	462

2 Value Chain

2.1 Value chain description

The Salmon PH sector is characterized by a high level of specialization and automatization and a high dependence on the sufficient availability of Salmon to "feed" that sector. In difference to the whitefish sector that can work with different species such as Cod, Haddock, Saithe, Pollock or Redfish Atlantic Salmon can be only replaced with pacific Salmon or large Salmon Trouts.

In the PH Salmon sector, especially in A–D (Figure 1), there is a strong competition between independent players on the one hand and companies on the other hand that belong to vertically integrated "Salmon Groups", most of the based in Norway, which own farms, processing facilities, smoke houses and sometimes even retail brands. Since several years, the farmed Atlantic Salmon sector shows a demand overhang, meaning that the demand is higher than what is produced. This allows the farms to set the prices and to realize rather high margins and profits – despite the fact that the farms face a lot of challenges, some of them also resulting from climate change issues what increased the production costs too. These high profits in the farms allow companies in the same group but later in the value chain to undercut their independent competitors with lower prices.

Also, the competition in the PH sector has to deal with two huge oligopolies, one on the Salmon farm side with a couple of big suppliers that have together more than 80 % of the European production, the other one in retail chains. The last ten years have been marked by a massive thinning out of independent companies specializing in processing Salmon, many of them small- and mid-size companies.

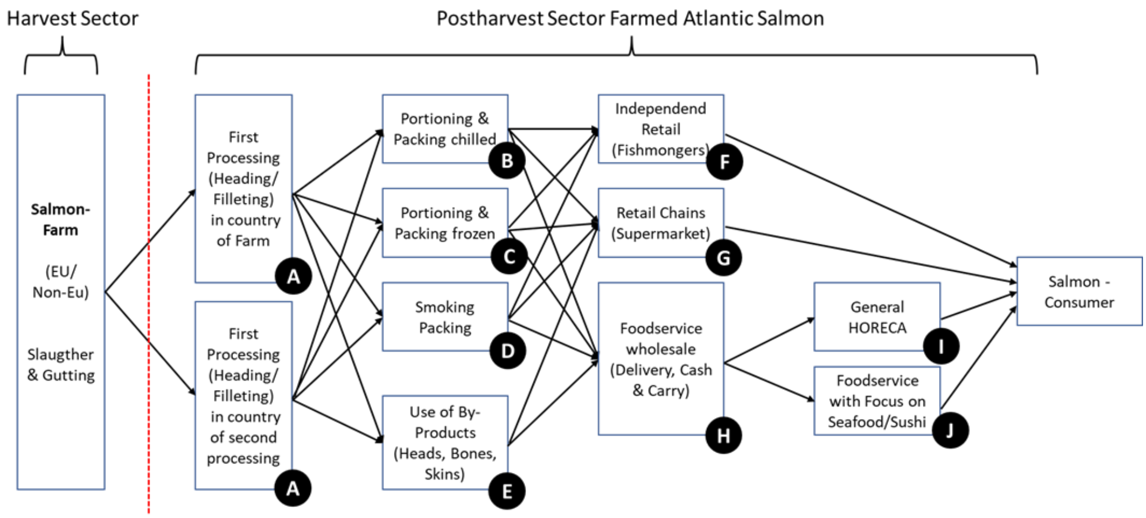


Figure 1. Postharvest value chain of Atlantic Salmon (Source AWF Consulting)

<u>From Farm to Table (Figure 1)</u>

To identify and to describe the PH sector (the value chain) for farmed Atlantic Salmon the input from the interview partners was used but also information from literature such as Aquaculture Europe (2019: Overview farmed Salmon Value chain from Norway), EUMOFA (2013: Value chain smoked Salmon France; and 2019: Fresh organic Salmon fillet packs).

Salmon farm: Slaughtering, gutting, sorting, packing (Harvest sector)

In the Salmon farm area, there is usually the slaughtering of the stunned fish which gets immediately gutted afterward. After the gutting the whole Salmon get sorted and packed together with some crash ice. A part of the Salmon is transported in bulk in big jars to processing facilities nearby, another part of the Salmon is packed in 20 kg EPS boxes for national and international truck transport in cooled cargo space.

A: First Processing in country of Farm or within EU country

This first processing usually includes the filleting and boning of the gutted Salmon, some-times also the skinning of the Salmon filets. Today these jobs normally are not done by hu-man workers by hand anymore but by highly specialized Salmon processing machines which require huge financial investments and high workloads. Resulting waste products as Salmon heads, Salmon spine bones, Salmon skins, belly flaps and recovered meat are collected and sold afterwards, mostly frozen. This first processing usually happened in a cooled facility that often contents several of these processing machines. Those machines are designed for Salmon processing and cannot be easily switched to process other finfish species. After the processing the Salmon fillets are usually packed in 5–10 kg EPS boxes, sometimes vacuumed, and cooled with some crash ice.

Most of those Salmon processing plants are located in seafood hubs and trading places or integrated in huge Salmon smoking factories.

B: Portioning and packaging

Today a huge share of the Salmon that is consumed fresh and sold by the retail is no longer sold by individual weight over the counter with service but in equalized weight packs in retail self-service shelves. The cutting of equalized Salmon portions from (not equalized) Salmon fillets require a highly specialized machinery that weights each Salmon fillet and cuts it individually by concentrated water jet or laser to portions of the same weight–minimizing waste at the same time. Those portioning units often are integrated in the Salmon filleting machines (A) or as individual machines in Salmon processing streets. After the portioning the portions are individually packed using vacuum or MAP techniques.

Packed Salmon portions are usually sold with rather low margins by many supermarkets and discount retailers.

C: Portioning and freezing

Equalized Salmon portions (B) can get vacuumed and blast frozen afterwards to be sold in smaller (retail) or bigger (wholesale) units. The machines that are used for this can be used for other seafood portions as well.

D: Smoking and packing

While there is still artisanal Salmon smoking in small units all over Europe the by far biggest share of smoked Salmon today comes from “Smoking factories” that are highly automated and cost efficient. The biggest ones are located in Eastern Europe (Poland, Lithuania) and France. To get a maximal shelf life and to control the difficult hygiene process most Salmon smokers work with whole gutted Salmon that they buy directly from exporters or specialized Salmon importers. The filleting with machines (A) is done directly before the smoking process that including salting (by hand or injection), maturing, salt removing, drying, smoking, cooling, trimming, slicing and packaging.

Most of the smoked Salmon today is packed in vacuum packs but some also in MAP packs. The whole process from whole Salmon supply to smoked Salmon packs delivery is temperature controlled and highly automated. The machinery is highly specialized and cannot be used for other finfish species except large Rainbow Trout (*Onchorhynchus mykiss*) that are farmed with the same aquaculture techniques as Atlantic Salmon.

E: Use of By-Products

Wherever Salmon is processed in large quantities, all waste that is generated in the process, such as heads, bones, skins, trims, is collected and marketed individually to other parts of the food industry to be used for soups, broths, Sushi, ready meals (all human consumption) or as raw material for animal feed (Fishmeal, Fish Oil), Pet food, medicine or cosmetics.

F: Independent Retail (Fishmongers)

All over Europe there are still independent fishmongers, some of them in fish shops others on weekly markets. Even if it is impossible to count the number of fish shops in the EU, it can be assumed that there are more than 30.000 units.

All of them sell fresh Salmon as fillet or steak, most of them also smoked Salmon. The product in the counter is usually cooled with ice, often combined with an integrated active cooling of the counter. But usually, Salmon is not playing the dominating role at the fishmongers than it plays in supermarkets because the fish mongers prefer to sell other fish species where there is less price comparison to supermarkets and hard discount.

Fishmongers buy their Salmon products together with their other seafood purchases from specialized seafood wholesalers, most of them located in seafood hubs. Depending on the distance of the fishmonger to the next seafood hub the decision is made whether to get the seafood delivered by the supplier or to pick it up at the seafood hub.

G: Retail chains

All retailers, no matter if supermarket or hard discount sell smoked Salmon (D) or frozen Salmon portions (C). In addition, many of them also sell fresh Salmon, some of them packed fillet portions in self-service, some of them over the service wet counter. In the seafood category of the retail chain Salmon is usually always within the Top-3 products, both in value and volume. Because of the easy comparability Salmon products in retail are usually rather sharp calculated. When it comes to selling Salmon to end consumers the retail chains are the biggest supplier to the consumer, followed by foodservice and fishmongers.

If Salmon is sold fresh, the temperature requirements by law are between 0 – 4°C; for smoked Salmon it's 2 – 7°C; and for frozen Salmon -18 - -21°C.

H: Foodservice wholesale

Foodservice wholesale is the typical supplier of all types of foodservices, from restaurants, canteens, hotels to catering (Horeca). There are two general business models, in one the Horeca visits the wholesaler (Cash & Carry), in the other the wholesaler brings the goods to the Horeca (Delivery wholesale). Usually, the transport of chilled or frozen seafood takes place in small to mid-size trucks or vans that have an active cooling to ensure compliance with the required temperatures.

Almost all food suppliers to the Horeca sector offer at least smoked and frozen Salmon, the majority is offering in addition also fresh Salmon fillet or whole gutted Salmon.

For the general wholesalers, who offer a wide food and non-food assortment, the seafood category is somehow important to build up a quality reputation but far less important when it comes to total turnover and profit. Within the seafood category Salmon is one of the most important products, but not a cash cow, and often used for promotion activities because of its multi-channel possible applications.

For seafood wholesalers with a focus mainly on seafood, Salmon is a key-product because it is purchased regularly by nearly all clients in rather high volumes. Good Salmon quality (i.e. long shelf life) and a good Salmon purchasing price are essential to survive in a very competitive environment. The competition with retailers and general wholesalers who both use Salmon for price promotion has damaged the popularity of Salmon at the seafood wholesalers over the last years.

I. General Horeca

If a Horeca format is not specialized in vegan/vegetarian food, it will offer Salmon with almost one hundred percent probability. From the food preparation point of view Salmon has many advantages compared to whitefish as longer shelf life, longer service life on buffets, still a premium food image and a high popularity for the guests. Fresh, smoked and frozen Salmon products are easy to store in cold stores or freezers and get normally purchased at least once a week.

J. Foodservice with focus on seafood/Sushi

Fish restaurants usually also offer Salmon dishes on their menus but for them Salmon is only one of many choices and not particularly suitable for differentiation to normal restaurants. The importance is that foodservice channel therefore is rather low.

Quite the opposite is found in the "Sushi sector", especially in the low- and mid-price range where Salmon is by far the dominating seafood ingredient. Salmon has a high recognition, a long shelf life, is easy to slice and compared to other raw seafood not too expensive. In the mid-price sector, the cooks usually use Salmon fillets for Sushi Nigiri, Maki and Rolls while the (industrialized) low-price sector often works with left-overs from the filleting process (A, E), the so-called "Bits & Pieces)

3 Resilience

3.1 Physical and financial resilience

All stakeholders interviewed were aware of direct problems that may arise from climate change. At the same time, with one exception, they could not name any event that would have directly disadvantaged their own company; e.g. rising sea levels, a strong flood, a long drought or so. Nor did they anticipate any events in the near future that would directly affect their own company. Even the one exception, a heavy storm that destroyed electric overhead power lines in Eastern Poland by falling trees, cannot be linked to climate change with 100 % probability.

However, what was mentioned by all stakeholders interviewed were indirect climate change-related developments in the countries of origin of the Atlantic salmon, resulting from changes in the temperature of the water and changes in the salinity of the water. These changes lead to necessary measures in the country of origin, which result in cost increases for the product that are passed through the value chains and make the product more expensive for PH sector up to the end consumer. The farming conditions get less predictable. Some of the indirect developments are:

- Higher life stock mortalities because of infestations with sea lice and emerging costs to fight against the infestations. Even though there is no final scientific proof that directly connects the growing numbers of sea lice with increased water temperatures most of the stake-holders believed in a correlation. To fight the sea lice the Salmon net cages are often moved to areas with colder water or Waters with a higher freshwater content.
- Higher water temperatures also favour toxic algal blooms that can kill high numbers of fishes within days. Prominent examples in the last years were Algal blooms in Northern Norway (2019) and Southwest Ireland (2021) and Chile (2016, 2022).
- "*The devastating algal bloom in northern Norway in May killed eight million salmon in the Nordland and Tromso regions in the space of a few days, with the Norwegian Seafood Council estimating the event caused losses of up to 2.2 billion kroner (EUR218,993 million)*" https://www.nytimes.com/2019/05/23/world/europe/salmon-norway-algae-bloom.html
- "*Salmon farming giant Mowi confirmed it suffered a sizeable die-off at its Ireland operations, the result of a toxic plankton bloom that hit its farming sites in Bantry Bay in late October. Local media is reporting as many as 80,000 salmon worth a total of EUR2.4 million ($2.8 million) were killed as a result of the bloom. The biomass on site prior to the event was 2,267 metric tonnes, a Mowi spokesperson confirmed to IntraFish*" https://www.intrafish.com/salmon/toxic-algae-bloom-causes-big-losses-at-mowi-ireland-salmon-farming-sites/2-1-1094592
- "*Salmon farming giants AquaChile and Mowi are the latest victims of an algal bloom outbreak in Chile's Aysen region that has now claimed 2,666 metric tonnes of salmon biomass. By Wednesday, 2,177 metric tonnes of dead fish had been cleared away at sites in the region operated by AquaChile, Mowi Chile, Blumar and Salmones Pacific Star, a division of Salmones Austral, according to Chile's National Fisheries and Aquaculture Service (Sernapesca).*" https://www.intrafish.com/salmon/salmon-farming-giants-aquachile-and-mowi-are-the-latest-to-fall-victim-to-algal-bloom-outbreak/2-1-1145605
- In some other areas colder water temperatures because of broken off melting icebergs that float southwards. Cooler water might result in slower-growing Salmon that take less feed.

Expected but above all unexpected inventory losses cause bottlenecks in the supply of Salmon and lead to rising purchase prices, which cannot always be passed on directly to customers. In this respect, there is a direct correlation with profitability in certain areas of the value chain.

3.2 Major financial constraints and reliability

In addition to direct and indirect impacts of climate change, cost increases for companies resulting from political measures to reduce climate change and temperature increases were mentioned in the interviews: Keyword energy taxes and politically forced measures to reduce GHG emissions by introducing e.g. new filtering technologies.

Beside raw product costs, labour costs and rental costs, the costs for energies such as electricity, water/wastewater and fuel are the fourth column in the costs structure of the Salmon PH sector. In this respect, it is not surprising that all stakeholders stated that they try to minimise energy use in many areas. However, the main motive behind this was almost always the associated cost reduction in order to remain competitive.

In the discussion with the stakeholders, most of all the independent ones (A - D) that buy from the Salmon farms and sell to the retail chains, another point was mentioned that causes many problems and worries for the future and damages the financial resilience of those companies more and more.

Because they are captured between the oligopoly of the Salmon farms on one side and the retail chains oligopoly on the other side they have to live with small margins and high risks. Usually those companies, most of them making over 50 % of their business with Salmon, buy the raw product in a mix of fixed contracts and spot market purchases to stay competitive against vertically integrated companies. Usually, the payment terms to the supplier of the independent ones are shorter than the payment terms to their retail customers, many of them always postponing price increases on the supplier side by several weeks. Very often the independent processor has to pay a higher price for the raw material for weeks than he gets paid by the retail chain customer.

Companies in the salmon processing sector, especially salmon smokehouses, are very dependent on a regular and predictable supply of raw material. To put it exaggeratedly: If no salmon arrives (because there are problems in the country of origin, for example), the factory stands still. There are almost no alternatives to the product Atlantic salmon, but of course there are different areas of origin between which one can switch - at least a little.

Companies that trade in fish or other food products are much less dependent on salmon than the salmon processors described above. If salmon is not available, other seafood products or even meat, vegetables and other foodstuffs can still be bought and sold.

Formulated as a rule, the further a stakeholder in the value chain is from the origin of salmon, the lower its dependence on that specific product and usually the higher its resilience.

3.3 Stakeholders’ perceptions

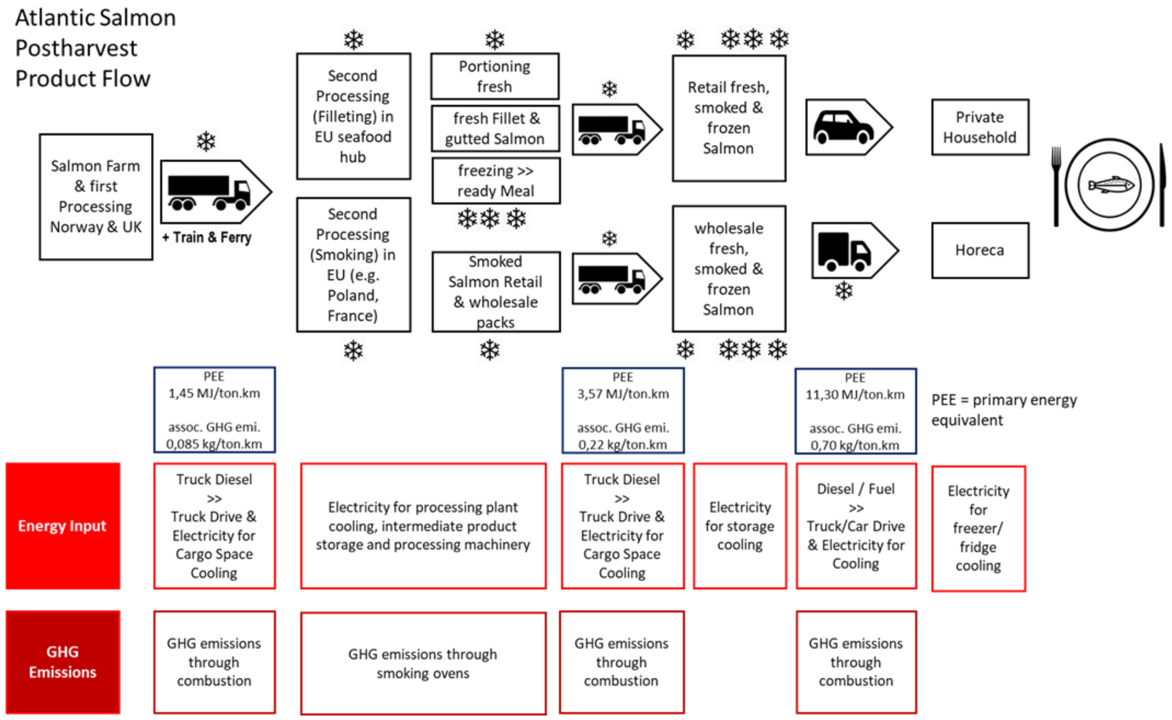
Several stakeholders discussed a hypothetical danger for the distant future resulting from a fundamental change in breeding conditions in the North Atlantic, for example if there were a massive warming of the world's oceans because the Gulf Stream failed to materialize.

Another stakeholder mentioned the development that farmed Salmon becomes increasingly “vegetarian” in its diet, resulting in changes in its taste, smell and general quality. The stakeholder expects that there is a risk that the consumer might be less satisfied with Salmon in the future.

There is an elephant in the room: Atlantic Salmon farmed in RAS systems that are located near to the value adding or consumption areas and require far less transport compared to the current situation. Most of the stakeholders believe that this will be an important part of the future; they cannot foresee when this will happen, but not yet in the next years. While there are many Salmon RAS with hundreds of thousands of tonnes yearly output in project planning or in production phase at the moment all over the world the already existing small- and mid-scale Salmon RAS still suffer from "childhood diseases" that regularly manifest themselves in partial or complete loss of life stock. Also, the ”climate balance” of those in-door RAS compared to conventional net farming in North Atlantic is still unclear: “Will the planned massive shortening of transport routes save as many emissions as are created on the other side by the necessary cooling/heating/water circulation in the RAS?”.

4 Greenhouse Gas Emissions

4.1 GHG emissions in the value chain



Preliminary remark: Being asked in the interviews where there would be the main energy consumptions and GHG emissions for Atlantic Salmon in the PH sector all stakeholders mentioned the same two areas: Salmon transport and keeping Salmon cooled.

The PH Atlantic Salmon sector is characterized by long distance transports and a product storage of usually 1 – 3 weeks – both with a permanent cooling between farm and consumer's plate.

In these 1 – 3 weeks between first processing and use by the consumer the Salmon is trans-ported through Europe and changes its state e.g. from whole gutted Salmon to a packed Salmon fillet portion or a small pack of smoked Salmon.

Most Atlantic salmon is transported fresh and chilled (0 – 2°C.). Commonly, single-variety truckloads of about 20 tonnes of product (whole salmon or salmon fillets) are transported over-land via Sweden, sometimes with a shortcut by ferry, saving a few hundred kilometres of land transport. So, with more than 800,000 tonnes of imported salmon, we are talking about 40,000 truckloads from Northern Europe that are driven refrigerated throughout Europe to be processed in Poland, the Baltics, France, Germany or Spain, for example, and then consumed somewhere else in Europe.

What was mentioned by all stakeholders interviewed were climate change-related developments in the countries of origin of the Atlantic salmon, resulting from changes in the temperature of the water and changes in the salinity of the water. These changes lead to necessary measures in the country of origin, which result in cost increases for the product. These are passed through the value chains and make the product more expensive for the end consumer. In addition, cost increases for companies resulting from measures to reduce climate change and temperature increases were mentioned: Keyword energy taxes (see section 2.1).

Some Salmon stakeholders mentioned that the Salmon farmers, most of them in Norway, are dealing with issues such as sea lice and algal blooms, that are probably related to climate change (see section 3.1) but that the need or will to reduce GHG emission in Norway is not very strong. A probable cause for this is the current profit situation which is excellent for the farms and the insecure and small output for the farms – compared to the emissions generated during transport which is not in the responsibility of the farms.

In this respect, it is not surprising that all stakeholders stated that they try to minimize energy use in many areas. However, the main motive behind this was almost always the associated cost reduction in order to remain competitive.

The stakeholders interviewed were not in a position to measure or calculate their own exact energy use per ton of product and an associated emission of greenhouse gases in their own company as well as in the upstream and downstream stages of the value chain. There seems to be less of a lack of will than of ability to do so.

So far, stakeholders have not felt any explicit pressure from their customers to submit a "supplier carbon footprint" for certain products. The initiative to take action to improve the carbon footprint has almost always come from the stakeholders themselves.

But all stakeholders mentioned that they (and their upstream and downstream) PH chain partners introduced measures to become more energy efficient what usually also results in a decline of GHG emissions.

Those measures came from the following fields:

1. Own on-site power generation by means of solar energy or wind power in order to reduce the share and cost factor of purchased energy. Typical examples are solar panels on factory roofs. In some cases, state subsidy programs have also been used for this purpose.
2. Use of intelligent heat exchange systems that simultaneously provide waste heat for heating, for example, when generating cold, or produce cold for cooling buildings when generating heat. Those systems were found in the processing industry, larger wholesalers and larger retailers.
3. Significantly better building insulation, especially for cold rooms and freezers.
4. More environmentally friendly refrigeration (CFC-free) through the use of new refrigerants such as CO_2 or sole glycol.
5. Use of refrigeration units closed with doors (for plus and minus cooling) instead of the open refrigeration units used in the past, which entailed high cooling losses.
6. Significant reduction in fuel consumption and exhaust emissions through renewal of the vehicle fleets.
7. Optimization of plastic consumption for consumer packaging through better, mostly thinner films that require less fossil raw materials. However, less packaging does not usually lead to lower costs.

<u>Calculation examples</u>

There are hundreds of different ways how Salmon moves from the farm to the consumers plate and how it is processed to very different products with different yields, also stored in different cooled environments for different durations.

The following table shows some sections of this journey with the energy consumption and GHG emissions attributable to them.

		Factor:		1,45 MJ/ton-km	0,0848 kg/ton-km		
Transport Salmon from Origin Norway to EU		full load truck 32 tons+		x 1,2 (refridgerated transport)			
Start	End	Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Bergen/Norway	Bremerhaven/Germany	1.560	20	54.288	3.175	2714,4	158,7
Bergen/Norway	Hamburg /Germany	1.390	20	48.372	2.357	2418,6	117,9
Bergen/Norway	Frankfurt/Germany	1.600	20	55.680	2.714	2784,0	135,7
Bergen/Norway	Urk/Netherlands	1.780	20	61.944	3.019	3097,2	150,9
Bergen/Norway	Ijmuiden/Netherlands	1.880	20	65.424	3.188	3271,2	159,4
Bergen/Norway	Oostende/Belgium	2.050	20	71.340	3.477	3567,0	173,8
Bergen/Norway	Boulogne-sur-mer/France	2.180	20	75.864	3.697	3793,2	184,9
Bergen/Norway	Paris-Rungis	2.330	20	81.084	3.952	4054,2	197,6
Bergen/Norway	Milan/Italy	2.490	20	86.652	4.223	4332,6	211,2
Bergen/Norway	Venice-Mestre/Italy	2.640	20	91.872	4.477	4593,6	223,9
Bergen/Norway	Vigo / Spain	3.560	20	123.888	6.038	6194,4	301,9
Bergen/Norway	Madrid /Spain	3.580	20	124.584	6.072	6229,2	303,6
Bergen/Norway	Warsaw /Poland	1.990	20	69.252	3.375	3462,6	168,8
Bergen/Norway	Gdansk/Poland	1.800	20	62.640	3.053	3132,0	152,6

		Factor:		x 1,2 (refridgerated transport)			
		full load truck 32 tons+		1,45 MJ/ton-km	0,0848 kg/ton-km		
Transport Salmon from Smokehouse Poland to EU		Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Gdansk/Poland	Hamburg/Germany	790	20	27.492	1.608	1374,6	80,4
Gdansk/Poland	Frankfurt/Germany	1.080	20	37.584	2.198	1879,2	109,9
Gdansk/Poland	Cologne/Germany	1.110	20	38.628	2.259	1931,4	113,0
Gdansk/Poland	Munich/Germany	1.120	20	38.976	2.279	1948,8	114,0
Gdansk/Poland	Vienna/Austria	920	20	32.016	1.872	1600,8	93,6
Gdansk/Poland	Zurich/Switzerland	1.380	20	48.024	2.809	2401,2	140,4
Gdansk/Poland	Urk/Netherlands	1.150	20	40.020	2.340	2001,0	117,0
Gdansk/Poland	Brussels/Belgium	1.290	20	44.892	2.625	2244,6	131,3

		Factor		x 1,2 (refridgerated transport)			
		full load large truck		2,79 MJ/ton-km	0,1699 kg/ton-km		
Transport Salmon from Smokehouse Northern France to French Cities		Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Boulogne-s.-Mer	Paris	280	12	11.249	1.142	937,4	95,1
Boulogne-s.-Mer	Lyon	760	12	30.534	3.099	2544,5	258,2
Boulogne-s.-Mer	Bordeaux	840	12	33.748	3.425	2812,3	285,4
Boulogne-s.-Mer	Marseille	1.080	12	43.390	4.404	3615,8	367,0

		Factor:		x 1,2 (refridgerated transport)			
		0		3,57 MJ/ton-km	0,2199 kg/ton-km		
Transport Salmon from central store house retail to retail outlet		Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Central store	very near	20	10	857	106	85,7	10,6
Central store	near	50	10	2.142	264	214,2	26,4
Central store	medium	100	10	4.284	528	428,4	52,8
Central store	far	200	10	8.568	1.056	856,8	105,6

Examples

1. Norwegian Salmon, smoked in Poland, sold in German retail

1 ton gutted Salmon, transported from Bergen/Norway to Gdansk/Poland, converted to 550kg smoked Salmon (includes 10 % packaging), transported to Hamburg (central storing Retail), then transported to retail outlet in 100 km distance.

					per ton		**per weight final product**	
From	to	Truck type	Distance km	weight kg	PEE in MJ	GHG in kg	**PEE in MJ**	**GHG in kg**
Bergen	Gdansk	32 tons+	1800	1000	3132	152,60	**3.132,00**	**152,60**
Gdansk	Hamburg	32 tons+	790	550	3132	152,60	**1.722,60**	**83,93**
Hamburg	retail 100km	mid truck	100	550	428	52,80	**235,62**	**29,04**
						total:	**5.090,22**	**265,57**
						per 1 kg	**9,25**	**0,48**

At the place of final sale (Retail Outlet 100km away from Hamburg) 1,0 kg smoked Salmon needed for transport a PEE (Primary Energy Equivalent) of 9,25 MJ and caused GHG emissions of 0,48 kg. The trip was 2.690 km.

2. Norwegian Salmon, filleted in France (Boulogne-sur-Mer), sold to wholesaler Bordeaux, sold to fishmonger 50 km away

1 ton gutted Salmon, transported from Bergen/Norway to Boulogne-sur-Mer/France, converted to 600kg fresh Salmon fillet (includes 5 % packaging and ice), transported to Seafood wholesaler in Bordeaux, then transported to fish-monger in 50km distance.

					per ton		**per weight final product**	
From	to	Truck type	Distance km	weight kg	PEE in MJ	GHG in kg	**PEE in MJ**	**GHG in kg**
Bergen	Boulogne-sM	32 tons+	2180	1000	3793	184,86	**3.793,20**	**184,86**
BsM	Bordeaux	large truck	790	600	2812	285,43	**1.687,39**	**171,26**
Bordeaux	Fishmonger	mid truck	50	600	214	26,39	**128,52**	**15,83**
						total:	**5.609,11**	**371,96**
						per 1 kg	**9,35**	**0,62**

At the place of final sale (Fishmonger 50km away from Bordeaux) 1,0 kg fresh-Salmon needed for transport a PEE (Primary Energy Equivalent) of 9,35 MJ and caused GHG emissions of 0,62 kg. The trip was 3.020 km.

5 Conclusions

- The PH value chain for farmed salmon is characterised by a multitude of processing steps and trade stages and by long truck transports between the origin of the farmed salmon in Northern Europe (Norway, Scotland, Ireland, Faroe Islands, Iceland) and the final consumption somewhere in the EU. During the usual period of one to four weeks between slaughter in the country of origin and consumption as a fresh or smoked product, the salmon usually travels between 2,500 and 3,500 km in a refrigerated vehicle, interspersed with refrigerated storage before processing steps and final sale.
- Even though the mostly automated processing of the salmon and its refrigerated storage in the factories and trade stages requires electrical energy, it is mainly the long transport in medium and large trucks powered by combustion engines that account for most of the fossil energy consumption, which also leads to greenhouse gas emissions.

- In order to reduce the enormous energy demand and the associated GHG emissions, the distance (=transport time) between salmon farm, processing and final consumption would ideally have to be reduced. This is, of course, a hypothetical discussion, since neither the location of the salmon farms, nor the currently existing highly specialised processing platforms, nor the consumers spread all over Europe can be spatially shifted. On the contrary, it is likely that the location of salmon farms will move northwards away from EU consumers rather than closer to them.
- Whether and when land-based RAS aquaculture will be able to minimise these transport effects remains to be seen, once these facilities have overcome their teething problems and are producing regular output.
- Another possibility to reduce the quantities of salmon transported from origin, and thus also the number of lorry transports required, would be to increase the level of processing at origin. While currently the vast majority of salmon is imported head on gutted (HOG) into the EU and only a small part is already filleted, a basic filleting at origin would of course be theoretically conceivable. This could - theoretically - reduce the transported volume by about 1/3; with over 750,000 tonnes, this would be approximately 250,000 tonnes, which in turn would correspond to 12,500 lorry transports over more than 1,500 km. It should be noted, however, that most processors and traders deliberately choose to fillet as soon as possible before processing, as the spoilage of a fillet is faster than that of a HOG fish. Faster spoilage leads to a shorter shelf life and thus higher discard losses in later stages of the shelf-life chain. In this respect, this approach is more of a pipe dream than something that can be practically implemented in the PH sector.
- Nevertheless, there is reason to expect that, despite the developments mentioned above, the energy demand and GHG emissions of the PH sector for farmed salmon will tend to reduce. There are a number of "small" measures and developments to achieve this:
    - Truck fleets are being progressively modernised, resulting in lower fuel consumption and GHG emissions.
    - Small and less energy-efficient processing units can no longer compete economically and are being replaced by larger and more efficient units.
    - More climate-friendly technologies are used for refrigeration, both during transport and storage before processing and sale (CO_2, sole glycol instead of CFCs).
    - The electricity mix used for stationary refrigeration is gradually decarbonised.
    - Modern stationary cooling systems, whether cold stores or refrigerated shelves in supermarkets, require less energy because they are better insulated.
    - Plastic packaging materials (films, trays) contain more and more recycled content or are lighter than in the past.

5.1 Gaps in knowledge and information

There are a multitude of unknowns and uncertainties when it comes to the description of the PH sector and to calculation of GHG emissions in it:

- The origin of the Salmon “gets lost” in the EU statistics once the Salmon has entered EU. It is not possible to find out on the level of sales to the consumer where the Salmon originally came from.
- It is unclear where exactly which processing steps take place, e.g. filleting, portioning, freezing.
- The volume of Salmon that goes into ready meals cannot be calculated.
- The yields at Filleting (skin-on fillet or skin-off-Fillet) or smoking can be very different but are unknown. Also unknown is the share of skin-on fillet (- 10 % weight) and skin-off-Fillet in the relevant EU-Statistics number.

- It is unknown how much energy is needed to cool Salmon in storehouses and where this energy is coming from (Nuclear power vs. Hard coal-fired power generation vs. Wind Energy). Also unknown is the length of stay of the products in the different transport vehicles and store houses.
- The temperature requirements for cooled products are different within the EU countries.
- The exact routes from Origin Norway/Scotland/Ireland/Iceland/.. to EU are unknown (distance unknown), the type of used truck is unknown, also unknown is the share and routes of trucks they do a part of the trip by ferry (usually to Hirtshals/Denmark).
- The location of the Salmon farm that sullies the seafood hub (Norway, Grimsby,..) is unknown. But for sure there will be another energy absorbing and GHG emissions causing transport within the country of origin, in Norway that can be many hundred kilometres.
- In some figures of the Eurostat statistics such as fresh Salmon fillet and frozen Salmon fillet there is not only Atlantic Salmon but also different Pacific Salmon species included.
- The size of the trucks that are used for the transport on the different routes is unknown, also the specific fuel consumption and the related GHG emissions.

6 References

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Supplementary 1: detailed trade-flows for salmon by product type

1. EU Extra Imports all EU 27 countries: Value
2. EU Intra Imports all EU 27 countries: Value
3. EU Extra Imports all EU 27 countries: Volume
4. EU Intra Imports all EU 27 countries: Volume

Table 1.1 EU Extra Imports all EU 27 countries: Value

Value	EU Extra Imports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	4.589.903.726 €	50.947.329 €	744.564.274 €	66.093.714 €
Belgium	1.635.699 €	920.976 €	34.443.420 €	2.376.499 €
Bulgaria	0 €	104.451 €	152.335 €	35.029 €
Czechia	365.354 €	6.127 €	18.093.931 €	11.946 €
Denmark	927.612.512 €	12.512.216 €	136.062.248 €	2.728.661 €
Germany	110.379.200 €	4.415.161 €	27.824.581 €	12.870.304 €
Estonia	1.216.592 €	712.805 €	1.423.618 €	0 €
Ireland (Eire)	18.413.722 €	218.592 €	7.123.182 €	391.977 €
Spain	4.044.177 €	10.410.382 €	5.315.348 €	394.547 €
France	206.553.489 €	744.135 €	38.033.105 €	13.666.271 €
Croatia	12.208 €	0 €	170.655 €	604.559 €
Italy	6.621.767 €	1.273.548 €	1.758.614 €	21.959.289 €
Cyprus	365.070 €	296.481 €	0 €	30.837 €
Latvia	2.697.555 €	141.186 €	6.911.105 €	61.398 €
Lithuania	3.364.955 €	5.009.777 €	6.265.028 €	23.841 €
Luxembourg	350.217 €	0 €	1.273.440 €	832.395 €
Hungary	125 €	0 €	715.072 €	0 €
Malta	10.407 €	0 €	0 €	201.082 €
Netherlands	80.107.266 €	1.380.263 €	102.776.065 €	639.591 €
Austria	529.229 €	216 €	463.652 €	139.273 €
Poland	245.024.374 €	2.578.668 €	138.867.411 €	148.165 €
Portugal	12.542 €	169.723 €	3.225.980 €	611.974 €
Romania	0 €	233.771 €	89.637 €	0 €
Slovenia	68 €	0 €	46.409 €	0 €
Slovakia	200 €	2.057 €	87.257 €	0 €
Finland	183.140.367 €	10.247 €	1.962.969 €	0 €
Sweden	2.777.029.370 €	9.532.229 €	211.376.905 €	5.250.706 €
Greece	20.417.264 €	274.321 €	101.659 €	2.852.484 €

Table 1.2 EU Intra Imports all EU 27 countries: Value

Value	EU Intra Imports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	2.533.611.069 €	117.025.196 €	657.164.259 €	1.186.350.857 €
Belgium	29.259.800 €	5.521.424 €	116.595.691 €	95.878.409 €
Bulgaria	4.392.765 €	181.474 €	1.330.731 €	1.829.372 €
Czechia	49.456.020 €	1.637.698 €	25.099.927 €	6.524.773 €
Denmark	12.772.716 €	29.742.673 €	9.305.371 €	35.800.559 €
Germany	274.820.955 €	11.449.336 €	158.684.691 €	527.380.925 €
Estonia	28.226.936 €	5.070.879 €	1.672.114 €	955.587 €
Ireland (Eire)	11.593.696 €	2.586.902 €	1.004.665 €	6.241.058 €
Spain	239.794.192 €	3.361.578 €	26.630.482 €	24.304.739 €
France	547.534.642 €	5.137.758 €	109.412.217 €	108.635.627 €
Croatia	3.003.715 €	23.751 €	1.013.827 €	1.977.071 €
Italy	271.452.414 €	5.459.245 €	35.395.464 €	220.757.570 €
Cyprus	1.239.403 €	376.679 €	314.801 €	645.382 €
Latvia	37.090.461 €	1.363.891 €	5.476.325 €	1.708.348 €
Lithuania	225.464.462 €	1.490.357 €	9.313.215 €	949.400 €
Luxembourg	4.267.928 €	223.571 €	7.245.127 €	6.597.439 €
Hungary	5.416.578 €	450.697 €	1.534.971 €	2.838.742 €
Malta	1.363.648 €	69.341 €	426.969 €	1.723.381 €
Netherlands	61.610.917 €	1.482.134 €	23.005.433 €	32.923.264 €
Austria	15.935.586 €	708.563 €	15.455.162 €	47.703.874 €
Poland	582.826.977 €	10.584.481 €	62.432.986 €	14.820.243 €
Portugal	49.147.739 €	1.992.184 €	8.005.386 €	11.307.028 €
Romania	21.322.731 €	2.694.688 €	4.670.696 €	3.760.727 €
Slovenia	2.402.728 €	117.037 €	1.556.194 €	1.997.800 €
Slovakia	1.109.274 €	226.565 €	7.184.710 €	1.904.954 €
Finland	32.389.083 €	75.672 €	10.142.833 €	3.511.499 €
Sweden	2.362.889 €	2.817.818 €	12.594.468 €	12.865.661 €
Greece	17.352.816 €	22.178.802 €	1.659.805 €	10.807.425 €

Table 1.3 EU Extra Imports all EU 27 countries: Volume

Volume in tons	EU Extra Imports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	776.022	12.232	45.590	13.824
Belgium	219	148	1.025	66
Bulgaria	0	35	0	0
Czechia	49	1	0	0
Denmark	157.575	2.221	5.651	2.770
Germany	18.003	859	1.497	3.553
Estonia	324	794	0	14
Ireland (Eire)	3.024	40	319	43
Spain	582	2.506	281	141
France	31.188	114	1.774	759
Croatia	2	0	0	0
Italy	856	117	149	6
Cyprus	43	48	0	0
Latvia	525	83	361	18
Lithuania	586	1.296	0	578
Luxembourg	41	0	106	0
Hungary	0	0	0	0
Malta	1	0	0	0
Netherlands	13.235	251	178	3.506
Austria	75	0	52	535
Poland	41.129	602	1.004	1.460
Portugal	2	49	12	14
Romania	0	63	0	12
Slovenia	0	0	0	0
Slovakia	0	0	0	0
Finland	32.280	6	755	0
Sweden	473.365	2.945	32.375	342
Greece	2.920	54	0	0

Table 1.4 EU Intra Imports all EU 27 countries: Volume

Volume in tons	EU Intra Imports main Salmon categories			
	whole fresh	whole frozen	fresh fillet	smoked
Country	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020	Ø 2015-2020
EU 27	413.785	19.899	70.021	86.629
Belgium	4.164	711	10.933	6.409
Bulgaria	684	49	156	144
Czechia	7.572	273	2.741	520
Denmark	1.920	5.199	1.130	3.178
Germany	43.349	1.625	16.141	38.599
Estonia	5.311	1.745	258	118
Ireland (Eire)	1.845	388	122	388
Spain	38.514	608	3.076	2.319
France	87.964	775	12.096	7.856
Croatia	449	4	107	113
Italy	42.200	837	4.087	15.702
Cyprus	168	51	48	48
Latvia	6.546	623	724	186
Lithuania	37.296	693	1.192	114
Luxembourg	548	19	568	327
Hungary	855	57	143	226
Malta	204	7	34	158
Netherlands	9.659	175	1.738	2.294
Austria	2.193	100	1.343	2.782
Poland	102.055	1.900	8.352	1.178
Portugal	7.559	292	760	753
Romania	3.487	470	517	287
Slovenia	335	19	167	128
Slovakia	179	33	813	679
Finland	5.832	17	1.261	255
Sweden	318	337	1.371	858
Greece	2.578	2.890	144	1.011

CASE STUDY 7: ROUNDFISH – RED MULLET (*MULLUS SURMULETUS*), GURNARD (*CHELIDONICHTHYS LUCERNA*) AND SQUID (*LOLIGO VULGARIS*) – NETHERLANDS, BELGIUM AND FRANCE

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Squid (Loligo vulgaris)

Photo: Oscar Bos, WUR

Red mullet (Mullus surmuletus)

Photo: Ingeborg de Boois, WUR

Gurnard (Chelidonichthys lucerna)

Hoekstra, G., Deetman, B., Turenhout, M., Van den Burg, S., Vernooij, V., Broeze, J. & Guo, X.

1 Background

Climate change is associated with rising water temperatures in the North Sea and displacement of fish species. Rising water temperature resulted in higher abundance of squid and other species like sardine in the North Sea (Van der Kooij et al, 2016). According to interviewees, increasingly red mullet and gurnard are landed by Dutch and Belgian fishers (beside squid). These "new species"[15], were not available in similar quantities to Dutch and Belgian fisheries earlier on (Pinnegar et al, 2017). They are highly valued by the EU market, in particular squid (*Loligo vulgaris*) with average prices ranging between 7 and 10 euro per kilogram sold as whole fresh at Dutch, Belgium and French fish auctions. Traditional flatfish species such as European plaice are sold at fish auctions between 1,80 and 2,50 euro per kilogram.

The high quality and freshness of the landed squid, red mullet and gurnard is due to the flyshoot/purse seine fishing technique. Contrary to other trawling fishing techniques the fish does not spend a lot of time in the fishing net. This results into less damage to the fish and thus higher quality and freshness, according to interviewed stakeholders. Attracted by commercial prices, there is an increase in fishing effort by purse seine/flyshoot vessels in the southern part of the North Sea targeting these new species.

For this CS three fish processors and one fish auction are interviewed in person. Unfortunately, the envisaged telephone with a French wholesaler did not succeed as it was hard to accomplish this interview in time (before summer 2022 and fitting within the company their time schedule). As a work-around a Belgian retailer was interviewed.

2 Value Chain

2.1 Value chain description

In Figure 1 the supply flows of squid, red mullet and gurnard s This strong increased energy old by Dutch processors are visualised. The majority of the sold volumes of these new species by Dutch fish processors are presented and preserved as a whole fish, fresh or frozen packed. Most of the sold fresh volumes are destined for the HORECA and retail in Italy, Germany, Spain, France and Belgium.

For squid, the estimated export volumes from the Netherlands in 2020 were around 3700 tonnes (CBS, edited by Wageningen Economic Research), divided by the following destinations:

- Italy: 1.400 tonnes (majority fresh preserved – food service)
- Germany: 500 tonnes (majority frozen preserved - retail)
- Spain: 400 tonnes (equally fresh and frozen preserved)
- France: 400 tonnes (majority frozen preserved)
- Belgium: 200 tonnes (majority frozen preserved)

These volumes include own domestic production and imports from (third) countries.

For species red mullet and gurnard export data are not available. In 2020, 2700 tonnes fresh gurnard were landed by Dutch vessels (excluding landings by British, Belgian and French vessels in Dutch harbours). Landings of red mullet were 1800 tonnes and of squid 1.200 tonnes (Wageningen Economic Research).

[15] These species (squid, red mullet and gurnard) are described as "new species": they are not entirely new in the waters of North Sea, however the abundance of their biomass stocks is increasing in northern waters of EU waters as a result of rising sea water temperatures (Pinnegar et al, 2017). These "new species" are an opportunity for local PH stakeholders to introduce these upcoming species to their existing market.

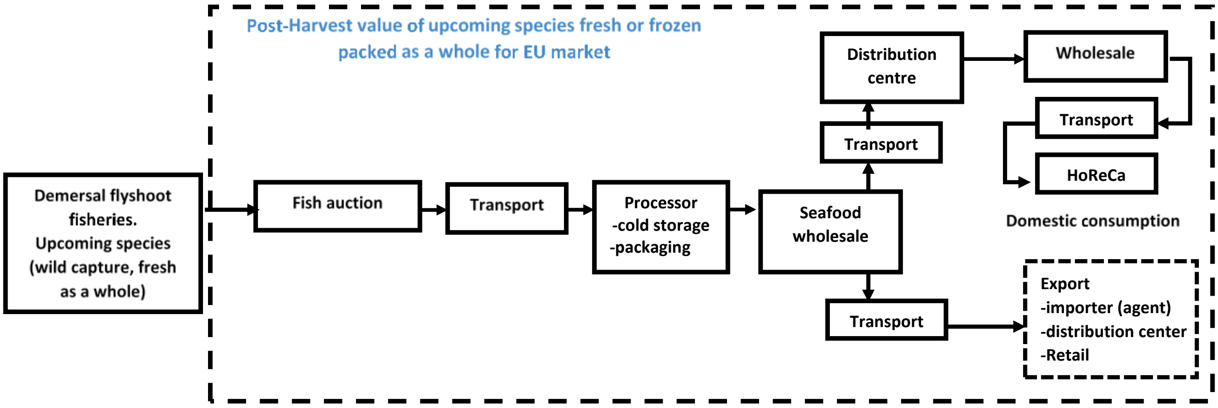

Figure 1. Postharvest value chain of new species. Source: CBS (edited by Wageningen Economic Research)

3 Resilience

3.1 Physical and financial resilience

According to the consulted stakeholders, the main perceived challenge by the PH chain of new species at the moment is the strongly increased energy prices due to the Ukraine war. Despite often seafood processors for activities such as freezing, canning, battering and fileting are large energy users, the PH of 'new' species sells the majority of products as a whole fish. Processors which freeze and glace fish products are in general large energy consumers. Fresh preservation and packaging of new species requires minimum energy consumption as hardly processing (filleting and freezing by machine) is needed.

Interviewees expect that due to climate change and urgency from EU policy to combat this, energy prices will more and more incline for the nearby future. The currently high energy prices stimulate investments into renewable energy such as solar panels at the roof of production factories. However, according to the consulted stakeholders, insurance companies discourage the installing of solar panels by a foreseen large risk of damage by fire or storms. Insurance companies are not willing to have the liability to pay the damage of an entire factory including refrigerated stocks of fish products in case of fire due to burning solar panels.

The PH chain is, in their own perspective, largely resilient to climate change, except for the uncertainty of landed volumes by fisheries fleet. In case the landed volume will decrease due to climate change driven events at sea, processors expect the loss of supply by local fishers. This could be partly compensated by imports.

3.2 Major financial constraints and reliability

No major financial constraint is found in the scarce relevant literature related to the new species of squid, red mullet and gurnard.

3.3 Stakeholders' perceptions

The insight provided by consulted stakeholders during interviews were often more market or political driven rather than direct climate change related. However, some insights do have links with climate change driven events that could impact the resilience of PH chain.

- Still much is unknown about the impact of climate change on the natural ecosystem of the North Sea and therefore the effects on the PH value chain.
- Fresh water consumption is large for fresh and frozen fish processing. During heat in summertime, fresh water could become scarce. This would decrease the productivity and resilience of fish processors in EU. Fresh preservation and packaging of fish (e.g. squid, red mullet and gurnard) requires minimum energy consumption as hardly processing (filleting and freezing by machine) is needed.
- Since fresh markets are familiar with fluctuating daily prices of fresh landed fish, cost inflations could easier pass on by processors compared to the frozen fish products for retail market
- Some of the consulted Dutch processors have already invested into modern cold storage capacity. Therefore, summer heats do not affect that much the ability to refrigerate the fish products.
- Not all PH companies are able to invest in panels at the roof of their production buildings. Insurance companies discourage the installing by a foreseen large risk of damage by fire or storms according to interviewees.
- Large processors of frozen fish product are consuming much more energy compared to fresh fish processors. Frozen fish processors could perceive challenges (e.g. increased costs) to refrigerate the frozen fish during summer heats. Processors who have invested into modern refrigerate capacity will experience less issues.
- In case of smaller volumes of landed fish, depending on the type of contract with EU retail, prices could sometimes not be adjusted. Passing on cost inflation is therefore not always a possibility.
- Seasons for fishing and abundance for gurnard and red mullet are getting longer. Squid, mullet and gurnard are moving further north. Red mullet and gurnard can be caught over a longer period of time, is the experience of consulted processors. Previously, the fishery ended at het end of February; now the fishery continues until mid-April. This helps to allocate production capacity and intensity for PH supply chains next to the short fishing season and intense production period for squid.
- New species are moving towards northern waters. They originate from traditional habitats of the Gulf of Biscay and Mediterranean seas into the southern North Sea.
- Current high energy prices stimulate investment in renewable energy.
- Organizing rest and waste streams could help to stimulate recycle and circular use of it.
- Creating joint ventures with local producers of fish or aquaculture species in foreign countries. These partners could immediately freeze the fish at the place of origin to shorten logistic chains, as end markets are often nearby while specialized processing is found further away by outsourcing the freezing activity.
- Remediation of fishing vessels (reduction of the Dutch fishing fleet size) could be a threat to the PH chain as landings are shrinking. Similar holds for reduced motivation of EU fishermen to invest into innovative and sustainable fishing techniques: due to increasing legislative restrictions, they do not see a perspective for their future which could quite the supply fresh fish to the PH chain.
- More frequent stormy weather could result into disruption of supply (via disturbed landings of fisheries or transport via trucks). This would be a problem financially and from a food safety and waste perspective, for the fresh markets as they cannot store perishable fresh fish for any longer than single or multiple days.
- The demand by EU market for squid (*Loligo vulgaris*) is currently larger than the supply. For the fresh market of squid there are not many substitutes available with similar high quality and freshness of the squid caught by purse seine/flyshoot in British Channel.

	Helpful	Harmful
Internal origin (attributes of the organizations)	Strengths • Fresh preservation and packaging of fish (e.g. squid, red mullet and gurnard) requires minimum energy consumption as hardly processing (filleting and freezing by machine) is needed • Fresh markets delivering for foodservice are familiar with fluctuating daily prices (no long-term supply contracts) of fresh landed fish, cost inflations (also related to climate change as stormy weather that results into scarcity/less landings by fisheries) could easier pass on by processors compared to the frozen fish products for retail market • From the consulted Dutch processors some have invested already into modern cold storage capacity. Summer heats do not affect that much the ability to refrigerate the fish products	Weaknesses • Still much is unknown about the impact of climate change on the natural ecosystem of the North Sea and therefore the effects on the PH value chain for 'new species' • Fresh water consumption is large for fresh and frozen fish processing. During heats in summertime, fresh water could become scarce. This would decrease the productivity and resilience of fish processors in EU • Not all PH companies are able to invest into installing solar panels at the roof of their production buildings. Insurance companies discourage the installing by a foreseen large risk of damage by fire or storms. • Large processors of frozen fish product are consuming much more energy compared to fresh fish processors. Frozen fish processors could perceive challenges (eg increased costs) to refrigerate the frozen fish during summer heats. Processors who have invested into modern refrigerate capacity will experience less issues • In case of less volumes of landed fish, depending on the type of contract with EU retail (often frozen in contrary to foodservice e.g. HORECA), prices could sometimes not be adjusted. Passing on cost inflation is therefore sometimes not possible
External origin (attributes of the environment)	Opportunities • Seasons for fishing and abundance for gurnard and red mullet are getting longer and larger at sea. Squid, mullet and gurnard are further north at sea and can be caught over a longer period of time. Previously the fishery ended at het end of February; now the fishery is until mid-April. This helps to allocate production capacity and intensity for PH supply chains next to the short fishing season and intense production period for squid • New species (here: squid, red mullet and gurnard) are moving towards northern waters. From traditional habitats of the Gulf of Biscay and Mediterranean seas into the southern North Sea. • Current high energy prices stimulate investment in renewable energy • Organizing rest and waste streams could help to stimulate recycle and circular use of it • Creating joint ventures with local producers of fish or aquaculture species in foreign countries. These partners could immediately freeze the fish at the place of origin to shorten logistic chains, as end markets are often nearby (Southern Europe, Mediterrean countries) while specialized freezing as processing (Northern Europe) is found further away as harvest companies (Mediterrean countries) often outsourcing this freezing activity	Threats • More frequently stormy weather could result into disruption of supply (via disturbed landings of fisheries or transport via trucks). This would financially, and from a food safety and food waste perspective, be a problem for fresh markets as they could not store perishable fresh fish for any longer than single or multiple days

3.4 Role of management – lessons learned of adopted strategies

PH parties such as flatfish processors and wholesales introduced these 'new' species to the existing EU markets as high quality, fresh and premium fish. This introduction of new species to traditional flatfish market could be perceived as successful adaptation strategy to increase resilience in relation to climate change driven events (displacement of flat fish species such as European plaice outside EU waters). The introduced 'new' species do not belong to the EU quota system, therefore there was no large financial investment for fishing rights (quota) by individual fishers or PH companies needed to catch and supply this new species. For this PH chain no large marketing budgets are available according to interviewed processors. These processors have adapted the strategy of sampling. They provide their current foodservice customers in France, Spain and Italy with a small batch as sample to try these new species. Soon as these customers were convinced of the high quality and freshness of these new products they started to order and purchase larger batch volumes. After the successful management strategy of introducing the new species products to current foodservice customers, the EU retail followed as the new species products became more and more popular among out-of-home consuming customers. This phenomenon is occurring in more food sectors: retail follows trends of the HORECA.

4 Greenhouse Gas Emissions

GHG emissions in the post-harvest chain are related to transportation (fuel use), processing and refrigeration (mainly energy use; with phasing out refrigerants with high GHG impact the contributions from leaking refrigerants is marginalized) and packaging. Also, food losses (indirectly) induce additional GHG emissions since losses induce extra demand for catch and related post-harvest chain emissions. The GHG emissions are estimated for typical post-harvest chains for the products of this case study: typical transportation distances, refrigerated storage durations and packaging solutions. Results show that for squid (with relatively high GHG emissions of catching), losses in the post-harvest chain induce significant GHG emissions.

GHG emissions in the value chain

Broad group of very different species; because of lack of detailed information in literature, here only one case is elaborated as an example.

<u>Fisheries</u>

Understanding GHG emissions for catching the seafood is relevant for this study since losses along the postharvest chain indirectly induce extra demand (thus extra catch).

For the catch of species squid (Loligo vulgaris), red mullet and gurnard no extensive GHG emission study was found in literature. As a work-around GHG emissions of catching and landing these species are derived from fuel use figures for flyshoot fisheries (www.visserijincijfers.nl): about 1 liter fuel per kg fish, which results in GHG emission intensity of 4 kg CO2-eq. per kg landed fish.

<u>Transport from auction to processor</u>

Transportation distances vary between countries and individual company situations; they are estimated at typically 50km. For a large truck, based on data from www.ecotransit.org and EcoInvent GHG emissions associated to this type transport are estimated at 0.20 kg CO2-eq, per ton product per km. Consequently, the GHG emissions related to this transport is estimated at 0.01 kg CO2-eq. per kg

<u>Processing, packaging and storage</u>

Part of red mullet is filleted, others are sold as whole product. Here we describe the produce that are sold as whole fish.

Refrigeration in processing, wholesale and storage: Almost half of the products is traded fresh; others are stored frozen up to a year. Based on typical electricity use for refrigerated storage (Evans et al., 2014) follows climate impact of storage up to 0.09 kg CO2-eq. per kg product.

The product is mostly packaged in eps packaging for hospitality sector. The weight of the eps packaging varies depending on the package size and filling degree, around 0.06 kg eps per kg seafood product. The net climate impact of this packaging adds 0.22 kg CO2-eq per kg seafood (based on GHG emission intensities for eps as reported by ETC-WMGE, 2021 and EcoInvent 3.6).

Distribution transport

Transportation to a distribution centre and retail outlet goes through large trucks. Transportation distances vary amongst the markets, typically 200km to markets in The Netherlands and surrounding countries to typically 1500km to South European markets. Based on 0.20 kg CO2-eq, per ton product per km, the distribution transport contributes 0.04 to 0.30 kg CO2-eq. per kg fish product.

Energy use for refrigeration in the retail display cabinet

(we derived typical electricity use of 0.06kWh per kg per day from a set of direct measurements for various product categories; the actual value however will largely depend on technical design, loading degree and operational use).

Assuming typical shelf period of 3 days follows total refrigeration electricity use of 0.3kWh per kg fish, which induces 0.04kg CO2-eq. per kg product. (this figure actually differs amongst countries because of varying GHG emission intensity per country; we used the EU-average in the calculation).

Effects of losses in retail

Losses in retail are estimated at 7.5% on average for fresh products (supermarket interview). Here we assume that this figure is also valid for this situation. Emissions associated to catching, processing and transporting these lost products are allocated to the actually sold products.

Summary of climate impact

Table 1. Summarized climate impact of described post-harvest chain for fresh and frozen stored fish

Chain stage	GHG emissions kg CO2-eq. per kg final product (fresh product)
transport from auction to processor	0.01
frozen storage	≤ 0.09
eps packaging	0.22
distribution transport	0.04 to 0.30 (average 0.17)
energy use in retail	0.04
effects due to losses	0.33
TOTAL post-harvest	**±0.8**

5 Conclusions

From literature, there is hardly any information about the effect of climate change for the PH chain. From interviews with traditional flatfish processors and one fish auction it became clear that there was a successful management intervention to solve the issue of decreasing landing volumes of European plaice due to displacement (climate change related by rising sea water temperature). These Dutch processors analysed increasing landing volumes year to year of these 'new' species sold at Dutch fish auctions. As landed volumes of flatfish were decreasing due to displacement (rising sea water temperature by climate change) these processors utilized the upcoming trend of higher abundance of squid, red mullet and gurnard in Northern Eu waters and therefore catchers of fishers. These processors started with introducing these fresh squid, red mullet and gurnard to their existing foodservice customers as sample to taste and to try. After these customers were convinced of the high quality and freshness increasing volumes were supplied by the Dutch PH companies to their customers in mainly France, Spain and Italy. As often occurs in food sectors, subsequently to the HORECA the retail started to ask for these frozen and glace 'new' species. The financial and physical resilience of the traditional flatfish PH chain was strengthened by introducing new species to their current market. This CS illustrates how a threat of climate change for one particular species (flatfish, plaice here) could be mitigated by the opportunity of new species that have increasing abundance in local fishing areas due to climate change (rising sea water temperature).

GHG emissions in post-harvest chains for squid are estimated around 0.8 kg CO2-eq per kg food product for squid. Half of this is related to food loss and waste in the distribution/retail phase (because it induces extra catch). For other products of this case study no estimate for catching GHG emissions was found, and consequently the effect of losses cannot be estimated.

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Case Study 8: Roundfish – Whitefish - France

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Sébastien Metz, Marie-Pierre Mommens

1 Background

The French fishing fleet has specialised over the last 50 years in targeting a large variety of fish species, commonly regrouped under the generic term whitefish: sole, plaice, monkfish, hake, whiting, haddock, ling, saithe, turbot or cod are the top species targeted by a large variety of vessels.

Most of these species enter the fresh seafood market, competing with imports of fresh products from North European fisheries (Iceland, Norway, UK, Ireland, Denmark).

2 Value Chain

2.1 Value chain description

This CS will focus on the fresh whitefish sold on fish counters in France. The general flow diagram integrates French-caught products but also imports mainly originated from Northern European countries (Iceland, Norway, UK and Ireland notably). For this CS, we are focusing on one particular type of route, consisting of the processing of fresh fish (mainly filleting) to be sold in fish counters of supermarkets and specialised shops (fishmongers). The supply chain can be described as follows:

- First sale: The French production relies heavily on 37 fish auctions where fish transit, mostly to be sold by adjudication a few hours after landings. Some of the production
- Imports:
- The first steps of PH operations occur in the production country: sorting and fish gutting are always performed before shipping to improve the shelf life of the fish.
- 480 “mareyeurs”, organisations that are buying fish under auctions or directly to fishermen than performing primary processing activities, with many small enterprises (more than half of the mareyeurs have less than 11 employees). Mareyeurs are sorting, sometimes cutting the fish (filets, …).
- Fresh whitefish are imported either whole (head-on gutted), to be processed in France, or in fish filet format. Depending on the actors involved in the supply chain, filleting is performed by the mareyeurs-importers or in supermarkets.
- There are very rarely refreshed products on French counters. Refreshed products tend to be associated with poor quality by consumers, and retailers have not developed any suitable process to counter this belief.
- Due to specific retailers’ requirements, the fresh fish supply chains must operate very fast. There’s rarely more than 24 hours between the first transaction (auctioning or direct sale) and the delivery to supermarkets.

Boulogne-sur-Mer has for example evolved from an important French port partly processing the catch of the local fleets to one of the most important seafood platforms in Europe. In recent years, the ratio between local production and local processing reached a difference of 10: when the landings are close to 30 000 tonnes per year, the seafood hub is estimated to process close to 300 000 tonnes of fish per year.

3 Resilience

3.1 Physical and financial resilience

Historically, primary processing was organised very close to the landing points, in and around the fishing communities. In some ports, processors were situated close to the landing point or the auction to limit the distance travelled between the first sale and the mareyage stage. In some cases, the fish auctions are organised to host several mareyeurs under the same roof, which may be problematic when fish auctions are located right on the quayside where the effect of climate change may be the more pressing such as sea level rise, stronger storms that may happen more frequently

The entire sector relies on the smooth operations of specialised transport companies. The two French leaders are STEF and Delanchy, but regional specialists are also adding options for stakeholders to work with. One of the main challenges for these companies lies in the regular decrease of the average speed of French roads, either in rural areas, where speed limits decreased from 90 km/h to 80 km/h in 2018, but also in urban and sub-urban areas where speed limits are more amore decreasing towards 30 km/h. The decision to lower the maximum speed limits is increasing the time lorries need to reach their final destination, increasing the stress on all stakeholders of the supply chain. As long as retail chains do not revisit their ultra-fresh pledge, this constraint will be the one that is structuring the entire value chain.

4 Major financial constraints and reliability

The fresh fish supply chains are highly dependent of major supermarkets to operate. Supermarkets are aggregating more than half of the sale of fresh fish in France, combining the catch from French vessels and imports mainly from Northern Europe. For most French supermarkets, fresh fish counters are loss leaders: they are a feature that all medium-size and large-size supermarkets must have, but they are seldom profitable. FranceAgriMer evaluates that the profit margin of the fish counters is mostly negative. This low-profit margin for supermarket counters is adding more pressure to mareyeurs that are also experiencing very low-profit margin, which doesn't allow them to invest in

5 Stakeholders' perceptions

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	***Strengths*** • High adaptability of the mareyeur model: new species can be quickly integrated in the process without disruption	***Weaknesses*** • Climate change and GHG reductions are not the most important issues facing the fresh fish supply chains in 2022: disruptions following Brexit, price increases following the war in Ukraine and the consequence of two years of Covid pandemic are more pressing issues • The current model is orientated toward a 24-hour supply chain • A lot of SMEs are processing fresh fish, with limited staff availability to look into climate change issues
External origin (attributes of the environment)	***Opportunities*** • New species are already appearing on the French coast (octopus since 2020) that have been successfully integrated by the mareyeurs	***Threats*** • Diminishing average speed on the French roads • Competition from countries that will have lower environmental standards • French consumers may not appreciate new species (octopus has been mostly exported to Spain)

6 Role of management – lessons learned of adopted strategies

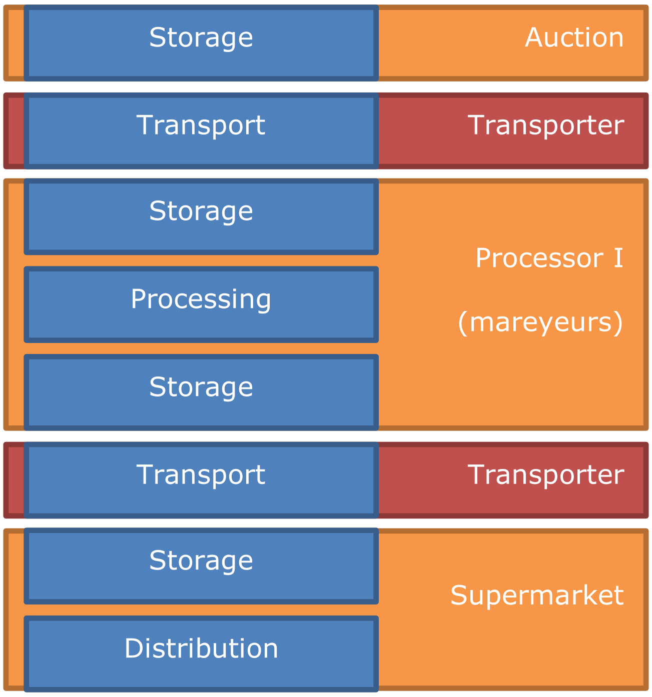
The French national climate change adaptation plan doesn't explicitly cite the PH sector as a critical sector for which specific policies should be implemented at the national level to help businesses adapt to climate change. Such governmental communication doesn't incentivise businesses to take the issue seriously. Incentives have nonetheless been integrated into the design of the national EMFF and EAMFF programmes. Processors must highlight the potential energy reduction and GHG loss reduction when requesting sectoral support for new investments.

7 Greenhouse Gas Emissions

7.1 GHG emissions in the value chain

The French fresh whitefish supply chain is relatively short, involving only a few actors:

1- Auctions where fish is sold by fishermen. Direct sales are possible in the French system, wich means that this stage would be omitted in a GHG.
2- Transport from the auction to the primary processor
3- Primary processing (called mareyeurs in France)
4- Transport from mareyeurs premises to the supermarket platforms, with potential stops in
5- Distribution



7.2 Auctions

Auctions are publicly owned in France. Most of them are managed at the local or regional level. From a GHG perspective, their most important contribution is the refrigeration system used in cold stores and auction halls. Fish is only staying under the auction for a few hours. However, there are no available figures to estimate the level of GHG emissions associated with this step.

7.3 Transport from auction to the primary processor

Most of the primary processors are sourcing fish under multiple auctions, some very close to the processor premises, some more distant. Depending on the distance, the transport may be operated by the processor with small unoptimized vans (not fully loaded) or by a service of regular delivery (neither fully optimised). A fully optimised lorry is estimated to emit 0.20 kg CO2-eq, per ton product per km, but the inefficiencies of this step are increasing the emission coefficient. There is also no record of the distance travelled by each fish lot, which hinders the estimation of GHG emissions at this stage.

7.4 Mareyeurs (primary processors)

Discussion with sectoral representatives led to the conclusion that most of the mareyeurs do not attribute any of their consumptions to particular species, even though some species are only transiting through the mareyeurs shop (live animals: lobster, crab, scallops) when others are sorted, processed (filleted mainly) and packed, implying a higher use of energy and material. Estimating GHG emissions at this stage is not possible at sectoral level.

Wastes are in some cases collected and further processed by companies specialised in co-product extraction, but there is still a significant share of French mareyeurs where wastes are sub-optimally used (compost, energy production). This may have a considerable impact on the total GHG emissions: if wastes are destined for an economic application, the emissions associated with their share of the initial fish weight are transferred outside the seafood value chain. But if the wastes are disposed of or used as a source of energy (in most methodology), the emissions associated with their share of the initial fish remain with the fish products.

7.5 Transport companies

Transport companies usually report GHG emissions ratios combining all their activities. There is a difference between the long hauls and the last kilometres that are not operated by the same type of vehicles. French companies do not provide fuel per kg transported but average fuel consumption per 100 km (depending on the companies, the consumption communicated is close to 30 litres per 100 km) – in most methods,

One important caveat in these ratios is the high variability in the completeness of the shipments: lorries are rarely fully loaded when they operate. To the supermarkets' requests, transport operators are developing a complex timetable of routes linking the major processing hubs (auctions, medium-to-large processors) with transit platforms where packages may be rearranged in different loads to be distributed to supermarkets in less than 24 hours. The current organisation is mainly following the concept of hub and spoke (Figure): transporters visit all processors in an area with specific routes before regrouping all the packages in a grouping platform to ship them in larger lorries to a central platform that is going to reallocate the packages to be sent to regional distribution platforms to reach individual supermarkets.

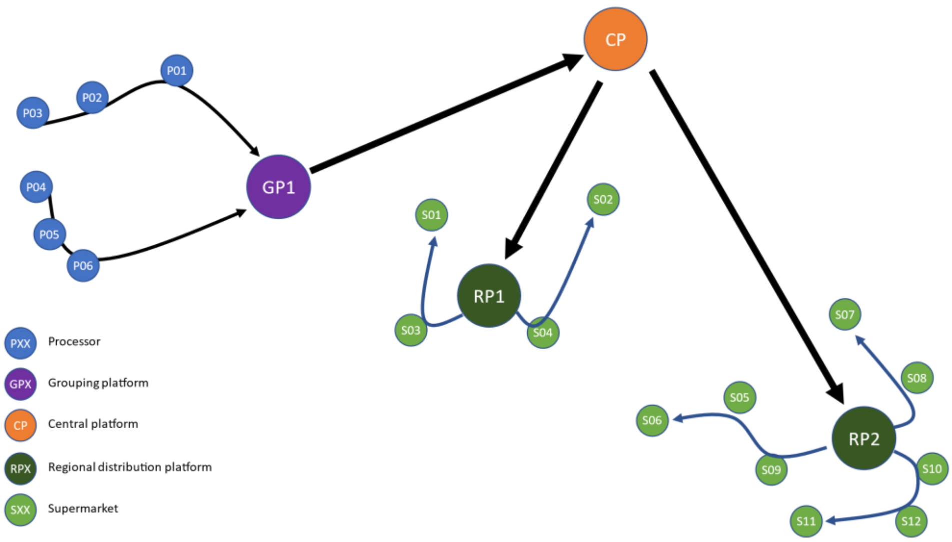


Figure 1: Illustration of the Hub and Spoke principle

This organisation doesn't allow flow to cross (ie flow of empty boxes to come back along the same routes), nor does it permit any delay in the chain. With limited information before landings, the logistic companies can't optimise the load they are going to transport and, therefore, adjust their fleet to the quantities transported. One of the key factors constraining this organisation is the "A for B" rule: to meet the supermarket requirements, transporters need to organise up to three passages in some fish auctions (Guilvinec auction, for example) with none of the three passages loaded at full capacity.

There is no systematic record of the distance travelled nor the load factor of the trucks used, which would allow the evaluation of the GHG emissions associated with this transport.

7.6 Supermarkets and fishmongers

Fresh fish is usually sold within 2 to 3 days in supermarkets. Fishmongers tend to have smaller stocks and sell most of their supply in 1 day. Fish is presented on fish counters refrigerated with ice flakes and stored in cold chambers at night.

8 Alternate distribution systems

Discussion with stakeholders in France led to considering alternate distribution systems from two angles:

- How could existing distribution systems be modified to implement a more decentralised approach
- How could new companies enter the market of delivering fresh fish outside the supermarket/wholesaler system

8.1 More decentralised approach in current distribution system

Options to develop alternative distribution systems are currently hindered by several factors:

- Very limited information exists on the stock available for the entire French fresh seafood supply chain. There are a multitude of silos of information that are not connected: the supermarket chains, the logistic companies and the mareyeurs all understand the fish quantities that are transiting by their premises, but no one has a complete view on all the quantities available for a particular day.
- Several supermarket chains are not centrally organising their fresh seafood buying strategy, but let individual supermarkets decide the range of products they want to offer to customers. This leads the central buying team to act as a marketplace between mareyeurs and individual supermarkets. This kind of organisation increases the inefficiencies in the system as there is no substitution between lots that may cross-travel: a supermarket in Bretagne can order whiting to a mareyeur in Boulogne-sur-Mer, while the supermarket from Boulogne-sur-Mer buys whiting to a mareyeur in Bretagne. An integrated system would switch the orders to minimise travel, sending the product processed in Bretagne to the supermarket in Bretagne while the product processed in Boulogne-sur-Mer would be shipped to the supermarket from Boulogne-sur-Mer, but the current marketplaces do not allow these compensations to happen.
- None of the containers used to transport fish in the current distribution chain is equipped of IoT: trackers, RFID or QR codes automatically detected by scanners are not implemented in the seafood supply chain. This leads to many manipulations with potentially a high level of errors, and it forbids implementing the concept of intelligent supply chains. For some providers, the scannable information doesn’t hold all the information necessary to qualify the content of the package (species, gear, zone of catch…), which would be necessary to implement these intelligent supply chains.

8.2 New entrants in e-commerce

Several actors have developed either business to business or business to consumer platforms to trade fish while eliminating one or two intermediaries. The Covid pandemic has accelerated the development of these solutions. However, these platforms are currently replicating the distribution channels developed by supermarkets, using the major transporting companies for the B-to-B platforms and existing fresh package delivery services for the B-to-C platforms. At this stage, they are not operating substitutions or other optimisations that would increase the efficiency of the distribution chain by minimising the need for transport.

9 Limitations for structural improvements in GHG emissions

Currently, GHG emission reductions are not at the top of the agenda for processors in the fresh seafood value chain. Cost efficiency and timely delivery are the two main factors influencing the current organisation of the fresh fish supply chains in France:

- Fresh seafood is a loss leader for most French supermarket chains: according to FranceAgriMer, the profit margin of fresh seafood counters in supermarket is negative (which has been confirmed by supermarket owners) and profit margin are very low for mareyeurs and processors (which has been confirmed by industry representatives). The recent increase of energy prices has further complicated the situation for several mareyeurs and processors, as supermarket groups have championed their price increase restrain to appeal shoppers. This additional pressure on the different actors of the French fresh seafood supply chain
- Fresh seafood has to be delivered within 24 hours, from auctioning to delivery to the supermarket cold storage. This time frame limits dramatically what can be achieved in terms of GHG reductions when planning

10 Reducing GHG emissions by technical means

10.1 Trends in technological evolutions and industrial strategies

Fresh seafood is primarily packed in polystyrene boxes that are currently not recycled. There are currently two workstreams in the French fresh seafood sector. The associations of mareyeur are participating in research to improve the recycling of polystyrene boxes, while most supermarket chains are developing specific chains of reusable plastic boxes (similar to the boxes used in the fruit and vegetable supply chains). Supermarkets have implemented their use during the last two years, with mixed results. Supermarkets have provided the boxes to mareyeurs and have developed a specific supply chain to collect and wash the box before return to the mareyeurs. There seems to be an important number of boxes not reintegrating into the system as fish counters tend to keep them for other purposes rather than sending them back. There is also no industry standard, each supermarket chain trying its own type of box, which further complicates its management at the mareyeurs level.

10.2 New processing and logistic techniques and their challenges

Primary processing in France is still heavily relying on hand processing. Stakeholders mentioned that automatic filleting machines were not profitable due to the number of species to be filleted daily, which would lead to much downtime needed to adapt the chain specifications for each fish species.

11 Conclusions

The current constraints imposed by supermarket chains are pushing the entire value chain towards an ultra-fresh chain that has to complete all its operations in a 24-hour timeframe, from landings to delivery in individual supermarkets. Several steps must be performed within these 24 hours, notably: auctioning, primary processing, packaging and transport to close to 10 000 supermarkets. At the same time, external constraints are further restricting logistic operators who experience a regular decrease in trucks' average speed adding more pressure to respect the 24 hours window to distribute all fresh fish products.

This organisation leads to several inefficiencies in the system that are detrimental to GHG emissions: route duplications to meet the time requirements, sub-optimal load levels for most trucks in the system, loss of market for auctions that are too far to serve all supermarkets, suboptimal seafood flows. Without the

CASE STUDY 9: ROUNDFISH – EUROPEAN SEABASS (*DICENTRARCHUS LABRAX*) AND GILTHEAD SEABREAM (*SPARUS AURATA*) - CROATIA, CYPRUS, FRANCE, GREECE, ITALY, SPAIN, TURKEY

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions




Photographs Credit: Dr. Yannis Kotzamanis, HCMR

George V. Triantaphyllidis

LIST OF ABBREVIATIONS

Term	Description
ADP	Abiotic Depletion Potential
API	Italian Association of Pisciculture
APROMAR	Asociación Empresarial de Acuicultura de España (Aquaculture Business Association of Spain)
AZAs	Allocated Zones for Aquaculture
EBIT	Earnings Before Interest and Tax
EP	Eutrophication Potential
EPS	Expanded polystyrene
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FEAP	Federation of European Aquaculture Producers
FFA	Fédération Française d'Aquaculture
FGM	Federation of Greek Maricultures
g	Grams
GHG	Green House Gas
GLOBEFISH	A multi-donor funded project within the FAO Fisheries Division responsible for providing up-to-date trade and market on fish and fishery products
GWP	Global Warming Potential
HABs	Harmful algal blooms
HGK	Croatian Chamber of Economy
HORECA	Hotels, Restaurants, Catering
LCA	Life Cycle Assessment
LDPE	Low-density polyethylene
OIE	World Organisation for Animal Health
ROA	Return on Assets
ROE	Return on Equity
TETP	Terrestrial Ecotoxicity Potential
PP	Polypropylene

1 Background

Within the Mediterranean, European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) has predominantly been farmed using marine cage aquaculture since the mid-1980s. The development of this industry utilised French understanding of controlled European seabass reproduction from the mid-70s and seabream from the early-80's (Cardia and Lovatelli, 2007), while cage farming technology was known and adopted from the salmon industry. The two species make up for 95 % of total Mediterranean aquaculture production, while others such as meagre (*Argyrosomus regius*) and greater amberjack (*Seriola dumerili*) have also started to emerge (Stavrakidis-Zachou, et al., 2021).

The global production of European seabass from aquaculture has been steadily rising from 2015 to 2019 (most recent available data), reaching 256,820 tonnes in 2019 (98 % of the global production of European seabass) (Table 1). The top 5 European seabass producers are Turkey, Greece, Egypt, Spain and Croatia and they represent 93.58 % of the total production; Greece (41,236.80 tonnes), Spain (25,259.98 tonnes) and Croatia (6,100 tonnes) represent 86 % of the EU total output. In this respect, of this production 33 % has originated from European Union (EU) countries, with 67 % from non-EU countries. In comparison, the wild catch of European seabass comprised only 5,206 tonnes in 2019 (2 % of the total global production of European seabass).

Table 1: European seabass production from aquaculture (2015-2019). ***Source: FAO Global Aquaculture Production database.***

Country	2015	2016	2017	2018	2019
Albania	700.00	800.00	1,000.00	1,000.00	1,020.00
Croatia	4,488.39	5,310.02	5,615.81	6,220.13	6,100.00
Cyprus	1,726.00	1,517.00	2,254.00	2,389.00	2,836.00
Egypt	14,343.00	24,498.00	30,720.00	24,914.00	30,313.00
France	2,156.20	1,750.00	1,400.00	1,721.52	2,460.60
Greece	36,600.10	42,479.40	44,284.70	46,910.80	41,236.80
Italy	5,800.00	6,800.00	6,800.00	5,738.10	5,720.00
Malta	27.00	38.82	59.37	76.75	62.22
Montenegro	76.00	79.00	54.00	78.00	68.00
Morocco	181.00	134.00	112.70	120.53	169.20
Portugal	295.41	403.29	700.57	199.68	674.65
Slovenia	70.00	70.00	80.00	80.00	80.00
Spain	18,600.37	22,956.19	17,655.92	21,268.82	25,259.98
Tunisia	2,802.00	2,564.00	3,448.00	2,288.00	3,331.00
Turkey	75,164.00	80,847.00	99,971.00	116,915.00	137,419.00
Israel	50.00	67.00	70.00	70.00	70.00
	163,079.47	190,313.72	214,226.07	229,990.33	256,820.45

The global production of gilthead seabream reached 252,737 tonnes in 2019 (97 % of the total global production), with the top 5 seabream producers being Turkey, Greece, Egypt, Tunisia and Spain, representing 87.66 % of the total production; while Greece (55,452.0

tonnes), Spain (12,475.32 tonnes) and Italy (7,350 tonnes) represent 80 % of the EU total output. In this respect, 37 % of gilthead seabream production originates from the EU, while 63 % from non-EU countries. Wild catch reached 8,258 tonnes (3 %) in the same year, mainly in the Mediterranean Sea basin (REF).

The main exporting countries of European seabass and gilthead seabream are Turkey and Greece and the main markets are in Europe (Italy, Spain, France, Portugal, Germany, The Netherlands), where the distances are often 2.5-5 thousand kms, contributing on greenhouse house gas (GHG) emissions due to transport.

European seabass and gilthead seabream are mainly sold fresh head-on, round or gutted (Monfort, 2007; EUMOFA, 2019). Currently there is a relatively small level of processing of both species (industrial production of fillets), but this is increasing. However, the costs of processing large sized fish are extremely high, as the cost ranges from 0.30 to 0.40EUR/kgr of whole fish for filleting + 0.20EUR for the packaging material, leading to a lack of competitive pricing for such production. In this respect, there are no value-added items using either species within the market. For example, organic fish are up to 60 % more expensive than non-organic and therefore demand is very low. Early initiatives to label the specific Producer Organisation that the fisher is associated with are starting.

Table 2: Gilthead seabream production from aquaculture (2015-2019). ***Source: FAO Global Aquaculture Production database.***

Country	2015	2016	2017	2018	2019
Albania	1,800.00	1,900.00	2,400.00	2,300.00	2,450.00
Croatia	4,074.79	4,100.96	4,829.60	5,590.97	6,750.00
Cyprus	3,656.00	5,039.00	4,949.00	4,885.00	5,168.00
Egypt	16,092.00	26,663.00	35,221.00	29,994.00	35,880.00
France	1,381.20	1,500.00	1,500.00	1,608.00	2,344.26
Greece	47,713.40	49,620.80	55,947.50	56,203.10	55,452.00
Italy	6,800.00	7,600.00	7,600.00	7,316.32	7,350.00
Malta	2,337.00	2,221.21	2,458.20	1,779.08	1,783.24
Montenegro	45.00	59.00	62.00	45.00	71.00
Morocco	0.00	0.00	0.00	0.00	0.00
Portugal	1,098.82	1,162.36	1,038.01	897.89	2,315.82
Slovenia	0.00	0.00	0.00	0.00	0.00
Spain	16,005.26	12,396.90	17,005.46	13,810.44	12,475.32
Tunisia	10,216.00	12,168.00	16,841.00	18,463.00	18,017.00
Turkey	51,844.00	58,254.00	61,090.00	76,680.00	99,730.00
Israel	1,820.00	2,065.00	2,255.00	2,255.00	2,950.00
Total	164,883.47	184,750.23	213,196.77	221,827.80	252,736.64

There are differences between the official statistics on European seabass and gilthead seabream aquaculture production volumes between the Food and Agriculture Organization of the United Nations (FAO) ,EUROSTAT and the National Statistical Authorities (that provide the same figures) and the data available from the Federation of European Aquaculture Producers (FEAP) and National Producers i.e. Aegean Exporters Associations, Italian Association of Pisciculture (API), Asociación Empresarial de Acuicultura de España

(APROMAR), Croatian Chamber of Economy, Cyprus Mariculture Association, Fédération Française d'Aquaculture (FFA), Federation of Greek Mariculture (FGM) and Hellenic Aquaculture Producers Organization (HAPO). This lack of robustness of available data prevents a comprehensive analysis of the current situation on production figures and a reliable projection of future trends for the European seabass and gilthead seabream aquaculture sector. The following data summarises these differences in production data between the National Producer Associations and the databases of FAO, EuroStat and National Statistical Authorities (Table 3).

Table 3: Differences in reported data of aquaculture from European Seabass and Gilthead Seabream production from aquaculture (2015-2019). ***Sources: FAO Global Aquaculture Production database, Eurostat, the Federation of European Aquaculture Producers (FEAP), Federation of Greek Mariculture (FGM)***

Country					
Greece	2015	2016	2017	2018	2019
European seabass					
ELSTAT, EUROSTAT, FAO	36,600.10	42,479.40	44,407.70	46,910.80	41,252.00
FEAP, FGM	45,000.00	46,000.00	44,000.00	45,500.00	55,200.00
Gilthead seabream					
ELSTAT, EUROSTAT, FAO	47,713.30	49,620.80	55,884.60	56,203.10	55,531.00; 55,500.10; 55,452.00
FEAP, FGM	65,000.00	59,000.00	51,000.00	61,000.00	65,300.00
Turkey	2015	2016	2017	2018	2019
European seabass					
TURKSTAT, EUROSTAT, FAO	75,164.00	80,847.00	99,971.00	116,915.00	137,419.00
FEAP	77,000.00	72,342.00	84,000.00	75,000.00	105,000.00
Gilthead seabream					
TURKSTAT, EUROSTAT, FAO	51,844.00	58,254.00	61,090.00	76,680.00	99,730.00
FEAP	48,000.00	67,612.00	72,000.00	83,000.00	99,000.00

The following Tables summarise the market and consumption per capita for both European seabass and gilthead seabream in Croatia, Cyprus, France, Greece, Italy, Spain and Turkey. Depending on the source of data (from the FAO Global Aquaculture Production database or from the Federation of European Aquaculture Producers (FEAP), fisheries production (from the FAO Global Capture Production), imports and exports (from the FAO Global Fish Trade database), the apparent market (aquaculture production + fisheries production + imports - exports) is calculated, whereas fish consumption per capita (apparent market/Number of inhabitants) is calculated. The population figures are from EUROSTAT (population at 1st of January 2018 and 1st of January 2019).

Table 4: European seabass apparent market and consumption per capita (2018-2019). ***Source: FAO & FEAP data***

Country	Aquaculture – FAO data (tonnes) A	Aquaculture – FEAP data (tonnes) B	Fisheries (tonnes) C	Imports (tonnes) D	Exports (tonnes) E	App (to A+
2019						
Croatia	6,100.00	6,089.00	12.00	204.51	4,072.84	2,2
Cyprus	2,836.00	5,000.00	3.00	71.32	1,978.73	931
France	2,460.60	2,123.00	2,621.00	7,861.81	1,468.00	11,
Greece	41,236.80	55,200.00	311.00	5,497.27	46,347.42	697
Italy	5,720.00	7,000.00	166.00	35,045.81	4,716.99	36,
Spain	25,259.98	27,335.00	578.91	13,861.89	8,337.19	31,
Turkey	137,419.00	105,000.00	155.80	33.30	49,599.11	88,
2018						
Croatia	6,220.13	6,220.00	9.00	175.84	4,385.28	2,0
Cyprus	2,389.00	1,500.00	3.00	85.00	1,618.12	858
France	1,721.52	1,433.00	2,665.00	7,538.12	1,709.72	9,9
Greece	46,910.80	45,500.00	276.00	4,166.44	40,699.80	9,2
Italy	5,738.10	7,300.00	204.00	32,333.60	3,494.12	34,
Spain	21,268.82	22,460.00	21,268.82	11,424.40	6,644.88	47,
Turkey	116,915.00	75,000.00	151.40	208.60	42,756.80	32,

Table 5: Gilthead seabream market and consumption per capita (2018-2019). Sources: FAO & FEAP data

Country	Aquaculture – FAO data (tonnes) A	Aquaculture – FEAP data (tonnes) B	Fisheries (tonnes) C	Imports (tonnes) D	Exports (tonnes) E	Apparent market (tonnes) A+C+D-E – B+C+D-E	Consumption per capita (kg)
2019							
Croatia	6,750.00	6,774.00	123.00	153.24	4,580.88	2,445.36 – 2,469.36	0.600 – 0.606
Cyprus	5,168.00	2,500.00	14.00	57.72	3,560.38	1,679.34	1.917
France	2,344.26	2,081.00	1,140.00	10,745.55	930.89	13,035.66-13,298.92	0.194 - 0.198
Greece	55,452.00	65,300.00	504.00	8,236.58	54,134.47	10,058.12 - 19,906.12	0.938 – 1.857
Italy	7,350.00	9,100.00	654.00	36,465.52	6.189.44	38,280.08 – 40,030.08	0.634 – 0.663
Spain	12,475.32	13,521.00	640.18	8,168.61	2,533.89	18,750.23 – 19,795.91	0.399 - 0.422
Turkey	99,730.00	99,000.00	558.00	56.17	61,302.78	38,311.39 - 39,041.39	0.467 - 0.476
2018							
Croatia	5,590.97	5,591.00	131.00	151.76	3,823.68	2,050.05	0.499
Cyprus	4,885.00	5,000.00	5.00	23.00	3,383.20	1,529.80 – 1,644.80	1.770 - 1.903
France	1,608.00	1,879.00	1,225.00	10,886.20	874.04	12,845.16 – 13,116.16	0.192 – 0.196
Greece	56,203.10	61,000.00	554.00	6,468.28	52,904.20	10,321.18 – 15,118.08	0.961 – 1.407
Italy	7,316.32	9,700.00	1,047.00	35,035.12	4,653.08	38,745.36 – 41,129.04	0.641 – 0.680
Spain	13,810.44	14,930.00	836.00	7,780.60	3,291.48	19,135.56 – 20,255.12	0.410 - 0.434
Turkey	76,680.00	83,000.00	544.00	107.00	52,970.92	24,360.08 – 30,680.08	0.301 – 0.380

2 Value Chain

2.1 Value chain description

Data from Life Cycle Assessment of Mediterranean Sea bass and sea bream shows that packaging and delivery processes contribute for more than 40 % towards the global warming score (Global Warming Potential – GWP), especially since the transportation from

South East Med (Greece and Turkey) to the main European markets. This contribution is mainly due to the electricity consumption, the polystyrene production process and transport emissions.

The procedure to harvest European seabass and gilthead seabream from aquaculture facilities initiates with fasting (i.e., non-feeding) of the fish for a period of 1 to 3 days up to 8 days (though fish should not be fasted for longer than 48 hours at any one time[16]), to ensure that gut contents are evacuated (Pinto et al., 2007). For gilthead seabream, the mechanical properties of the muscle change as the starvation time progresses, so the flesh is firmer when they are starved for up to 8 days compared to the standard 1 to 3 days, due to changes in protein solubility and pH (Gines et al., 2002). However, the temperature at which starvation is undertaken may have negative impacts on the fish, with approximately 1 % of weight lost during starvation at higher temperatures than 20°C. Such starvation, by reducing the amount of faeces in the intestines, reduces spoilage in the fish while also reducing digestive enzyme activity.

The vast majority of European seabass and gilthead seabream are slaughtered under commercial conditions by live chilling in ice slurry. Fish are pumped or netted from (ambient) holding water into ice slurry. This is a mixture of ice and water in a ratio ranging from 1:2 to 3:1, with typical temperatures of between 0°C and 2°C. Fish die from thermal shock (Smart. 2001). This is a low-cost method used to kill many fish species and is used globally. The influence of starvation, harvesting stress, slaughter conditions, and harvesting season on the different quality characteristics of gilthead seabream has been studied by Mendes (2018) and this is important as depending on these parameters, the shelf life (in days) is affected i.e. the PH period that the fish can be characterised as fresh and range between 9 and 17 days.

Wild fish after capture follow a period of air asphyxiation on board until they die. In farmed European seabass and gilthead seabream, the method most farmers use is to immerse the fish directly into iced water. It is very important to check that the water is kept close to 0°C at all depths. If the temperature should rise to 8°C, the fish will not die of thermal shock but of asphyxia, which adversely affects their appearance, colour, and texture. In the case of European seabass, it is very important that crowding prior to cropping be kept to a minimum and that fish are swiftly killed, otherwise considerable damage, such as de-scaling and other skin lesions, and bleeding around the belly can occur (Smart, 2001). The replacement of conventional flake ice with slurry ice as a slaughtering method led to improved stability in individual fish quality during subsequent refrigerated storage and shelf-life extension, with reduced microbial growth, and enhanced sensory quality of fish (sensory parameters include appearance, texture and odour of raw and cooked samples, and taste of cooked samples) (Ntzimani et al., 2021).

When European seabass and gilthead seabream reach a commercial weight (European seabass are sorted into 6 classes depending on the weight of the fish: 200-300 g/piece, 300-450 g/pc, 450-600 g/pc, 600-800 g/pc, 800-1000 g/pc and >1000 g/pc, while gilthead seabream are sorted into 4 classes: 300-450 g/pc, 450-600g/pc, 600-800 g/pc and >1000 g/pc) they are harvested and delivered to the packaging station for further processing (Globefish, European Price Reports[17]). The post-slaughter procedure has been described in detail by Konstantinidis et al. (2021) and is detailed below. Fish are transported inside isothermal bins filled with ice water to the packaging plants. In the packaging plants, the bins are overturned and the fish are forwarded to the production line that consists of automatic grading, batching and weighing machines, where fish are

[16] See: https://www.compassioninfoodbusiness.com/media/7436994/improving-the-welfare-of-sea-bream-and-european-sea-bass-at-slaughter.pdf

[17] See: https://www.fao.org/in-action/globefish/publications/details-publication/en/c/1479717/.

sorted into appropriate sizes. The production line, which runs on compressed air and electricity, channels the fish to the appropriate gates (based on size) where they are manually placed into expanded polystyrene (EPS) boxes. In the EPS box fish are placed with the belly cavity upwards and fitted in to avoid unnecessary movement during transportation (Borderías and Sánchez-Alonso, 2011). Then, a low-density polyethylene (LDPE) film is placed on top of the fish to avoid direct contact with flake ice, which may cause thermal burns on the skin of the fish. Adding ice to the EPS box helps to maintain the cool chain at the required temperature. Moreover, ice keeps the fish moist and retains their fresh appearance. Most packaging plants have indoor flake ice production machines.

European seabass and gilthead seabream are packaged in various sizes of EPS boxes with different capacities: 3 and 5 kg (open), 5, 6, and 8 kg (with a lid) (Kallitsis et al., 2020; Konstantinidis et al., 2021). Approximately 2.3 kg (38 % in 6 kg boxes) and 4.5 kg (43 % in 10 kg boxes) of flake ice are needed, based on the total weight of the EPS boxes. The most commonly used boxes have a holding capacity of 6 kg for European seabass and gilthead seabream and the mean weight of packaged fish is 5.73 kg (Konstantinidis et al., 2021).

The subsequent packaging stage consists of affixing labels on each box, wrapping them with polypropylene (PP) sealing tape and, finally, piling the boxes on a wooden palette and covering it with stretch film (LDPE). As regards the wood needed for transportation, 95 % of Euro palettes[18] are reused, while the remaining 5 % (taken into consideration for calculations) are either destroyed or lost (i.e., waste) during transportation. Finally, the "ready to go" palettes are placed by hand-operated forklift in a freezer before being loaded onto refrigerated trucks (at the exit gate of the packaging plant), for further transportation/distribution to the markets. Fish are transported to end-consumer markets (i.e., small retailers / fish mongers, large retailers (supermarkets) as well as hotels, restaurants, catering - HORECA) and the packaging is removed before it reaches the shelf.

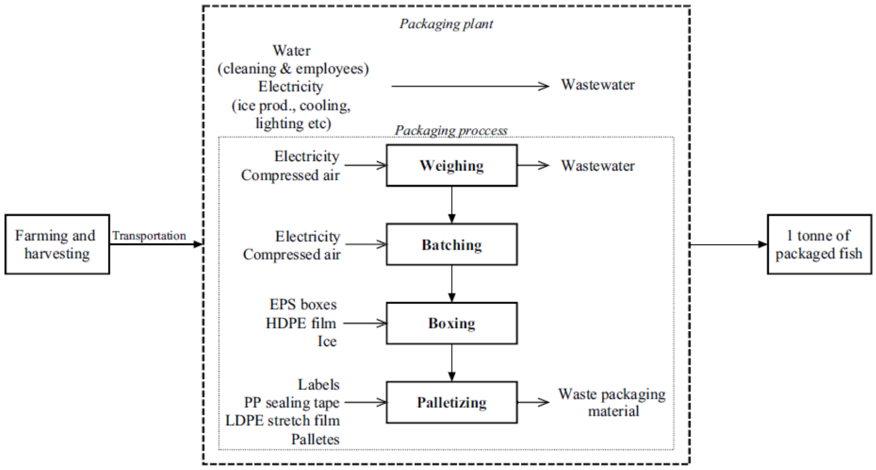


Figure 1. Packaging process of farmed European seabass and gilthead seabream. *Source: Konstantinidis et al., 2021.*

The life cycle inventory for the packaging and delivery process of 1 ton of European seabass is shown below. The facility requirement was modelled based on a generalised Ecoinvent inventory for fish freezing plants (Kallitsis et al., 2020). The fish was assumed to be transported for 300 km to reach end-consumer markets, where it is unpackaged and

[18] The EUR-pallet, also known as Euro-pallet or EPAL-pallet, is the standard European pallet as specified by the European Pallet Association (EPAL) (see https://www.epal-pallets.org/eu-en/load-carriers/epal-euro-pallet.

sold. However, fish can reach up to UK, Ireland and Sweden via truck, whereas through air transport it can reach in the USA within 25-30 hours.

The total electricity that is used in the PH of European seabass and gilthead seabream is predominantly utilised to power the refrigerators (66 %), with the packaging process (7 % of the total electricity used) and supporting machinery utilising the rest of the needed electricity (Kallitsis et al., 2020). Table 6 depicts the Life cycle inventory of 1 t packaged European seabass but it is similar with the quantities needed for gilthead seabream as well, since Kallitsis et al. (2020) do not provide different values for the packaging and delivery process. 93.11 kW of energy and 0.37 m3 of ice and some 30.27 kg of packaging material (expanded polystyrene boxes, plastic film, labels etc) are needed per tonne of European seabass and gilthead seabream for packaging.

Table 6: Life cycle inventory of 1 t packaged European seabass (main inputs and outputs/averages from three packaging plants). ***Source: Konstantinidis et al., 2021.***

Inputs	European seabass	Unit
Ice	0.370	m^3
Electricity (GR energy mix)*	93.11	KW
Expanded polystyrene (EPS)	28.505	kg
Pallet (Euro-pallet)	2.004	P
Plastic labels (polyethylene)	0.168	kg
Stretch film (low-density polyethylene)	1.002	kg
Sealing tape (polypropylene)	0.146	kg
Plastic film (low-density polyethylene)	0.451	kg
Computers (use)*	40	Min
Air compressor (maintenance)*	1	p
Refrigeration machines (maintenance)*	5	p
Outputs		
Waste paper (rolls)	0.251	kg
Waste water (ice from bins)	0.526	m^3
Waste water (cleaning and employees)	0.230	m^3
Waste EPS*	0.518	kg
Waste wood (from pallet)	2.204	kg
Waste steel (from pallet)	0.019	kg
BOD (5)	850	mg

* Data refer to whole working time of the packaging plant

Both species are mainly traded as fresh (whole fish), freshly chilled products, while fresh and frozen fillets have gained more attention in the past 5 years. Fillet yields for European seabass and gilthead seabream are about 45 % and 40.14 % respectively in terms of whole fish body mass (see Table 15) but this may vary depending on the size of the fish. Fraslin et al., (2018) reported that although fillet weight and body weight are strongly correlated and proportional to each other, moderate selection gains on fillet yield are possible.

It is estimated that around 10,000 tonnes of fillets are produced in Greece and about 25,000 tonnes in Turkey, whereas in Cyprus about 1,000 tonnes are exported to Israel.

In all three Countries, the process is often done by hand but machinery is available as well in Turkey. Fillets from Turkey end up in seafood suppliers in the Netherlands where they are frozen and provide supplies to the Hotels, Restaurants, Catering (HORECA) sector, including large cruise ships that operate in the Mediterranean Sea (home port).

Until now value adding for both species was limited to specific 'labelling' or the production of 'organic' fish. In complying with specific organic production standards, some farmers add a true value to their product, but this is perceived by only a fraction of consumers. Other farmers have established partnership contracts with retailers that allow their fish to carry the quality label of the retailer. Importantly, branding fresh fish is a marketing option rarely used by producers, mainly because of their small size and lack of financial resources. Yet retailers and large-scale wholesalers are developing their own brands to apply to fresh fish, and more specifically to farmed fish. European seabass and gilthead seabream are often distributed with retailers' quality brands.

Packaged, cleaned, branded fish is a tempting proposition especially for the young housewife, thus expanding the acceptance of the supermarket as a distribution channel for fresh fish. The popular market attracts the older consumers, while the traditional fishmonger shops maintain their shares, based on the offer of various services to the customer, such as grilling, cooking and distribution, etc. The relevant trends are to increase the share of the category of "processed" fish that has more than doubled its sales in volume in the last five years.

Figures 2 to 7, depict the PH value chain of European seabass and gilthead seabream in Greece, Spain, Croatia and Turkey. The vast majority of the production is from aquaculture. Exports constitute 64.59 %, 75.97 %, 21 % and 70.59 % of the European seabass production (aquaculture production plus catches and imports) in Croatia, Greece, Spain and Turkey respectively for 2019. For gilthead seabream, exports constitute 73.11 %, 11.35 % and 80.75 % of the production (aquaculture production plus catches and imports) in Greece, Spain and Turkey respectively for 2019.

In Greece, the domestic supply of European seabass and gilthead seabream reach the final consumers mainly through specialised retailers (fish mongers) by 45-50 %, large-scale retailers (supermarkets) by 35-40 %, whereas the HORECA sector absorbs 5-10 % of the domestic supply for both species (Figures 2 and 3).

In Spain, the domestic supply of European seabass and gilthead seabream reach the final consumers mainly through specialised retailers (fish mongers) and large-scale retailers (supermarkets), whereas the HORECA sector absorbs 25-35 % of the domestic supply of wild caught European seabass and gilthead seabream and 2500-to 3500 tonnes of farmed European seabass and gilthead seabream (Figures 4 and 5).

In Croatia, the domestic supply of European seabass reach the final consumers mainly through specialised retailers (fish mongers) and large-scale retailers (supermarkets), whereas the HORECA sector absorbs 25-35 % of the domestic supply of wild caught European seabass and gilthead seabream and 2500-to 3500 tonnes of farmed European seabass and gilthead seabream (Figure 6).

In Turkey, in 2019, the domestic supply of European seabass was 25,000 tonnes and for gilthead seabream 14,544 tonnes (Figures 7 and 8).

Table 7 depicts the PH value chain of European seabass for Croatia, Cyprus, France, Greece, Italy, Spain, Turkey and other Mediterranean Producers (Albania, Egypt, Malta, Montenegro, Morocco, Portugal, Slovenia, Tunisia and Israel) for the years 2015-2019. The main markets are in Italy (19.6 %), North Europe (16.4 %) and Spain (14.7 %). Non-EU Mediterranean Countries (Egypt, Tunisia) absorb 18 % of the global European seabass production. In general, EU countries produced 84,430.25 tonnes in 2019 (32.88 %) and non-EU countries 172,390.20 tonnes (67.12 %). The top 5 producers are Turkey, Greece, Egypt, Spain and Croatia and account for 93.58 % of the production (see Table 1). Figure 7 depicts the production, trade flows and apparent markets for European seabass.

Tables 9 to 11 present the imports of European seabass in Italy, Spain and France in the period 2015-2019 whereas Tables 12 to 14 present the imports of gilthead seabream in the same Countries for the period 2015-2019. Greece and Turkey are the main exporting countries and the vast majority of the fish is transported by tracks. Figure 10 shows the land-based export routes of the Turkish production of European seabass and gilthead seabream. The longest itinerary is from Mugla to UK via Paris, a distance that exceeds 4,100 km. From Mugla to Lisbon it is about 5,000 km. According the WWF study of 2021, the duration of shipments to the UK is reported to be about six days, and around four days to Italy. Turkey also exports frozen European seabass and gilthead seabream fillets to the USA by sea (WWF, 2021).

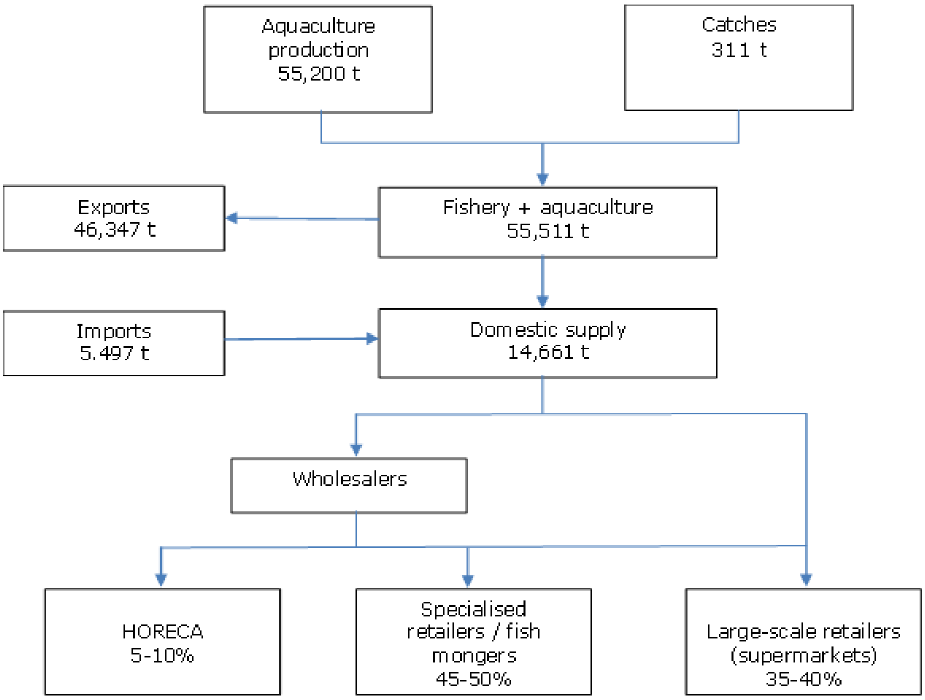


Figure 2. Postharvest value chain of European seabass in Greece (2019). ***Source: EUMOFA and FAO data***

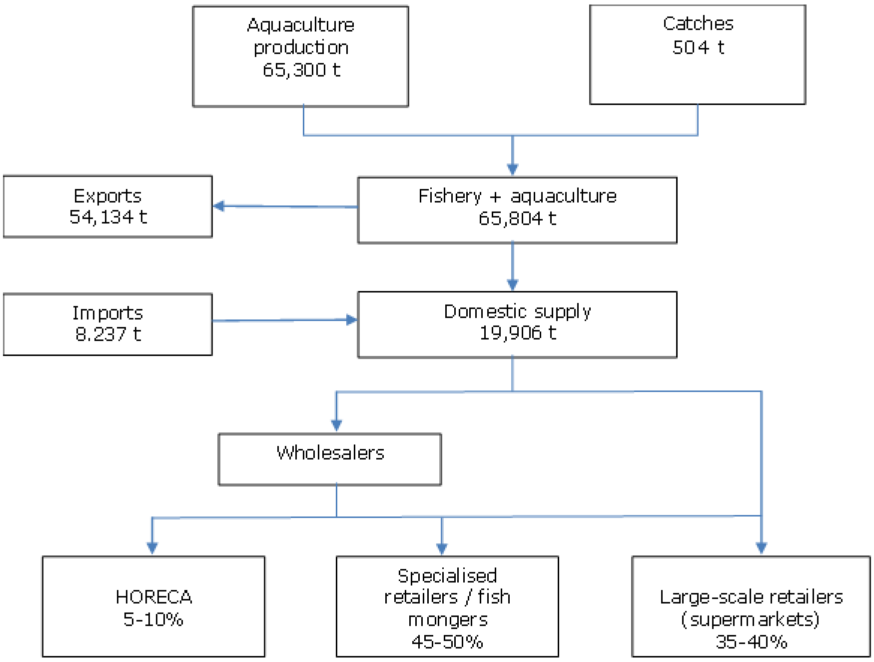


Figure 3. Postharvest value chain of gilthead seabream in Greece (2019). ***Source: EUMOFA and FAO data***

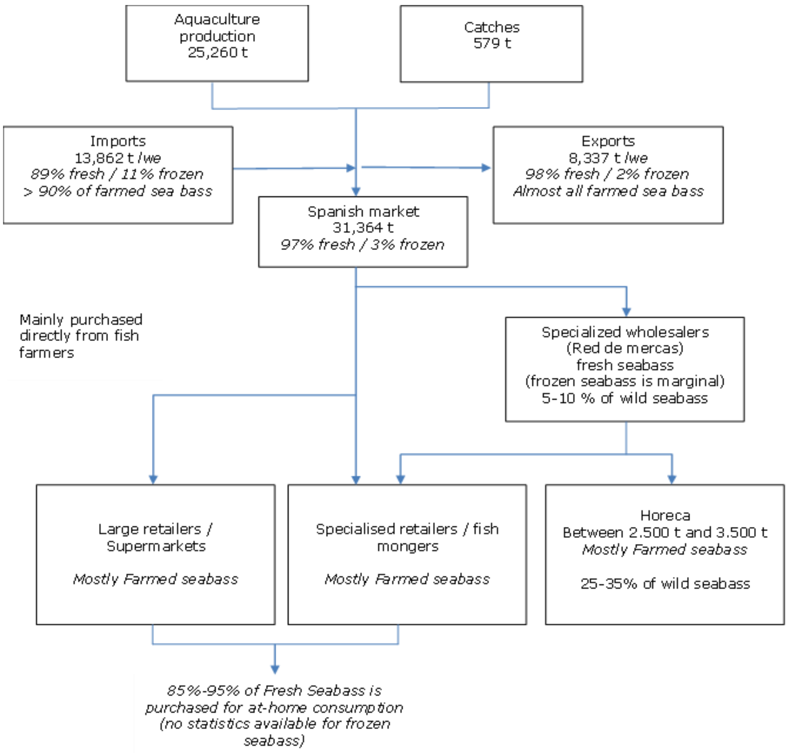


Figure 4. Postharvest value chain of European seabass in Spain (2019). ***Source: EUMOFA***

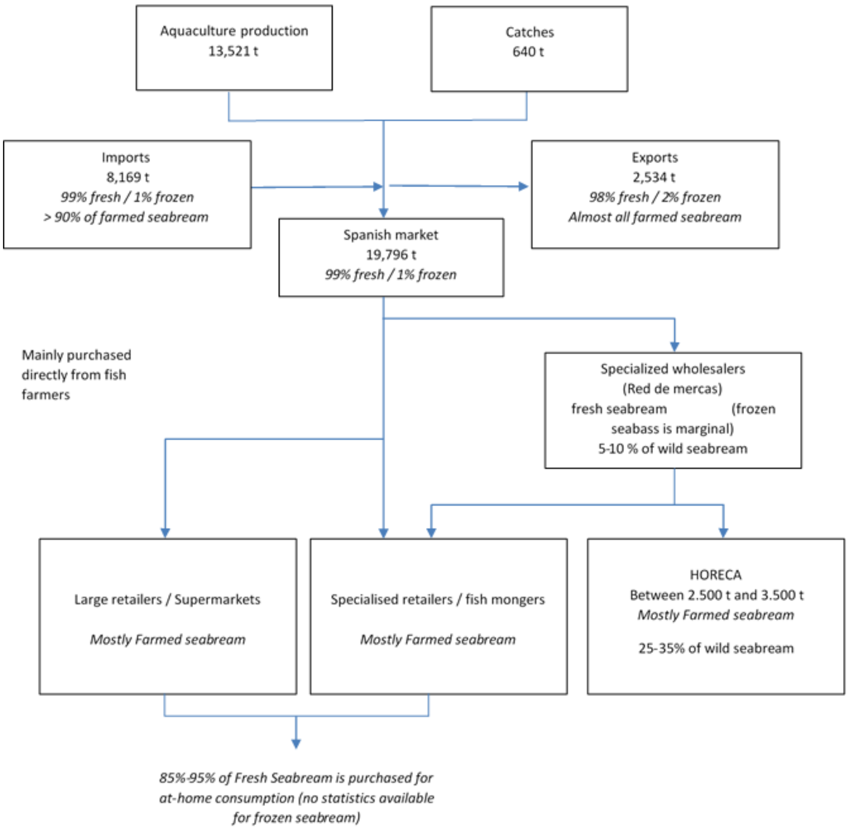


Figure 5. Postharvest value chain of gilthead seabream in Spain (2019). ***Source: EUMOFA***

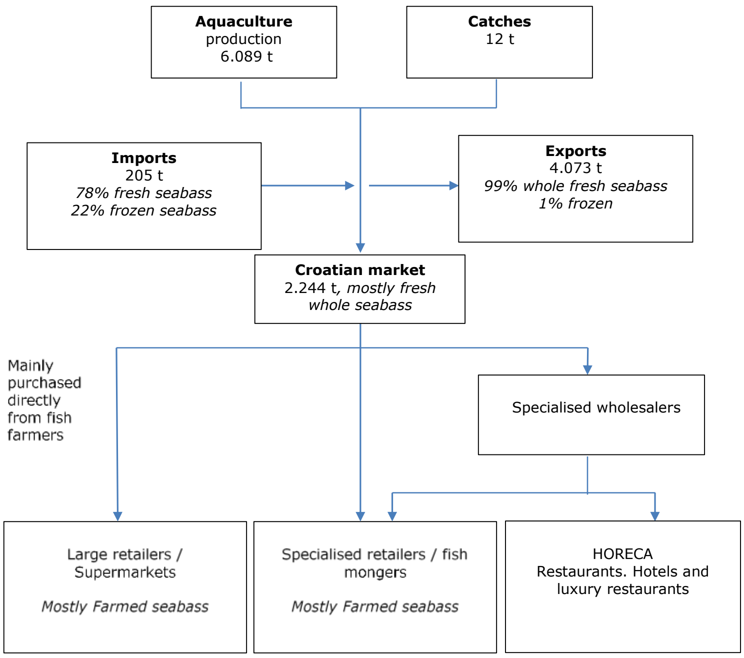


Figure 6. Postharvest value chain of European seabass in Croatia (2019). ***Source: EUMOFA.*** **Sources: Aquaculture production: FEAP; Catches: FAO, 2019; Conversion factor for fresh sea bass=1; Conversion factor for frozen sea bass=1,18 (frozen seabass is traded predominantly gutted-EUMOFA 2019); Trade data: FAO Global fish trade- 2019**

Table 7: Numbers of the Postharvest value chain of European seabass (2015-2019). ***Source: FAO, APROMAR.***

Main primary production	Countries	Average Volume first sales (annually) 2015-2019 Tonnes	Average value first sales (annually) 2015-2019 Thousand Euros	Main markets for European seabass (2019 APROMAR data)
	1.Croatia	5,546.87	34,333.98	1. Italy (19.6 %)
	2.Cyprus	2,144.40	13,677.64	2. North Europe (16.4 %)
	3.France	1,897.66	15,780.10	3. Spain (14.7 %)
Aquaculture	4.Greece	42,302.36	224,817.10	4. Turkey (11 %)
	5.Italy	6,171.62	51,787.94	5. Greece (4.9 %)
	6.Spain	21,148.26	135,071.30	6. France (4.5 %)
	7.Turkey	102,063.20	425,677.00	7. Portugal (2.3 %)
	8.All others	29,611.64	121,681,60	8. North Africa (18 %)
	TOTAL	210,886.01	1,022,826,74	
Wild capture				Total: 225,348 tonnes (220,224 Aquaculture & 5,124 Fisheries) for 2019

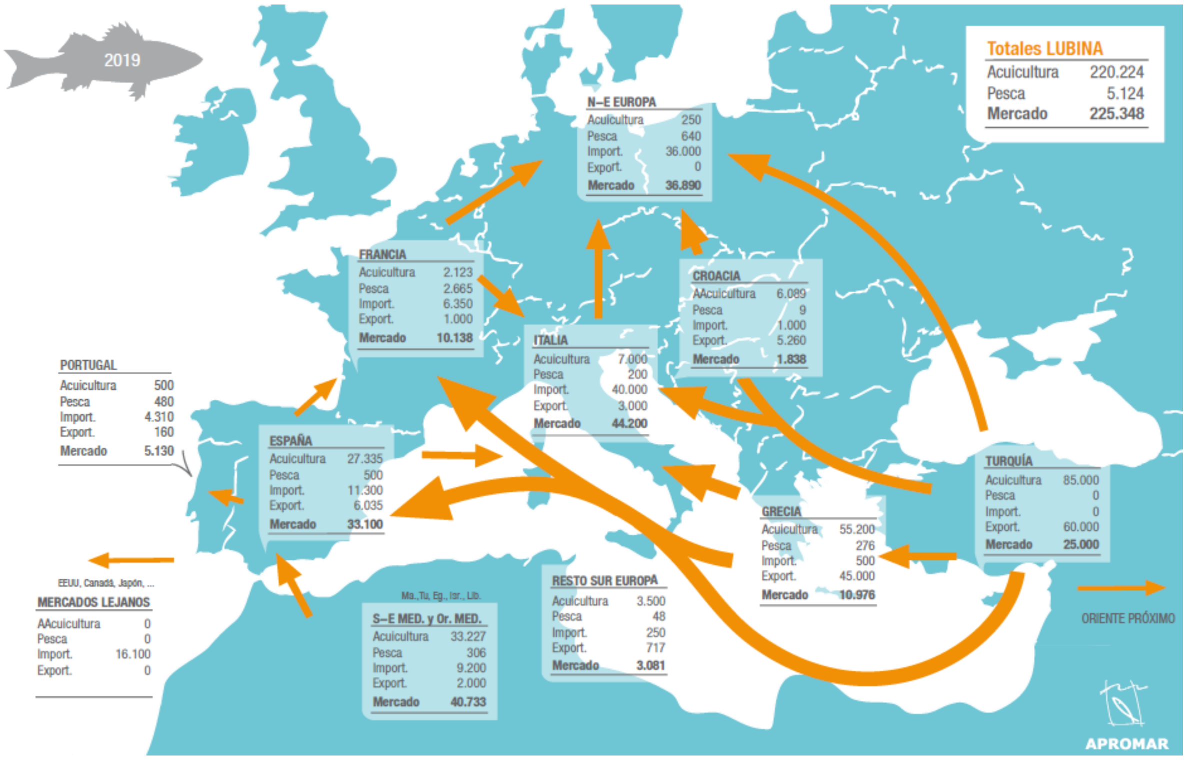


Figure 7. Diagram of production, trade flows and apparent markets for European seabass in Europe in 2019. ***Source: APROMAR*.**

Table 8: Numbers of the postharvest value chain of Gilthead Seabream (2015-2019). *Source: FAO, APROMAR*

Main primary production	Countries	Average Volume first sales (annually) 2015-2019 Tonnes	Average value first sales (annually) 2015-2019 Thousand Euros	Main markets for gilthead seabream (2019 APROMAR data)
Aquaculture	1.Croatia 2.Cyprus 3.France 4.Greece 5.Italy 6.Spain 7.Turkey 8.All others TOTAL	5,214.66 4,750.20 2,735.69 53,390.36 8,241.46 15,270.51 70,053.20 56,257.43 215,913.52	31,117.82 23,419.57 13,229.14 251,245.27 54,943.28 74,919.72 264,049.04 234,761.97 947,685.80	1. Italy (21 %) 2. North Europe (20 %) 3. Spain (11 %) 4. Greece (6 %) 5. France (6 %) 6. Turkey (6 %) 7. Portugal (4 %) 8. North Africa (21.5 %)
Wild capture	Consumption			Total: 240,786 tonnes (232,475 Aquaculture & 8,311 Fisheries) for 2019

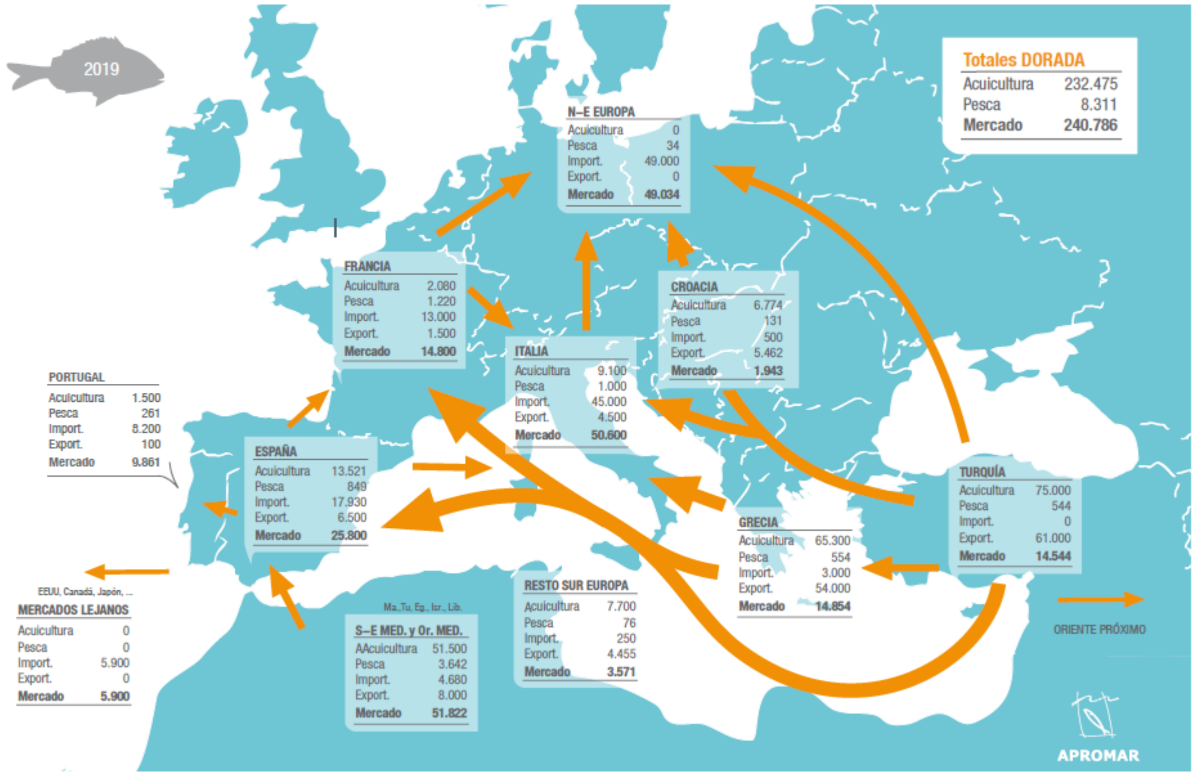


Figure 8. Diagram of production, trade flows and apparent markets for gilthead seabream in Europe in 2019. *Source: APROMAR*.

According to GLOBEFISH, prices for farmed European seabass continued their unusual off-season climb in February 2022. The usual price for European seabass is 4.5 EUR/kg for 2021. However European seabass fished in Greece of the size 300-450 g bass reached a multi-year peak in Italy in February 2022, selling at EUR 5.20 per kg (Figure 9). Such prices last reached these heights in July 2017, at the peak of the summer tourist season, when demand for European seabass and gilthead seabream is traditionally at its strongest (EUR 4.8 EUR/kg). The change in seasonal patterns is in large part due to the pandemic, as the sector has made a concerted effort to pivot towards retail and reduce their dependence on the heavily impacted restaurant sector. Gilthead seabream supply has been relatively more plentiful and prices have not climbed so steeply, but this species also seems to have avoided the winter dip.

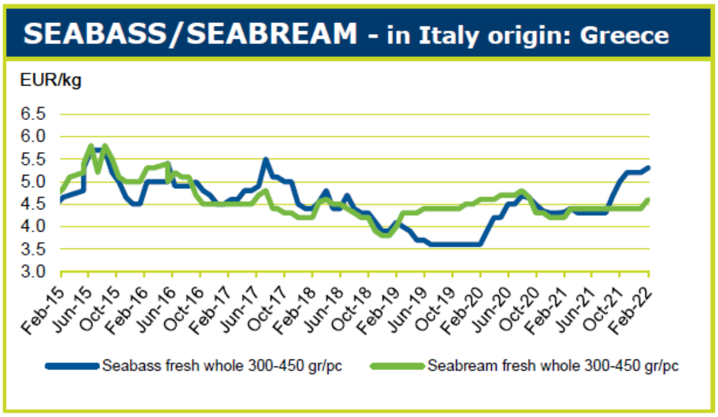


Figure 9. Evolution of prices of fresh whole European seabass and gilthead seabream (size 300-450 g/piece) with origin from Greece. *Source: GLOBEFISH*.

Table 9: Italy. Imports of European Seabass (2015-2019). *Source: FGM, Kontali*

Country	2015	2016	2017	2018	2019	Average
Greece	15,253.00	18,565.00	20,252.00	20,034.00	20,182.00	18,857.20
Turkey	4,927.00	5,844.00	5,853.00	5,909.00	7,283.00	5,963.20
France	419.00	300.00	235.00	237.00	255.00	289.20
Croatia	2,141.00	2,542.00	3,010.00	3,110.00	2,921.00	2,744.80
Spain	945.00	1,072.00	860.00	944.00	956.00	955.40
Others	155.00	229.00	247.00	516.00	435.00	316.40
TOTAL	23,840.00	28,552.00	30,457.00	30,750.00	32,032.00	29,126.20

Table 10: Spain. Imports of European Seabass (2015-2019). *Source: FGM, Kontali*

Country	2015	2016	2017	2018	2019	Average
Greece	1,863.00	2,942.00	5,751.00	5.944.00	8,358.00	4,971.60
Turkey	2,261.00	1,698.00	2,619.00	4.594.00	4,128.00	3,060.00
France	129.00	129.00	97.00	185.00	241.00	156.20
Portugal	78.00	97.00	110.00	164.00	142.00	118.20
Italy	573.00	821.00	751.00	14.00	159.00	463.60
Others	11.00	43.00	232.00	104.00	110.00	100.00
TOTAL	4,915.00	5,730.00	9,560.00	11,005.00	13,138.00	8,869.60

Table 11: France. Imports of European Seabass (2015-2019). ***Source: FGM, Kontali***

Country	2015	2016	2017	2018	2019	Average
Greece	2,884.00	3,170.00	4,335.00	4,263.00	3,944.00	3,719.20
Turkey	29.00	148.00	366.00	626.00	666.00	367.00
Spain	1,408.00	1,488.00	1,063.00	1,067.00	1,293.00	1,263.80
Croatia	219.00	350.00	246.00	231.00	129.00	235.00
Italy	477.00	554.00	745.00	857.00	1,049.00	736.40
Others	445.00	388.00	1,8757.00	1,787.00	1,293.00	4,534.00
TOTAL	5,462.00	6,098.00	8,630.00	8,831.00	8,374.00	7,479.00

Table 12: Italy. Imports of Gilthead Seabream (2015-2019). ***Source: FGM, Kontali***

Country	2015	2016	2017	2018	2019	Average
Greece	17,725.00	20,568.00	22,396.00	22,900.00	20,559.00	20,829.60
Turkey	5,384.00	9,609.00	7,012.00	7,179.00	9,030.00	7,642.80
Spain	1,398.00	1,301.00	1,117.00	934.00	794.00	1,108.80
France	418.00	491.00	507.00	500.00	531.00	489.40
Malta	1,595.00	1,647.00	2,154.00	1,883.00	2,386.00	1,933.00
Croatia	1,557.00	1,613.00	2,201.00	2,281.00	2,846.00	2,099.60
Others	299.00	415.00	1,129.00	1,565.00	2,070.00	1,095.60
TOTAL	28,376.00	35,644.00	35,516.00	37,242.00	38,216.00	34,998.80

Table 13: Spain. Imports of Gilthead Seabream (2015-2019). ***Source: FGM, Kontali***

Country	2015	2016	2017	2018	2019	Average
Greece	8,236.00	9,962.00	8,876.00	8,800.00	12,702.00	9,715.20
Turkey	3,294.00	2,950.00	3,770.00	5,085.00	5,282.00	4,076.20
Italy	1,122.00	3,642.00	1,869.00	228.00	427.00	1,457.60
Portugal	150.00	244.00	297.00	315.00	419.00	285.00
Others	4,176.00	4,370.00	4,213.00	3,709.00	3,434.00	3,980.40
TOTAL	16,978.00	21,168.00	19,025.00	18,137.00	22,264.00	19,514.40

Table 14: France. Imports of Gilthead Seabream (2015-2019). ***Source: FGM, Kontali***

Country	2015	2016	2017	2018	2019	Average
Greece	5,286.00	5,613.00	7,527.00	6,977.00	6,876.00	6,455.80
Turkey	24.00	527.00	984.00	978.00	868.00	676.20
Spain	1,863.00	1,473.00	1,384.00	1,245.00	1,160.00	1,425.00
Italy	838.00	1,032.00	1,004.00	1,652.00	1,643.00	1,233.80
Croatia	122.00	154.00	118.00	197.00	163.00	150.80
Others	1,693.00	1,778.00	2,151.00	2,6967.00	3,260.00	7,169.80
TOTAL	9,826.00	10,577.00	13,168.00	13,745.00	13,970.00	12,257.20

Figure 10. Land-based export routes of Turkish European seabass and gilthead seabream to main markets in Europe. ***Source: WWF, 2021.***

Table 15: Fillet yields from European seabass and gilthead seabream. ***Source: Malcorps et al., 2020.***

Species/fraction		Fraction of whole %	Flesh yield %	By-product fraction of whole fish %	Total edible yield from by-product %	Total edible yield %
European seabass	Fillet	45.04	100	54.96	25.83	70.87
	Heads	21.19	40.62			
	Frames	11.92	41.78			
	Trimmings	7.11	73.64			
	Skin (incl scales)*	7.00	100			
	Viscera	7.74	0			
Gilthead seabream	Fillet	40.14	100	59.86	31.21	71.35
	Heads	27.55	48.94			
	Frames	12.42	46.05			
	Trimmings	5.98	83.85			
	Skin (incl scales)*	7.00	100			
	Viscera	6.91	0			

* Share (%) of skin for gilthead seabream and European seabass is based on (Pateiro et al., 2020).

3 Resilience

3.1 Physical and financial resilience

The life cycle assessment of Mediterranean European seabass and gilthead seabream revealed that packaging and delivery processes (considering a distance of 300 km) contribute approximately 40 % towards the global warming score (Global Warming Potential - GWP; Kallitsis et al., 2020). This contribution is mainly due to the electricity consumption and the polystyrene production process. Packaging and delivery contributed more than 10 % towards all environmental impact categories examined, except from Eutrophication Potential (EP), Terrestrial Ecotoxicity Potential (TETP) and Abiotic Depletion Potential (ADP).

Given that the majority of the production takes place in Greece and Turkey, and the main markets are in Europe where the distances are often 2.5-5 thousand kms, the actual GWP is apparently higher. It is therefore crucial to include this contribution in the determination of the environmental impacts of gilthead sea bream and European sea bass production for estimating GWP.

For the two species, the reported GWP on a 100 g edible protein basis is 1.04 kg CO_2-eq for gilthead seabream with 41 % for packaging and delivery, whereas for European seabass the reported GWP on a 100 g edible protein basis is 1.34 kg CO_2-eq, with 39 % for packaging and delivery for a distance of 300 km to the market (Kallitsis et al., 2020).

Table 16: Inventory for the postharvest (packaging and delivery) process for European seabass and gilthead seabream. *Source: Kallitsis et al., 2020.*

Quantity	Units	In	Out	Ecoinvent Process
Fish, at seller	kg		1000	
Live fish	kg	1000		
Styrofoam	kg	110		RoW: polystyrene production,
Electricity, medium voltage	kWh	320		GR: market for electricity, medium voltage
Packaging factory	Units	2.2×10^{-3}		RoW: fish freezing plant construction and maintenance
Transportation	tkm	300		GLO: market for transport, freight, lorry with refrigeration machine, 7.5-16 tonnes, EURO5, R134a
Waste expanded	kg		110	GR: market for waste polystyrene

In the framework of the MedAID[19] EU Horizon 2020 project (Cidad et al., 2018), information about the commercialization and processing activities collected for 137 companies from 9 Mediterranean countries surveyed. Table 17 shows the distribution of the quantities and incomes according to fish size from the MedAid Project. As some of the companies surveyed reported quantities marketed and their value according to the size of the fish, while others reported only the quantity or only the value, it is impossible to relate the value of sales to the quantities sold. However, from these data we can see that gilthead seabream and European seabass between 400g and 600g is the most commercially lucrative product (40 % of sales). In addition, approximately 70 % of sales are of fish

[19] See http://www.medaid-h2020.eu/

between 300g and 800g, and this percentage rises to 80 % if we include the individuals between 800g and 1000g. Just around 15 % of sales corresponds to fish at or over 1000 g, and this figure is reduced to approximately 6 % in fish at or over 1700 g. Only 13 of the 171 surveyed companies in the MedAID project, reported very low level of processing (mainly degutting and fileting) but without providing details. The information from the companies surveyed in the MedAID project, shows how the transportation systems used depend on the distance and access to the destination markets. Companies supplying the national market mainly use trucks on trips that have durations between 2 h and 10 h. When the target markets are further away, such as the USA, the Middle East, or Europe for companies located in African countries, planes are used to reduce the duration of transport. Air transport lasts from 12 to 64 hours, depending on the distance (Cidad et al., 2019). The main commercialisation/ transportation problems pointed out by the companies surveyed are transportation time, that conditions the shelf-life and freshness of the product and, and failures in product temperature preservation along the value chain. The most common customer demands are related to the size of the fish and a high degree of processing (Cidad et al., 2019).

Table 17: Distribution of gilthead seabream and European seabass commercialisation by fish size (g). Period 2015-2017. *Source: MedAid project (Cidad et al., 2018).*

Fish size (g)	Quantities	Value
>4000 g	0.10 %	0.05 %
3500 – 4000	0.39 %	0.21 %
3000 - 3500	1.10 %	0.68 %
2200 - 3000	1.49 %	0.97 %
1700 - 2200	3.30 %	2.47 %
1300 - 1700	3.82 %	4.09 %
1000 – 1300	5.41 %	5.45 %
800 - 1000	5.68 %	11.09 %
600 - 800	22.71 %	21.68 %
400 - 600	39.91 %	23.02 %
300 - 400	14.49 %	21.30 %
<300 g	0.35 %	2.18 %
Malformations	0.08 %	0.50 %
Others	1.17 %	6.31 %
TOTAL	**100 %**	**100 %**

3.2 Major financial constraints and reliability

An assessment of the economic performance of the gilthead seabream and European seabass aquaculture industry in the EU has been published recently by Llorente et al. (2020). The cultivation of both species was initiated in the 1980s and production was relatively high due to rapid growth in the 1990s (Fig. 10). The first crisis in the production of both species occurred at the beginning of 2000, resulting in a production decrease for a couple of years. Since then, production of both species has followed a positive growth trend, however, at a much slower pace, and with cycles in production and profitability (Fig. 10). Llorente et al. (2020) estimated that over the period 2008–2016, the evolution of the economic performance parameters, Earnings Before Interest and Tax (EBIT) margin, Return on Assets (ROA) and Return on Equity (ROE), have been showing a positive trend, but with significant year-to-year variation. The year 2009 was particularly bad as all the performance parameters were negative. After another negative year in 2013, all the three indicators considered doubled or almost doubled from 2015 to 2016. The margin generated by sales, as well as the return on assets, have followed a very similar positive trend. The results show that since 2009, except 2013, EBIT margin has been positive, taking off in 2013 until registering the best result of the series in the last year. This positive evolution is explained in part by the positive trend followed in general by seabream and seabass price until 2014, and by the significant increase in the quantities produced during 2015 and 2016.

According to STECF (2018), the ROA of the EU seabream and seabass sector was 11.8 % in 2016, which was slightly lower than the ROA of the whole EU marine aquaculture (13.8 %) and of the whole EU aquaculture (14.5 %).

The two species constitute the main finfish aquaculture industry in the Mediterranean and the second most important in the EU after salmon, whereas since the EU exit it is the most important in the EU. Despite the technical developments, the mature nature of the industry and the continuously larger scale of production (due to increased Turkish production), the operational cost per kilo produced has followed an increasing trend over time, mainly caused by the rise in the costs of feed, fingerlings and energy (STECF, 2018). This trend is different from what is experienced in salmon (Asche et al., 2013) and trout (Nielsen et al., 2016) aquaculture industries. The EU production has slowed its growth since 2010 compared to non-EU countries in the Mediterranean area such as Egypt, Tunisia and especially Turkey.

In Greece, the major EU production country that dominated in the period 1990-2011, European seabass and gilthead seabream development was based on the availability of suitable sites, French, Italian and Japanese know-how, and financial support from EU structural programs (Perdikaris and Paschos, 2018). However, after 1995, a few large corporations were formed via aggressive merging and direct purchasing of smaller farms, backed by bank loans and 'cheap' money from the Athens stock exchange. The process was further accelerated by artificial price recession, suffocating small and medium scale producers. The result was that approximately 300 farm owners were present in the industry in the late 1980s-early 1990s, while by the mid-1990s only 16 groups of companies controlled approximately 70 – 75 % of total production, with 3 companies controlling 90 % of juvenile production and 60 % of fish feed production (Barazi-Yeroulanos, 2010).

The substantial inflow of capital with low interest rates during the 2000's and the international financial crisis of 2008 - 2009 further deteriorated the structural problems of the Greek economy, resulting in non-sustainable public finances. Greek aquaculture companies have been affected by the financial crisis that followed the Lehman Brothers collapse. Although previously rescued by banks, these were restricted and sold off. As of early 2019, the European Commission (EC) has approved the merger of Nireus and Selonda with Andromeda, another large Greek aquaculture firm owned by the acquiring fund Amerra. Large vertically integrated companies control the majority of the Greek production (70 %) with the largest groups being Avramar Group, Philosofish and Kefalonia Fisheries. A Producer Organisation was established in 2016 (the Hellenic Aquaculture Producers Organization - HAPO) representing approximately 80 % of the Greek aquaculture industry and has 23 members (Group of companies). The restructuring of the marine aquaculture industry in Greece is waiting for the finilisation of the marine spatial planning in Greece for the creation of Allocated Zones for Aquaculture (AZAs) that has still not been accomplished, which means that investments in the sector, including the postharvesting segment are delayed. In 2011, a framework for common spatial planning for aquaculture, provided guidelines, directives, and criteria for the development of aquaculture, aiming to ensure protection for the environment and the competitiveness of the sector. Eleven years later, no Presidential Decrees have been issued and only six out of the 23 AZA plans have passed the controls of the Council of State (the Supreme Court of Greece) and the respective Presidential Decrees signed as of September 2022 (in Chalkidiki, Cephalonia, Oxia island, Thesprotia and Megara for fish and one more in Pieria for mussels). The fate of the remaining 17 AZA plans remains vague and the respective Presidential Decrees will be signed hopefully by November of 2024. Article 63 of Law 4964/2022 (Government Gazette A' 150/30.07.2022)[20] extended the deadline for the completion of the process of institutionalizing AZAs for two years, i.e. until 4.11.2024. As the approval of the AZAs means an increase of the production by more than 100 %, with investments in the on-growing and postharvesting facilities, the delay in the establishment of AZAs affects negatively the future of the sector.

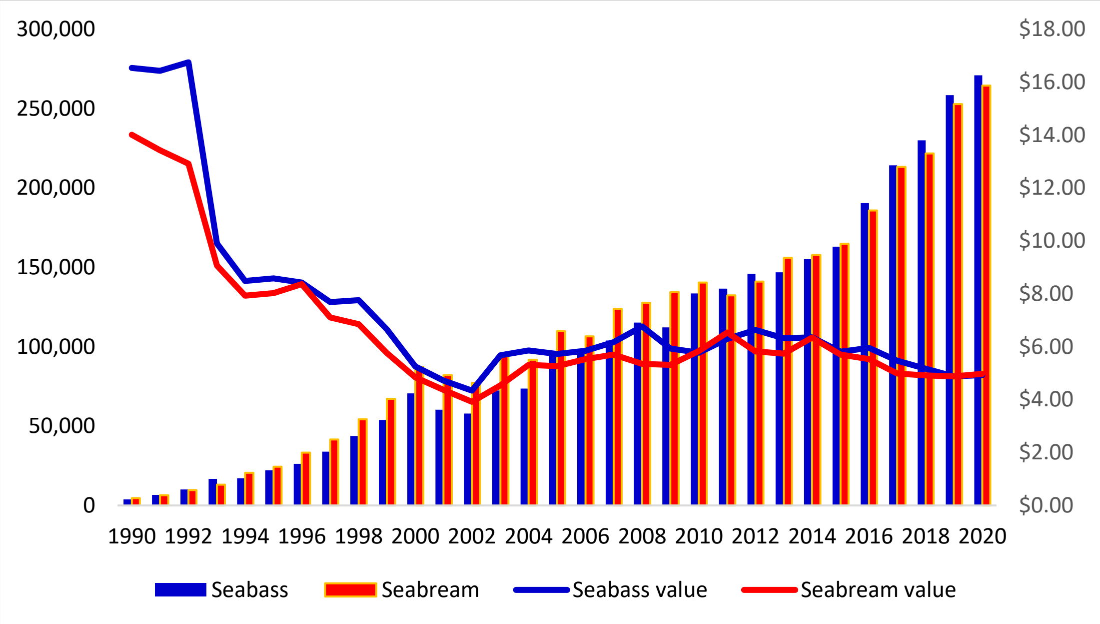


Figure 11. Gilthead seabream and European Seabass aquaculture production and price fluctuation for the period 1990–2020. *Data from FAO (2022).*

Greece and Turkey are the main producers of European seabass and farmed gilthead seabream, together accounting for close to 65 % of global Output (2019 figures) that takes place mainly in the Mediterranean basin. In 2015 and 2016 the recovery of the profitability of companies in the sector was confirmed and since then, trade data up to 2020 showed increases in the exports of the main producers, which suggest that production continues to increase. Furthermore, export prices during 2017 indicated that the price of gilthead seabream and European seabass began to adjust downward by the increased supply. This situation has shown that there is uncertainty in the industry about the potential for new price drops, due to further increases in production volumes and severely depressed prices (GLOBEFISH, 2017; 2021). This is particularly the case for Turkey, the largest producing country since 2012, whose producers can deal with price decreases thanks to the sustained depreciation of the Turkish lira. Overall throughout the EU, companies have made efforts in innovation and improvements on production efficiency (use of renewable energy sources and more efficient energy use), as well as development of new markets in EU as well as Russia, USA, Gulf Cooperation Council (GCC) countries to

[20] See: https://www.e-nomothesia.gr/kat-periballon/periballontike-adeiodotese/nomos-4964-2022-phek-150a-30-7-2022-1.html

be able to economically deal with increases in production and possible falls in price (Cidad et al., 2018).

A combination of factors, including a favourable exchange rate, government assistance and development opportunities in Middle Eastern markets has seen Turkey quickly rise to become the world's leading producer of farmed European seabass and gilthead seabream. Turkish harvests of both species, primarily from large-scale offshore cage farming operations, have more than doubled in the last decade. In the last five years or so, the production growth rate has accelerated as exporters sought to simultaneously undercut European producers in EU28 markets and avail of new opportunities elsewhere, like Russia (before the war in Ukraine), in the Middle East and the GCC countries – Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. Encouraged by their rapid market share gains, the Turkish sector pushed for further expansion, licensing and opening multiple new sites in areas such as Mersin and Hatay while increasing juvenile production. At the same time, sector-wide investment drove efforts to develop improved production processes and technologies, while growing aquaculture companies acquired and built hatcheries and feed plants to secure a more vertically integrated supply chain.

Following the expansion of European seabass and gilthead seabream, within Turkey there are now 430 companies producing fish in open water aquaculture facilities. The product is exported fresh or frozen to more than 30 countries as whole round fish, gutted, or as fillets. Some companies have been experimenting with value-added products, such as fresh or frozen ready meals or ready-to-cook meals. The focus on export markets has shielded these companies from the depreciation in the Turkish lira over the last years, which has caused the lira price of dollar-denominated raw materials to shoot up.

Prices for farmed European seabass and gilthead bream have been strong this winter, with the price of Greek 300-450 g bass reaching a multi-year peak of EUR 5.20 per kg in Italy in February of 2022. Bream prices have been lower but still above the seasonal norms observed over the last few years. This strong off-season market reflects the new market environment for European seabass and gilthead seabream, in which a more established presence at retail points supplements the traditionally important restaurant sales. With demand now strengthening and the tourist season expected to be much improved this year 2022, the outlook for the sector is good (Globefish European Price Report, March 2022).

3.3 Stakeholders' perceptions

In general, direct and indirect climate change effects on the aquaculture activities are perceived as a major concern for the Mediterranean aquaculture industry. Most stakeholders believe that climate change (i.e., global warming) will bring negative events and conditions that will induce stress in the fishes, requiring increased disease prevention and treatment strategies, feed and raw material limitations, in and out movements of the surrounding biota, unfavourable market, and logistic conditions (see also Stavrakidis-Zachou et al., 2021; Yildiz and Ganioğlu, 2020).

Extreme weather events might affect harvesting, feeding and mortality. The simulations suggest that while storm events will occur predominantly in offshore locations, both inshore and offshore locations will be eventually afflicted by heatwaves in the long-run as temperatures continue to rise, which is in line with the current understanding of heatwaves and their consequences for aquatic life as well as increased energy requirements and associated costs for cooling the environment for the PH processing.

In Turkey, since 2010 there is a National Climate Change Strategy and a national climate change action plan (National Climate Change Action Plan 2011-2023), however, these documents are not specific for fisheries and aquaculture and are more general documents.

The projections for the Mediterranean area highlight a potential rise in sea surface temperature (SST) of 1–1.5°C in the Eastern Mediterranean, Aegean, and the Adriatic Sea from 2000 to 2050 (Miladinova et al. 2017).

Resilience-building initiatives may include the following:

- Investments in the packaging facilities to better utilise the energy requirements. That includes modernisation of the facilities, use of heat pumps and modern refrigeration systems that reduce energy consumption.
- Investments in renewable energy production systems like photovoltaic solar panels and wind turbines.
- Detailed and focused guidance papers on diversified alternative logistics.

Table 18: SWOT analysis of stakeholders' perceptions for European seabass and gilthead seabream of the most influential climate change impacts and the major consequences to financial and physical resilience based on interviews.

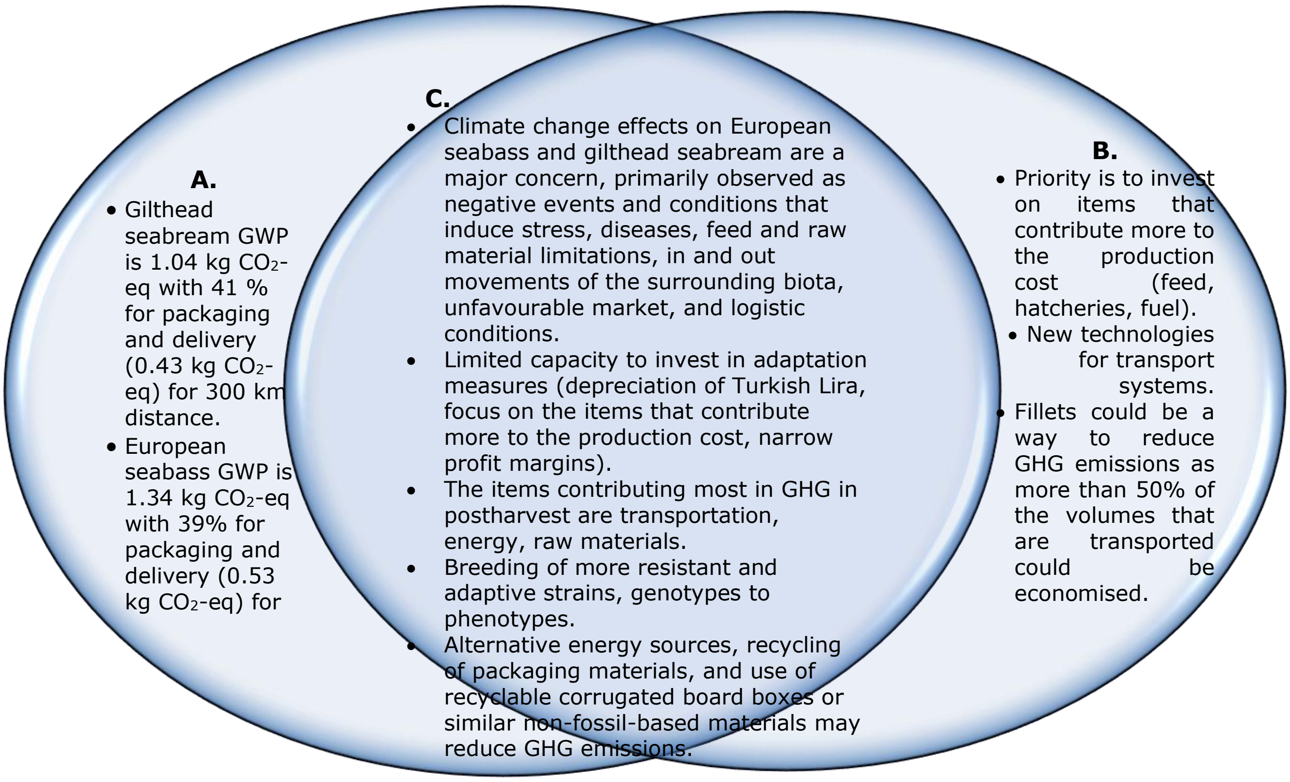
	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	Strengths In most regions, there seems to be a progressive decrease in the time to reach the market size when projecting forward in time climate change – which means strength in economic outcome. Marine fish cultivation is among the most environmental friendly food production systems, generating the least GHG emissions compared to red meat and poultry production thus increasing the PH marketing efforts to promote fish consumption. There are relatively fewer steps in the processing of European seabass and gilthead seabream compared to other seafood sectors, which reduces cost. The EU is the second-largest trader of fisheries and aquaculture products after China in 2019. The EU has a deficit in seafood trade and therefore aquaculture of European seabass and gilthead seabream will continue to be supported by EU policies.	Weaknesses Limited capacity to invest in adaptation measures due to low economic outcome/high economic costs. The major consumption countries are in the EU (Italy, Spain, France, Germany, BENELUX, Portugal), and land transport substantially increases GHG emissions and therefore potential costs of the getting products to market. High dependency for transport of the raw materials and products to the markets leading to increased GHG emissions. Increased energy cost due to the war in Ukraine and Russian revisionism. The marine spatial planning in Greece for the creation of Allocated Zones for Aquaculture (AZAs) has still not been accomplished, which means that investments in the sector, including the postharvesting segment are delayed. Low fish prices do not allow investments in new technologies.
External origin (attributes of the environment)	Opportunities Investing in renewable energy (solar panels) to reduce electricity costs in the packaging plants. The war in Ukraine might act as a catalyst and attractive incentives for investments in renewable energy sources might be given in the near future. The establishment of AZAs in Greece will lead to increased productions that will require new packaging units that could incorporate the latest technologies for reduced GHG emissions. In the EU, there are five electric truck manufacturers (with TESLA's SEMI on the way[21]). European truck manufacturers have committed to a transition to 100 % electric and hydrogen vehicles by 2040 in a joint declaration from December 2020[22]. This will contribute to transports of European seabass and gilthead seabream to EU markets with reduced GHG emissions.	Threats Aquaculture could suffer in numerous ways from warmer waters, resulting in higher disease risk and lower overall production. The geopolitical instability caused by the war in Ukraine has caused an increase of the energy cost, which could lead to what problems? The risk of a new pandemic that might lead to a new lockdown, affecting seafood consumption and exports. The delay in the marine spatial planning for the establishment of AZAs. The focus of the companies is on the feed cost and energy/fuel prices that are the major cost element compared to the PH stage.

[21] See: https://www.tesla.com/semi

[22] See: https://www.acea.auto/uploads/publications/acea-pik-joint-statement-the-transition-to-zero-emission-road-freight-trans.pdf

3.4 (Mis)Fits between literature review and stakeholders' perceptions

The impacts from European seabass and gilthead seabream aquaculture PH activities are largely in agreement between the peer-reviewed literature and from stakeholder consultation for the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gases emissions (Figure 9). Both perspectives share concerns regarding the climate change.



A. = From literature review
B. = From stakeholders' perception
C. = Overlapping as found both in literature and stakeholders' consultation

Figure 12. Agreement and divergence in the identified postharvest activities of greatest importance resulting from European seabass and gilthead seabream aquaculture from the peer-reviewed literature and from aquaculture stakeholders.

3.5 Role of management – lessons learned of adopted strategies

There is increasing evidence of the impact of climate change on the European seabass and gilthead seabream industry. Depending on the severity one assigns to the drivers of climate change, the effects can vary from insignificant to devastating for production and thus farm viability. In fact, their impact can be severe enough to overshadow the effects of all other environmental and managerial drivers which further stresses the need to view climate change holistically and not only as the result of rising temperatures. Future climate work should give emphasis in generating the necessary climate and biological data to bridge some of the existing knowledge gaps and also on including effects of additional drivers into modelling.

Mediterranean marine finfish culture that is mainly seabass and seabream, has been growing steadily over the years, but any growth strategy must seriously consider the impact of climate change, and implement adaptation and mitigation measures if the sector is to continue to thrive and prosper. Aquaculture may suffer in numerous ways from warming waters. In Egypt and Turkey small-scale fish farmers, such as those farming European seabass and gilthead seabream in earthen ponds, are among those likely to be most affected by climate change. Limited capacity to invest in adaptation measures, such as aerators, when the oxygen content of the water falls, makes them particularly vulnerable.

Climate change is also expected to lead to changes in the availability and trade of products from aquaculture and fisheries, which could have consequences for producers everywhere. The potential short-term impacts of climate change on aquaculture could include the consequences of extreme events such as storms, droughts, floods, diseases, or harmful algal blooms, which reduce yields and increase costs. In the long term reduced precipitation, warmer water, ocean acidification, and hypoxic zones will force policy and technical adaptations in the sector. Higher water temperatures can also have an impact on disease outbreaks and on the relationship between pathogens, the fish, and the water they inhabit. The current level of knowledge, however, makes it difficult to predict how climate change will affect pathogens and disease occurrence in aquaculture. On the other hand, warmer water may increase fish growth rates, as well as open up new areas for aquaculture. It may increase phytoplankton production and biodiversity which could prove beneficial for the culture of bivalves.

The geography in Turkey allows farm operations in the Black Sea, the Aegean Sea and the Mediterranean, allowing the marine aquaculture sector to optimise the distribution of species, which partly explains the growth in marine aquaculture production despite climate change. The recent outbreak of mucilage in the Sea of Marmara is linked to the climate change forcing the Government to establish a new national ministry for environment and climate change. Workshops and seminars on climate related issues are being held to discuss cross-ministerial plans of action and to create awareness of the threats posed by climate change, whereas the government is encouraging fishers and farmers to switch to renewable forms of energy and is subsidising the switch to more energy efficient equipment.

In many EU countries and Turkey, private companies are starting to implement measures that will reduce their carbon footprint. The use of renewable energy and batteries instead of fossil fuels and a greater degree of recycling are among the changes some have introduced. Kilic, the largest producer in Turkey, believes that the international certification agencies and also banks will require from the European seabass and gilthead seabream industry to demonstrate what they are doing for the environment, so there is a vested interest in making the operations more sustainable.

There are no new species that can be cultivated as successfully as European seabass and gilthead seabream, with attempts to diversify production largely foundering within the Mediterranean. Research has been carried out on many species including Meagre (*Argyrosomus regius*), Sharpsnout seabream (*Diplodus puntazzo*), Red porgy (*Pagrus pagrus*), Japanese red sea bream - Mandai (*Pagrus major*), Greater amberjack (*Seriola dumerili*), Atlantic bluefin tuna (*Thunnus thynnus*), Orange-spotted grouper (*Epinephelus coioides*), Shi drum (*Umbrina cirrosa*), Brown meagre (*Sciaena umbra*), Wreckfish (*Polyprion americanus*), Common dentex (*Dentex dentex*). However, in 2019 only 37,425.99 tonnes of meagre, 34.30 tonnes of sharpsnout seabream, 2,932.70 tonnes of red pargy, 38.57 tonnes of greater amberjack, 12,129.76 tonnes of bluefin tuna, 132.60 tonnes of shi drum and 27 tonnes of common dentex have been reported. This is versus 256,820.45 tonnes of European seabass and 252,736.64 tonnes of gilthead seabream in 2019. That means that there are still numerous technical problems growing the fish as well as potentially lack of market acceptance. Mr. Ihsan Bozan, the vice chairman of Kilic, the biggest producer of farmed fish in Turkey, mentioned that attempts to breed bluefin tuna from eggs succeeded until the fish reached some 10 kg at which point they perished.

The company finally abandoned the project because it was hugely expensive. Another project was to cultivate greater amberjack, but this too the company shelved after five or six years because despite producing the eggs each year growing those to viable juveniles proved impossible.

One species that has shown a lot of promise over the last years in Turkey is rainbow trout that is first grown on land and then introduced into cages in the Black Sea for the final grow-out. Companies use different strategies when growing the fish, some grow the fish to 200-600 g before growing them further either in cages in a dam lake or cages in the Black Sea. Other companies grow the fish to 500-1,000 g in a dam lake and then place the fish in the Black Sea where they grow to 4-5 kg or even 5-6 kg. The fish are introduced into the sea in October and stay there for six to nine months. In July the Black Sea water starts getting too warm so the fish must all be harvested. The product has found favour on the Japanese and Russian markets and its success there has encouraged producers to invest in processing facilities, where the fish can be made into value-added products such as fillets, steaks, portions, and even smoked products, for export to the EU.

4 Greenhouse Gas Emissions

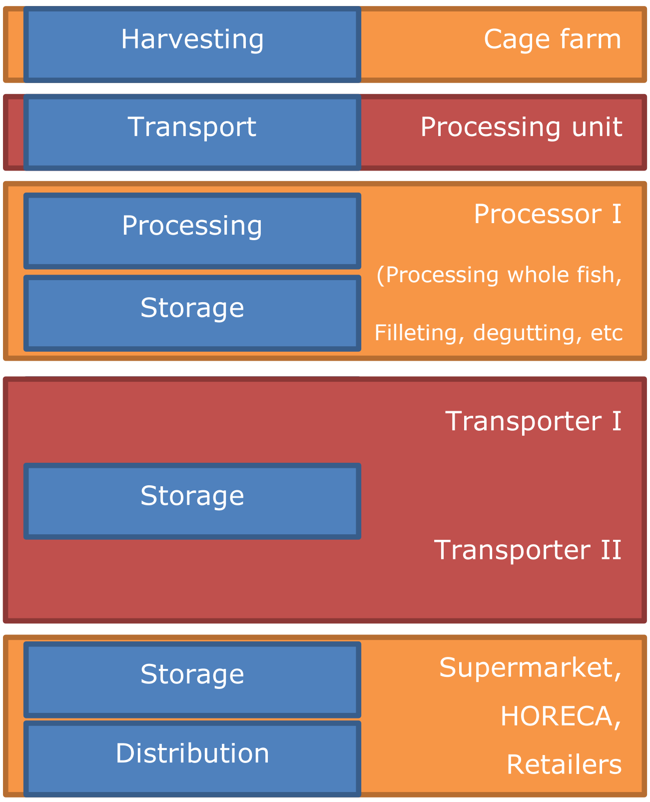
4.1 GHG emissions in the value chain

The harvesting stages have been described in detail in 2.1. Figure 13 depicts the postharvesting procedure of the European seabass and gilthead seabream value chain.

The basic weighing, batching, packaging, and palletizing line leading to fixed-weight packs, with a capacity of up to 125 fish/minute, is similar to that used in whitefish and salmon primary processing (i.e., excluding further processing such as evisceration, skinning, beheading, filleting, deboning, and slicing) (Konstantinidis et al., 2021).

In all the previous stages, energy is needed to maintain an appropriate low temperature in the packaging plant, as well as water for (a) cleaning the packaging plant, (b) employee needs (wastewater), and (c) production of ice. The waste includes paper from the packaging material (i.e., stretch film and sealing tape rolls), the waste/destroyed EPS boxes, the destroyed wooden pallets, as well as the animal by-products (viscera, gills, backbone, heads etc) depending on the processing.

Transportation type (truck and/or ferry) and routes vary according to export destinations for EU member countries. Exports to the USA are sent by air for chilled fresh products and by sea for frozen products.



From Turkey, it takes two trucks around four days to reach Italy and six days to reach the UK. According to the surveyed companies, veterinary inspections at customs, speed violations, customs waiting times and a lack of necessary documents are the main constraints and logistical problems. Exporters are responsible for the safekeeping of the product, checking the labels, preparing the necessary documents and safely delivering the product to the transporter; while transporters are responsible for protecting the cold chain and safely delivering the product to the customer on time.

The reported GHG emissions from a packaging station along with the use of material and waste production from a large company that operates several packaging stations is shown in the following Table 19.

Figure 13. Postharvesting value chain of European seabass and gilthead seabream marine aquaculture.

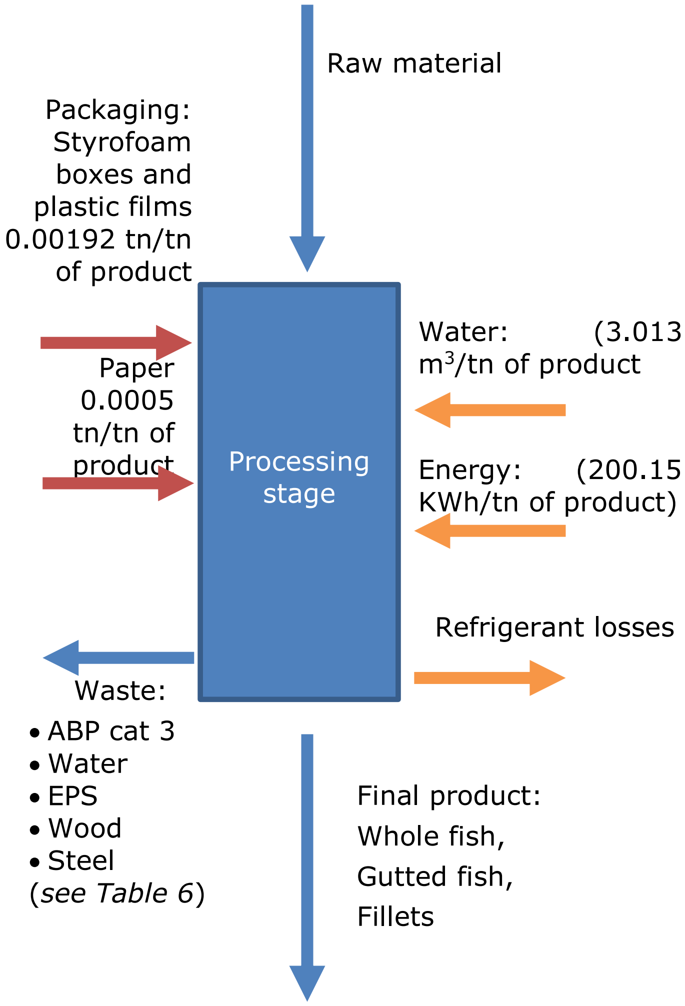


Figure 14. Materials and energy requirements for the postharvesting of 1 tonne of European seabass and gilthead seabream marine aquaculture.

Table 19: GHG emissions from packaging stations along with the use of material and waste production for the years 2015-2017.

Parameters	2015	2016	2017
CO_2 emissions	0.141 tnCO_2/tn of product	0.186 tnCO_2/tn	0.143 tnCO_2/tn
Plastics (Styrofoam boxes and plastic films)	0.00169 tn/tn of product	0.001484 tn/tn	0.0026 tn/tn
Filter waste material	---	0.000036 tn/tn	---
Sewage sludge	0.000042 tn/tn of product	0.000057 tn/tn	0.0431 tn/tn
Paper	0.0005 tn/tn of product	0.000374 tn/tn	0.00017 tn/tn
Energy (KWh)	165.65 KWh/tn of product	219.8 KWh/tn	215 KWh/tn
Water	2.1189 m^3/tn of product	3.7 m^3/tn	3.22 m^3/tn

Parameters	2015	2016	2017
Lubricants	0.000015		
Lamps	0.00000363 tn/tn of product		

4.2 Alternate distribution systems

Currently there are limited distribution systems for the transport of European seabass and gilthead seabream and the majority are transported by trucks. Transportation type (truck, ferry, plane) as well as routes vary according to export destinations for EU member countries. Exports to the USA are sent by air for chilled fresh products and by sea for frozen products.

From Turkey, it takes around four days to reach Italy and six days to reach the UK by truck. As stated above, and according to a WWF 2021 report, veterinary inspections at customs, speed violations, customs waiting times and a lack of necessary documents are the main constraints and logistical problems. Exporters are responsible for the safekeeping of the product, checking the labels, preparing the necessary documents and safely delivering the product to the transporter; while transporters are responsible for protecting the cold chain and safely delivering the product to the customer on time.

Many truck manufacturers have announced interim targets for the transition to electric and hydrogen in the heavy-duty vehicle market. Scania expects that electrified vehicles will account for around 10 % of total vehicle sales volumes in Europe by 2025, and by 2030, 50 % of total vehicle sales volumes are expected to be electrified. Volvo, the world's second largest truck manufacturer, says they want to achieve 50 % electric sales in Europe by 2030 and 100 % electric and hydrogen sales by 2040. MAN plans to adopt its production so that 60 % of delivery trucks and 40 % of long-haul trucks will be zero-emission by 2030. Daimler, the world's largest truck manufacturer, announced that all new trucks it sells will be zero-emission by 2039. IVECO and DAF were parties to the declaration that 2040 should be the last year that diesel trucks are sold in Europe. DAF's electric offering is more advanced than that of IVECO at the moment.

Since the transportation of goods is responsible for an increased GHG emissions footprint (see Supplementary 1), the transportation industry provides solid signs of responding as the main European truck manufacturers — Daimler, Traton and Volvo — announced the creation of a $600 million joint venture to deploy an electric battery-charging network for long-haul trucks and buses in Europe starting in 2022[23].

4.3 Limitations for structural improvements in GHG emissions

The surveyed stakeholders expect climate change to have a negative impact on production, immunity, disease risk, water quality, fish biology and the ecosystem. Focusing on the PH, there are no clear plans for structural improvements in the GHG emissions in the PH section. With the late energy crisis, it seems that the companies mainly worry and focus their priority in the main production units as the main cost element lies therein. The main raw materials used in the production of European seabass and gilthead seabream are fish feed (57 % - 59 % of the production cost) and juveniles (13 % - 16 %). Together they represent a total of 70 % of production costs (FGM, 2019). The remaining 30 % varies according to the size and organization of each company and is

[23] See: https://climatechampions.unfccc.int/5-ways-the-eus-new-climate-target-will-transform-global-electric-transportation/

divided into labour costs (13 %), depreciation (2 %) and other operating expenses (16 %).

Some stakeholders reported that they prefer to focus investments on hatcheries as the energy cost is much higher there by replacing the lamps with LED, boiler systems by heat pumps and improve the hot-cold water exchanger systems. In addition, many stakeholders are trying to improve their feeding systems as feed is 58 % of the production cost.

5 Reducing GHG emissions by technical means

5.1 Trends in technological evolutions and industrial strategies

In the European seabass and gilthead seabream industry the main production cost is the fish feed. Therefore, the sector mainly invests in the pre-harvest phase in systems that will reduce the feed loss and much less in the PH phase where the production cost is a lot less.

Table 20: Comparative energy and CO_2 emissions from European seabass and gilthead seabream farms (cages), hatcheries and packaging stations for the years 2015-2017.

Parameters	2015	2016	2017
Fish farms			
Energy	175 kWh/tn of product	175 kWh/tn	102 kWh/tn
CO_2 emissions	0.1488 $tnCO_2$/tn of product	0.1488 $tnCO_2$/tn	0.0662 $tnCO_2$/tn
Hatcheries			
Energy			126.081 MWh/10^6
CO_2 emissions	157.33 $tnCO_2/10^6$ fish fry	140.79 $tnCO_2/10^6$	82.00 $tnCO_2/10^6$
Packaging stations			
Energy (KWh)	165.65 kWh/tn of product	219.8 kWh/tn	215 kWh/tn
CO_2 emissions	0.141 $tnCO_2$/tn of product	0.186 $tnCO_2$/tn	0.143 $tnCO_2$/tn

Equipment providers for packaging and fileting systems, engines for the vessels, cooling systems and ice production are of crucial importance for stimulating energy savings in the sector.

All companies use stunning methods for killing fish at harvest. The majority use ice stunning, and a few electrical stunning. Ice stunning (thermal shock) is the more traditional method, however electrical stunning has recently become more popular specifically for sea bream.

The grading and packaging system is composed of several units:

The Weighing unit. It is weighing a continuous stream of individually separated pieces of European seabass and gilthead seabream.

Control unit. Touch-sensitive and IP69 water resistant. Built-in Ethernet connection links to standard PCs and a production management software.

Packing unit. Each packing unit is equipped with a holding bin, a pack-off chute and a tilted packing table for full visibility and easy access. Gate division is 700mm for easy removal and rotation of finished packages.

Label printing. Several labelling options available where barcode and real-time information can be printed for each batch.

Box take-away. Built-in take-away conveyor for delivering complete boxes to common exit point.

The system has a capacity to pack 125 pieces per minute. The belt system has a speed up to 1.8 m/sec. Voltage 3 x 400 V + N / 3 X 230 v 50/60 Htz. Fish are packed in insulated boxes in which ice is added in order to achieve the optimum storage temperature. The packed boxes are loaded onto pallets and placed in refrigerated storage facilities to maintain a low temperature. There are two main packaging types, one for truck transport and a second for air freight shipping, with a net weight of 6 or 10 kilograms. The packaging station requires also an ice making machine as well as a refrigerator to store the packed fish.

Filleting is done either manually or using machines. Filleting can reduce the transportation cost, however it remains to be checked whether the new packaging material and modified atmosphere will have any effect to the GHG reduction.

5.2 New processing and logistic techniques and their challenges

The largest gain of reducing GHG emissions in the PH sector can be expected from the electricity cost as well as the transportation cost. In Turkey, the weak Turkish foreign exchange rate has a positive impact on exports but a negative impact on imported raw material (mainly fishmeal and fish oil) as well as the high energy cost would lead to increasing production costs.

Filleting is the new trend that could reduce the GHG emissions per tonne of product as 40-45 % of the product will be now transported instead of the whole fish.

6 Conclusions

For European seabass and gilthead seabream, packaging and delivery (for 300 km) contribute to the Global Warming Potential (GWP) by 41 %, whereas feed production and rearing contribute to GWP by 10 % and 49 % respectively (Kallitsis et al., 2020). Given that the majority of the fish production takes place in Turkey and Greece and they are exported by 70-80 % all over Europe and overseas often in distances of 2-5,000 km, the GWP due to packaging and delivery is much higher in reality, exceeding easily 60 %. The packaging and delivery process' GWP was primarily driven by polystyrene production (48 %) and electricity that is needed for the operation (40 %) (Kallitsis et al., 2020).

The two species constitute the main finfish aquaculture industry in the Mediterranean and the second most important in the EU after salmon, whereas since the EU exit it is the most important in the EU.

For the two species, the reported GWP on a 100 g edible protein basis for packaging and delivery is 0.43 to 0.52 kg CO_2-eq for gilthead seabream and European seabass respectively for a distance of 300km. These values are increasing depending on the distance of the final destination markets. The reported GWP values for European seabass and gilthead seabream are lower than those of ruminant meat and very similar to poultry and pork and they are at the lower end of the spectrum for other aquaculture products (Poore et al., 2019; Tilman et al., 2014). It is important also that the electricity production energy mix, meaning the range of energy sources used for electricity production, affects the GWP. The lower the energy mix in hydrocarbons (petroleum products and natural gas) and solid fossil fuels and the higher in renewable energy sources, will favour the GWP footprint and will reduce the climate impact of the aquaculture industry.

The current distribution systems to the destination markets in Europe, Middle East and GCC countries are primarily with trucks, whereas exports to the USA are sent by air for chilled fresh products and by sea for frozen products. If truck manufacturers will provide alternative distribution systems using electricity (i.e. batteries) or hydrogen in competitive prices, the GHG emissions footprint will be reduced.

In the Mediterranean Sea, domestic markets prefer fresh fish rather than value added processed (e.g. fresh or frozen fillets) and therefore processing facilities tend to be export-oriented. On average, stakeholders in Greece and Turkey reported that 20-30 % of total products are shipped to domestic markets, while 70-80 % are exported. The main export destinations reported by the surveyed facilities are the EU, UK, USA, Russian Federation and Arabic countries. All packaging stations and processing facilities use land routes for transportation of their products, while they also use air and sea routes for transporting to the USA market. Processors believe that climate change will have a negative impact on the stability of fish prices. The surveyed stakeholders declared they had an adaptation or mitigation policy for climate change, which included investments for more energy efficient systems (e.g. heat pumps, LED lights, installation of photovoltaic panels) and recycling schemes.

Turkey as a non-EU country reported complex and inconsistent legislation as well as low fish prices (up to last year) as the main existing constraints. As far as exports are concerned, lack of cold-storage facilities at airports for exports to North American markets are the main issues that the companies are facing. Raw material availability and the economic sustainability of European seabass and gilthead seabream production in the Aegean Sea are the main future concerns reported by the surveyed facilities in Turkey.

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Supplementary 1: GHG emissions by modality

EcoTransit and IMO Fourth Greenhouse Gas Study 2020 (imo.org)

Modality	**Primary energy equiv. MJ per ton.km**	**Associated GHG emissions (kg per ton km)**
Delivery van	31.38063902	1.9507
Delivery van, full load capacity used, empty return	11.30	0.7022
Lorry, very large (>32ton)	1.45	0.0848
Truck, large	2.79	0.1699
Truck, medium	3.57	0.2199
Truck, small	8.44	0.5253
Cargo train, electric	0.82	0.0468
Cargo train, diesel	0.87	0.0593
Inland cargo ship	0.71	0.0517
Sea ship, cargo	0.18	0.0115
Sea ship, containers	0.33	0.0210
Air cargo, continental	26.17764966	1.7004
Air cargo, intercontinental	16.88029816	1.0959
Non-motorized	0.00	0.0000

CASE STUDY 10: ROUNDFISH - BALTIC COD (*GADUS MORHUA*) AND COMMON BREAM (*ABRAMIS BRAMA*) – SWEDEN

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Photo: mostphotos.com

Johan Blomquist, Cecilia Hammarlund, William Sidemo-Holm, Staffan Waldo

LIST OF ABBREVIATIONS

Term	Description
GHG	Green House Gas
ICA	Major Swedish food retail chain
MSC	Marine Stewardship Council
SEK	Swedish Krona (approximately 0.1 Euro)

Term	Description
SSB	Spawning Stock Biomass
SwAM	Swedish Agency for Marine and Water Management
TAC	Total Allowable Catch
GPM	Gross Profit Margin
WWF	World Wildlife Fund

1 Background

Cod (*Gadus morhua*) used to be one of the main species targeted by the fishing industry in the Baltic Sea, along with herring, sprat and flatfish (ICES, 2019). Cod fisheries target the populations in the south and west parts of the Baltic Sea (known as the western and eastern cod stocks). While these populations have fluctuated historically, driven by changes in biological factors and fishing pressure, the fishery has faced a radical development from annual catches of about 350 000 tons in the early 1980s (ICES, 2019) to the current landing moratorium starting in 2019.

The main underpinning drivers to the negative development for the Baltic Sea cod fisheries include increased hypoxia in reproduction and feeding environments, fishing pressure, and interactions with other species (ICES, 2019). By affecting these and additional drivers, climate change is expected to have an increasing impact on both the cod population and the fishing industry in the coming decades (HELCOM, 2021). However, Froese et al. (2022) find climate change to be less of an issue than fisheries regulation for the recent development of the western cod stock.

This CS focuses on understanding effects of climate change on cod populations and landings in the Baltic Sea and how this in turn may affect the resilience of the Swedish fish processing industry. To this end, we analyzed historical data rather than using interviews as was done in other case studies. Due to large variations in the Baltic Sea cod stocks (Figure 1), an assessment of the Swedish processing industry can be useful to understand the resilience of the industry to changes in domestic fish stocks. As a final step of the analysis, Common bream (*Abramis brama*) is analyzed as an alternative species for the Swedish domestic processing industry and problems and possibilities for the bream industry are discussed in a climate change context.

2 Cod fisheries in the Baltic Sea

2.1 Historical development

For the Swedish Baltic Sea cod case a full value chain analysis is not provided since focus is on the development of the industry over time to understand the impact of climate change, and not the 2022 situation. The development of the stock, the size distribution, and total landings of cod going into the Swedish market is presented in Figure below. As is clear from the figure, landings are basically zero after having declined from about 20 000 tons domestic landings in 2000.

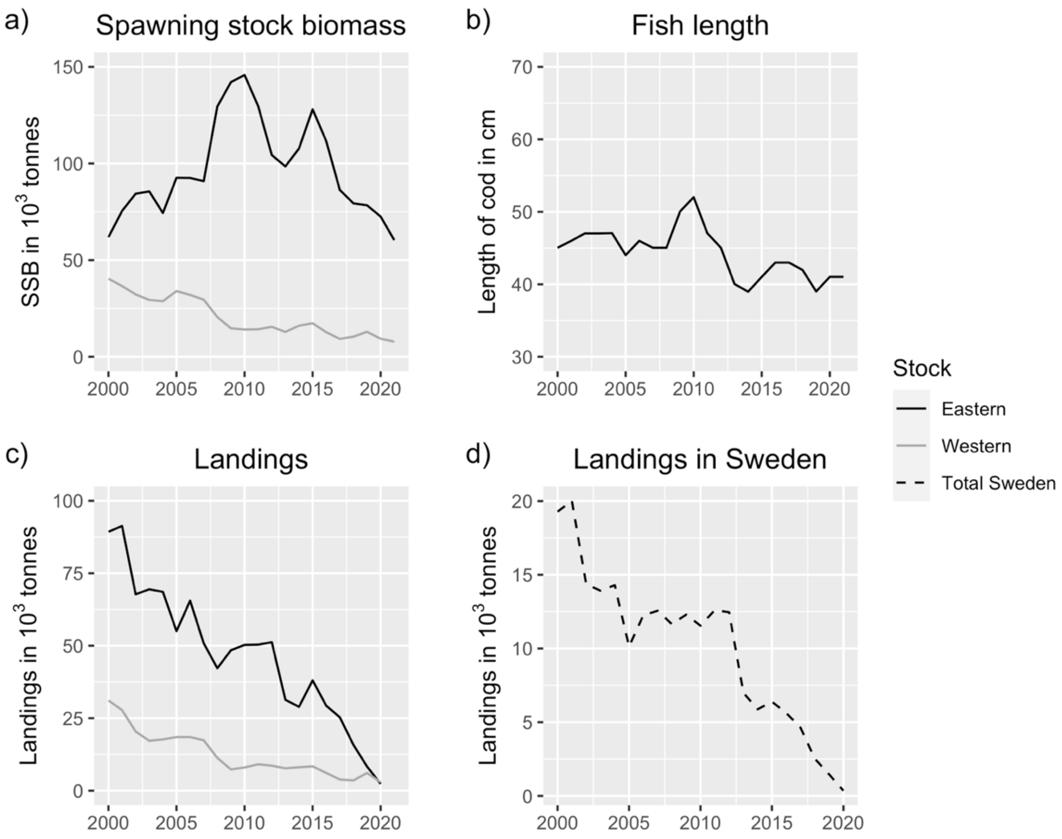

Figure 1 a) Spawning Stock Biomass, b) fish length and c and d) landings of Baltic Sea cod. Source: ICES, 2021a; ICES, 21021b; SwAM, 2022.

2.2 Climate change impact

Climate change affects the Baltic Sea by increasing average water temperatures, increasing precipitation (especially in the norther parts), rising the sea level and decreasing the pH (Christensen and Kjellström, 2018; Gustafsson and Gustafsson, 2020; Meier and Saraiva, 2020). The impact of increased water temperatures is expected to be negative for cod recruitment (successful reproduction and survival of offspring[24]) and body conditions, both directly and via changes in zooplankton communities (Goginaet, et al., 2020; Snickars, et al., 2015) and fish prey distribution (MacKenzie and Köster, 2004). For instance, sprat may expand northwardly when water temperatures increase (MacKenzie and Köster, 2004), which may not be the case for cod that live close to the bottom where temperatures will not change to the same extent due to vertical stratification (see below).

Climate changes may also affect cod by exacerbating hypoxia in reproduction and feeding areas (Saraiva, et al., 2019a, b). This can be driven by a reinforced vertical water stratification which prevents oxygen-rich surface water from mixing with deeper oxygen-depleted waters. The stratification is expected to be reinforced by greater temperature contrasts between surface and bottom waters (Gröger, et al., 2019) and salinity contrasts when more saltwater enters through Kattegat due to sea-level rise (Meier, et al., 2017) in combination with more freshwater entering from precipitation and river runoff (Vuorinen, et al., 2015). Climate change may also reinforce hypoxia by increasing the phytoplankton biomass consumed by decomposers. This is expected to be underpinned by increasing

[24] This is in line with the main scenarios in Bastardie, et al., forthcoming.

precipitation that brings higher inflows of nutrients to rivers discharging into the Baltic Sea, as well as rising water temperatures (Saraiva et al., 2019a). Hypoxia is known to impair cod recruitment, body growth and survival, both directly (Limburg and Casini, 2019) and by affecting their prey (Gogina et al., 2020; Snickars et al., 2015).

In addition to affecting cod via hypoxia, changes in salinity may affect cod by reducing its distribution in the north, where salinity is expected to decrease, while benefiting cod in the south where the salinity will increase due to sea live rises (Nissling and Westin, 1997). Other potential outcomes from climate change for which the impact on cod is more uncertain include decreased pH as the atmospheric partial pressure of CO_2 rises (Gustafsson and Gustafsson, 2020; Stiasny, et al., 2016), changes in predation pressure from grey seal and cormorant (Svels, et al., 2019) and establishment and range expansion of non-indigenous species (Rahel and Olden, 2008). As an example of the latter, climate change will likely benefit the non-indigenous species round goby, which prey on cod eggs but are also consumed by adult cods (Kornis, et al., 2012).

While climate change is expected to affect cod in various ways, of which many will be negative, it is complex to predict the net effect due to uncertainties and limited scientific evidence. Furthermore, there may be complex interactions between drivers in the environment, ecosystem and society, which are difficult to account for (Möllmann, et al., 2009; Pekcan-Hekim, et al., 2016). For instance, an increased salinity in the southern parts of the Baltic Sea may not lead to a higher cod SSB if other negative factors persist, such as an unsustainable fishing pressure or poor oxygen conditions. To better predict net effects of climate change on the Baltic Sea cod fisheries, there is a need to explain the causal relationships and interactions by means of monitoring and experimental modelling.

3 Impact of climate change on the value chain

It is generally assumed that climate change will mainly affect the Baltic Sea cod processing industry via changes in the SSB and fish conditions, as described above. In addition, climate change may contribute to a slower growth of cod individuals (Rogers, et al., 2011). A decline in average length of the fish (as seen since 2010, Figure 1B) affects the processing industry since small cod is harder to process into valuable fillets. Hammarlund (2015) analysed prices for different size categories of cod where she finds small cod to be less valued on the market and that price differences of different size categories become more important over time. Whereas real prices of larger cod increase between 1997 and 2011, the price of the smallest sized cod (with a weight between 0.3 and 1 kilo) is unchanged.

Two issues relevant for the quality of the cod going into the processing industry are the existence of very slim cod (see e.g. Neuenfeld et al., 2020) and the presence of parasites in the flesh (Sokolova et al., 2018). Thin cod are low valued for human consumption since these cod do not have enough fillet to process. The presence of parasites in the flesh stems from an increasing grey seal population, which host the parasites for part of their life cycles. The parasites need to be removed before putting the fillets on the market, which is a costly process.

The decline of the Baltic Sea cod stocks has further caused Swedish consumers to heavily reduce consumption of domestic cod (Carpenter et al., 2021; see also import statistics in figure 2 below). The cod fishery in the eastern Baltic lost its MSC certification in 2015 (Blomquist et al. 2020) and as shown in Carpenter et al. (2021), environmental labelling is extremely important for entering the Swedish value chain for cod. For example, the major food retail chain in Sweden, ICA, has a policy to follow the WWF fish guide and avoid red listed species as much as possible (ICA, 2020). Further, Carpenter et al. (2021) find that in 2020 there was only one major processor left processing cod on the Swedish Baltic Sea coastline. They provided transport services along the coast including landings from both the eastern and western cod stocks thus connecting these fisheries to a single market. During the cod moratorium, they have imported cod to keep the factories open, although they would prefer domestically landed cod due to customer's demand.

Declining landings, lost MSC certification, parasites, smaller fish, and a strong consumer demand for environmentally labelled cod products are potential drivers of an increase in cod imports thus leaving out Swedish cod from the value chain. The development of imports and exports of cod products at different levels of processing is presented below.

3.1 Physical resilience

The compensation of the reduced landings from the Baltic Sea with increased imports has mitigated the negative impact on the fish processing industry. We use trade statistics of the value of cod products (see Supplementary Material 1 for products included) to examine this development. Figure 2 shows how the value of cod imports[25] to Sweden developed between 2000 and 2020. It is clear that imports increased steadily beginning in 2008. In 2020, the value of imports was around one billion SEK.

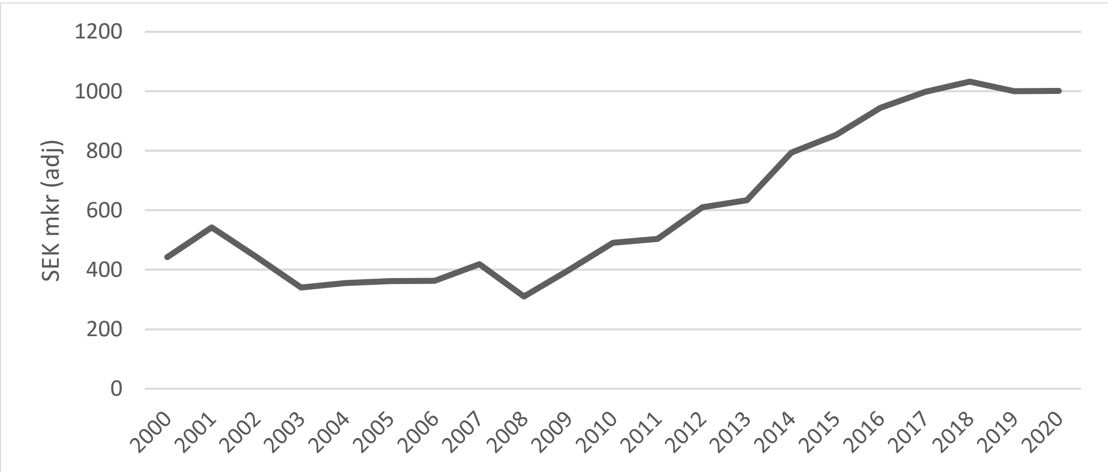

Figure 2: Imports of cod, 2000-2020[26] Source: Statistics Sweden (Trade statistics).

Figure 2 shows imports of different categories of cod. Imports of frozen fillets are dominating and there is a large increase after 2013 for this category. In 2020 the value of frozen fillets imports was more than 600 million SEK. However, it is clear that also imports of other product categories have increased. Imports of fresh and chilled cod, whole and fillets, increased as well as imports of prepared cod.

[25] The officially provided trade data at Statistics Sweden contain all registered imports and exports, not taking into account that some trade may not have Sweden as the final destination. Since we are interested in the development of the Swedish value-chain for cod we need to clear the data from trade that is passing through the country. Thus, we use data on so-called quasi-imports, i.e. goods that are imported to Sweden but are destined for another EU member state (European Commission 2012). See Annex A for product categories that are included.

[26] The values are adjusted using a consumer price index found at https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__PR__PR0101__PR0101A/KPIFastAmed/

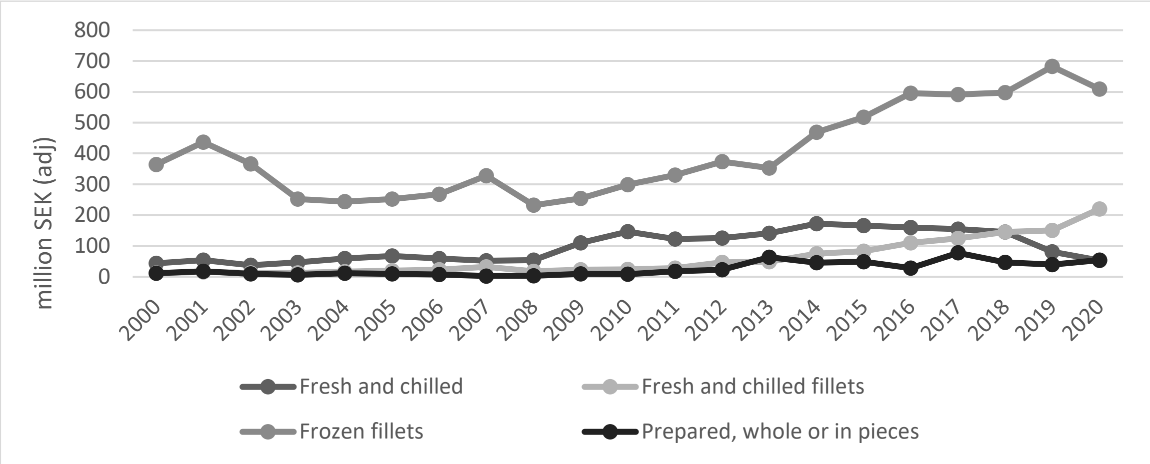

Figure 3: Import values of cod, different product forms, 2000-2020[27] Source: Statistics Sweden (Trade statistics).

Next, we examine exports of processed cod to give an idea how the processing industry has developed products for the non-domestic market[28]. Omitting categories with salted or dried cod and deducting quasi-imports, i.e. imports that do not have Sweden as the final destination (se footnote 2), from officially reported exports give an idea of the direction of the development of exports over time. However, this results in a number of negative values for exports for some years and categories, which is not convincing. Setting negative values to zero gives a somewhat better measure. However, the data should be interpreted with caution since quasi-imports cannot, as mentioned in footnote 5, be directly linked to exports. Figure 4 shows the development of exports of cod.

Figure 4: Exports of cod (excluding dried and salted cod), 2000-2020[29]

Figure 4 suggests that exports have decreased during the studied time period. Although there is only a small amount of processed cod exported from Sweden it may be worth looking at this product category more closely as the data are more reliable in this case

[27] The four categories constituted 97.2 % of cod imports in 2000-2020. The values are adjusted using a consumer price index.

[28] Export data are more uncertain than import data since we have no clear information on how quasi-imports enter the export data. The share of quasi-imports in officially reported exports is 96 percent on average where the exports of salted and dried cod are almost entirely consisting of quasi-imports.

[29] The values are adjusted using a consumer price index. Export data are more uncertain than import data since we have no clear information on how quasi- imports enter the export data. The share of quasi-imports in officially reported exports is 96 percent on average where the exports of salted and dried cod are almost entirely consisting of quasi-imports. See Annex A for a definition of included product categories.

because of the low share of quasi-imports. Quasi-imports are less than one percent of officially reported exports. Figure 5 below shows exports of processed cod.

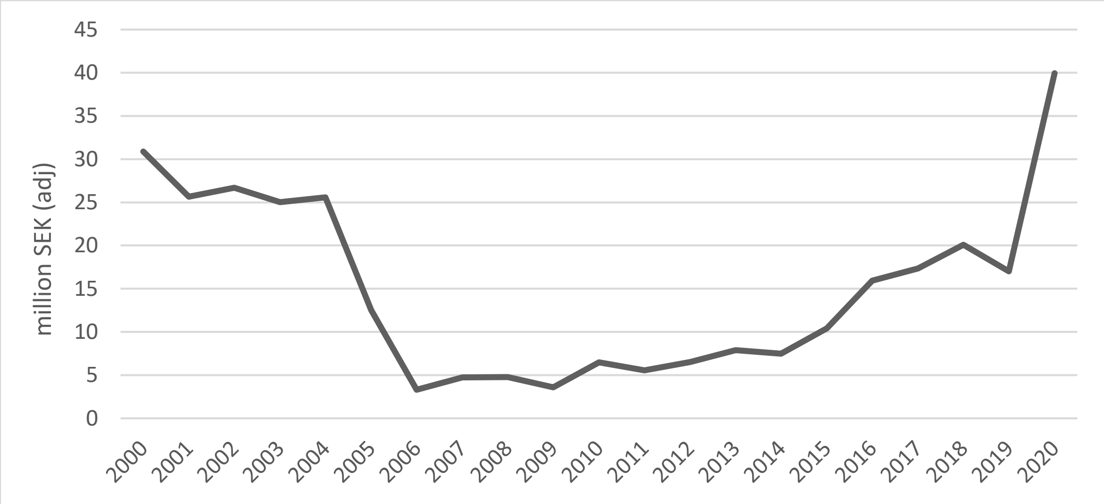

Figure 5: Exports of processed cod, 2000-2020.

Between 2004 and 2006, there was a sharp decrease in exports. However, from 2009 onwards it has increased again with a sharp increase in 2020 where export of processed cod was 40 million SEK.

3.2 Financial resilience

In this section, we take a closer look at the financial resilience of the Swedish fish-processing sector. In particular, it is interesting to see if the processing firms have been able to mitigate the effects of decreased landings of cod evident in Figure 1d. This will indicate how resilient the processing industry is to potential effects of climate change on the Baltic Sea cod population. From the Figure 1d, we see that the landings of cod dropped significantly between 2012 and 2013, from around 12500 to 7000 tons, and continued to decrease substantially in the subsequent period. To investigate the economic performance of the Swedish processing sector during this period, we use firm-level data provided by Statistics Sweden. The focus is on two economic indicators: (i) the gross profit margin (value added divided by net sales), and (ii) the share and fish imports to net sales. The first indicator is used to see if there has been a shift in firm profitability before and after the year 2012. The second indicator is used to see if processing firms are more dependent on imported fish after 2012.

Figure 6 shows, on the left y-axis, the gross profit margin (GPM) between 2003 and 2018 for firms in fish processing (later years not available). The right y-axis shows the value of fish imports divided by net sales. Looking first at imports, it is evident that processing firms have increased their fish imports significantly after 2012. Before 2012 the share of imports to net revenues was relatively stable around 0.25. In later years, this number has increased to around 0.45-0.50. However, as can be seen, increased dependency on imports has not lowered the average gross profit margin, which has been relatively constant over the period, at least up to 2015. Thus, the figure suggests that increased imports in recent years has not significantly lowered the profitability of Swedish processing firms.

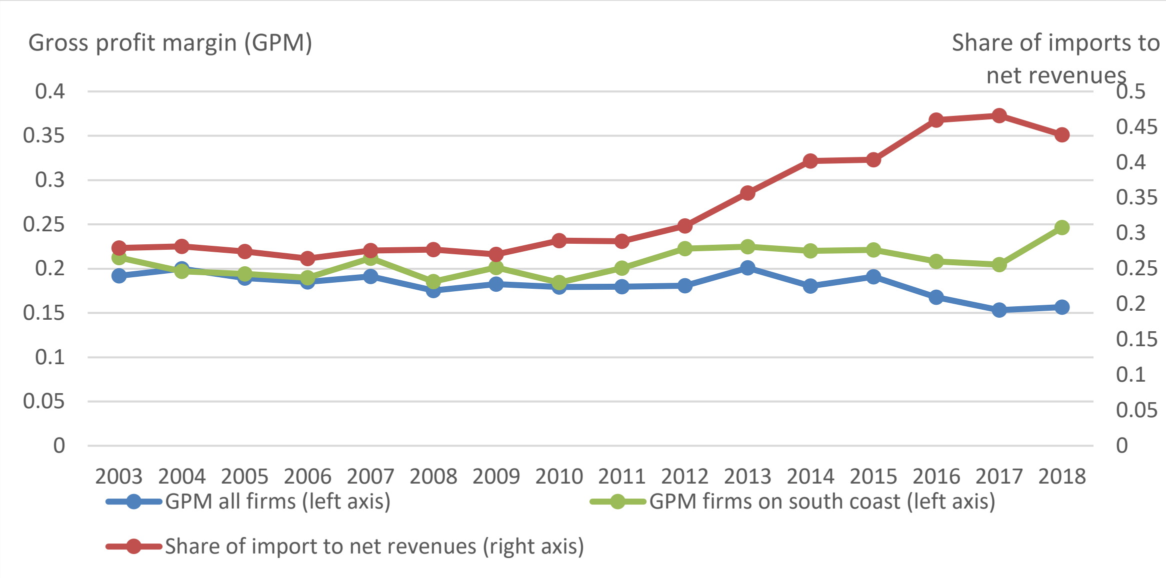

Figure 6. Gross profit margin and imports; fish processing firms in Sweden 2003-2018. Source: Statistics Sweden (Structural Business Statistics).

During the period 2003-2020, more than 90 percent of the Baltic cod catches from Swedish vessels were landed on the south coast of Sweden (counties of Skåne and Blekinge). As can be seen in the figure, the gross profit margin of the processing firms in these counties has also been stable around 0.2 during this period. The margin has actually increased somewhat from 0.20 in the period 2003-2012, to 0.22 in the period 2013-2018, which suggests that firms in this region show economic resilience to the dramatic changes in cod landings.

3.3 Climate change adaptation of the fish processing industry (bream)

Here we focus on how the fish processing industry can adapt to climate change by increasingly change to species that are predicted to benefit from climate change. Two main fish groups in the Baltic Sea that are projected to benefit from climate change are sprat and cyprinids (e.g., bream, roach and ide) (Lefébure, Larsson and Byström, 2011; MacKenzie and Köster, 2004; Polte, et al., 2021; Dahlin, et al., 2021). While sprat is a major species for the Baltic Sea fisheries that is primarily fished for the fishmeal market (see CS 1), cyprinids are still not landed to any larger extent. Below, focus is on the untapped potential of fishing Common bream as a species that can be consumed as an alternative to cod.[30]

Bream is fished using passive gear in the Baltic Sea and Swedish freshwater lakes. It is viewed as a fish well suited for consumption due to low fat content and low risk of accumulating marine toxins (Waldetoft & Karlsson, 2020). However, the current production is small, about 100 tons in freshwater (SwAM, 2021) and 5-20 tons in the Baltic Sea. This is considerably less than historical Swedish cod landings (e.g. more than 10 000 tons from the Eastern cod stock in 2010 (ICES, 2021)). If the utilization of the bream

[30] Note that bream is one of the species included in the case study for carp fish in Sweden and Poland (CS11).

resource is to increase, it is necessary that this is possible from both a biological and economic perspective.

From a biological perspective, the sustainable production potential for bream from both fresh- and marine waters are unknown. Hornborg and Främberg (2020) estimated that about 650 tonnes of carp fishes could be landed as by-catch from inland fisheries, but this also includes other carp species than bream. In addition to by-catch, carp fishes are on a regular basis a target for bio-manipulation of smaller Swedish lakes where the population levels are reduced in order to improve water quality. Turning to bream specifically, there are no biological estimates of maximum sustainable yields in either freshwater lakes or the Baltic Sea. Thus, it is currently not possible to define the biological limit for bream production, but it is likely to be considerably below that of cod. Notably, bream consists of many small populations which potentially makes biological advice expensive compared to the potential gains from fishing.

A fish stock that is biologically underutilized (i.e. it is possible to sustainably increase the fishing pressure) might not be underutilized from an economic perspective. For fisheries to be profitable, it is necessary that the consumers are willing to buy the products. Bream is not widely consumed in Sweden and the fishing industry is currently in the process of developing products for the consumer market, e.g. minced bream for school lunches and restaurants. In a survey to freshwater fishers, the respondents claim that the price for bream needs to be approximately the same as for cod (approximately EUR2 per kilo 2020) for them to increase the landings. Two issues for the expansion of the bream product production raised by the processing industry are the necessity of improved technical equipment to reduce processing costs, and local fishery specific regulations that affect landings (Malmström and Waldo, 2021). Further, the lack of biological advice is considered an issue by the industry since it effectively stops environmental labelling of the products despite the species being considered biologically underutilized.

In interviews with focus on climate change, representatives from the processing industry further highlight the problems discussed above with limited knowledge of the biological sustainability of the fishery (no systematic stock analyses) which affects opportunities for environmental labelling. They also mention problems with introducing new products on the market and expanding the production of current products. The latter is both due to low demand of carp fishes in Sweden today, but also due to bream not being competitive due to high prices (e.g. on the market for minced fish the entire fish is minced while for competing species such as cod the minced meat is a cheap by-product from the production of fillets). On the cost side, the industry is concerned about possible higher fuel prices and thus higher production costs of a product that is already not price competitive. Further, high costs due to e.g. storms affecting fisheries were mentioned.

4 Conclusions

The main underpinning drivers to the negative development for the Baltic Sea cod population include increased hypoxia, high fishing pressure, and interactions with other species. By affecting both these and additional drivers, climate change is expected to have a negative impact on both the cod population and the fishing industry in the coming years. While climate change will be an important factor in the future, past events provide information on how the PH value chain has been affected by changing environmental conditions. The Baltic Sea fisheries has experienced a steady decline in cod landings over the past two decades. The results from the study show that:

- Climate change may contribute to slower growth of cod individuals. This affects the processing industry since small cod is harder to process into valuable fillets. Small cod is less valued on the market and the price difference compared to larger size categories has become more important over time.

- Declining landings, lost MSC certification, and strong consumer demand for environmentally labelled cod products decrease the use of local cod catches in the Swedish value chain.
- Cod imports to Sweden (primarily from Norway) have increased from about SEK 300 million in 2008 to about SEK 1000 million in 2020 (SEK 1 ≈ 0.1 Euro). Total cod exports have declined although exports of processed cod have recovered slightly since 2006.
- The Swedish processing industry has become more reliant on fish import since 2012. Increased imports have, however, not significantly lowered the profitability of the industry. However, data are not available for a specific analysis of cod processing firms.
- Cyprinids, such as bream, are an alternative to cod since they are expected to benefit from a warmer climate. However, markets and management are not yet well developed, and the future landing volumes are likely to be lower than traditional cod landings.

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Supplementary 1: Categories containing Atlantic cod in trade statistics 2020-2022

Data on exports and imports are from Statistics Sweden for 2000-2020. We search for the phrase "gadus morhua", i.e. Atlantic cod, in 8-digit codes of the combined nomenclature used to classify trade in the European Union. Data is not adjusted for missing observations at this level. The threshold for reporting exports is 4.5 million SEK and for imports 9 million SEK (SCB, 2022) meaning that the smallest firms are not included in the data.[31] We find 10 codes that include "gadus morhua" as described below:

Table A1: Categories containing Atlantic cod in trade statistics 2020-2022.

CN-code	Type of processing	Comment
0302 5110	Fresh and chilled	0302 5010 from 2000 to 2011
0303 6310	Frozen	0303 5210 before 2012 and 0303 6011 before 2007
0304 4410	Fresh and chilled fillets	Also includes gadus ogac, gadus macrocephalus and boreogadus saida, 0304 1931 before 2012 and 03041031 before 2007.
0304 7190	Frozen fillets	Also includes gadus ogac and boreogadus saida, 03042929 before 2012 and 03042029 before 2007.
0304 9525	Frozen - chopped or ground	0304 9933 before 2012.
0305 3219	Dried or salted fillets	Also includes gadus ogac and gadus microcephalus, 0305 3019 before 2012.
0305 5110	Dried	Also includes gadus ogac and gadus microcephalus.
0305 5190	Dried and salted	Also includes gadus ogac and gadus macrocephalus
0305 6200	Salted	Also includes gadus ogac and gadus macrocephalus
1604 1992	Prepared, whole or in pieces	Also includes gadus ogac and gadus macrocephalus

Gadus morhua- atlantic cod, gadus ogac – Greenland cod, gadus macrocephalus – Pacific cod and Boreogadus saida: Arctic cod. For full description of codes, see https://www.scb.se/dokumentation/klassifikationer-och-standarder/kombinerade-nomenklaturen-kn/.

[31] The threshold for reporting imports changed from 4.5 million SEK to 9 million SEK in 2015. https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__HA__HA0201__HA0201B/ExpTotalKNAr/#

CASE STUDY 11: ROUNDFISH – CYPRINIDS: COMMON BREAM (*ABRAMIS BRAMA*) AND COMMON CARP (*CYPRINUS CARPIO*) – SWEDEN, POLAND

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Photo: Cyprinid farming in Poland (left; photo credit Marcin Rakowski) and fisheries in Sweden (right; photo credit Marie Sparréus).

Sara Hornborg, Kavitha Shanmugam, Marcin Rakowski and Adam Mytlewski

LIST OF ABBREVIATIONS

Term	Description
EUMOFA	European Market Observatory for Fisheries and Aquaculture Products
GHG	Greenhouse gas
HORECA	Hotels, Restaurants, Cafés
LCA	Life Cycle Assessment
LW	live weight
MSC	Marine Stewardship Council
SwAM	Swedish Agency for Marine and Water Management

1 Background

Many European countries have today a vulnerable seafood production and consumption due to reliance on e.g. temperature-sensitive species such as salmonids and cod — whereas many species of e.g. carp fishes (cyprinids) have higher temperature optima and are predicted to increase with climate change (Froese & Pauly, 2019; Blanchet et al., 2019). Carp is also a more robust species to farm compared to e.g. salmon, with different feed requirements and a generally higher resistance to unfavourable environmental factors compared to many species (National Research Council, 2011; Antychowicz et al. 2017).

Swedish cyprinid fisheries have been shown to have low GHG emissions relative to other animal-based protein (Hornborg & Främberg 2020). Sweden is today a country strongly dependent on imports of seafoods (more than two-thirds are imported; Hornborg et al. 2021), and consumer interest in domestic cyprinid species has declined compared to the 1950s from societal changes such as urbanization and improved accessibility of marine fish species (Bonow & Svanberg 2013). This has resulted in low fishing interest (Malmström & Waldo 2021). Around 100 tons of Common bream *Abramis brama* was landed in 2020, the only cyprinid species with reported landings in the yearly overview of Swedish fisheries (SwAM 2021). Increased utilization would add to domestic production, thus potentially contribute to lower dependency on imports, and allow for diversification for small-scale businesses.

Other member states in the EU have a higher consumption and production of cyprinids – total EU production was estimated to be 90 000 tons in 2019 (EUMOFA, 2021). The EU carp production is predominantly based on aquaculture (90 % of volume), representing 6 % of the total aquaculture production volume in the EU. In Poland, Common carp *Cyprinus carpio* is one of the most important aquaculture products (45 % of total production). Both conventionally and organically produced farmed carp has been found to be associated with lower GHG emissions than products from recirculating aquaculture systems or terrestrial animal products such as beef (Biermann & Geist, 2019). The value chain of Common carp in Poland has however changed in recent years. From being a local business with a product that was consumed locally, there are currently different systems of distribution and business strategies, depending on the size of aquaculture. Long distance to markets or inefficient transports can add to product GHG emissions. There are also climate change related challenges to current aquaculture practices: water shortage may result in higher costs of production and higher predation (from e.g., otter, cormorant) leads to lower production (Lasner, 2017).

Although there may be challenges from climate change, due to cyprinids' general robustness and low GHG emissions, increased EU production may add to climate resilience of the seafood sector if consumer interest and production economy allows. By looking at current value chains of cyprinids in Sweden and Poland, insights may be gained on how a sustainable growth of cyprinid value chains may be achieved. This includes both learning from different countries' experiences, available literature, and interviews with value chain actors on how viable and GHG efficient value chains may be established in Sweden and Poland.

2 Value Chain

2.1 Value chain description

2.1.1 Sweden

Different species of cyprinids caught in Swedish fisheries have in recent years gained renewed interest – including species such as Common bream *Abramis brama,* Ide

Leuciscus idus and Common roach *Rutilus rutilus (*Dahlin et al. 2021; Blått centrum Gotland, 2020; Malmström & Waldo, 2021*).* There have been attempts in recent years to utilize cyprinids for food instead of biogas when caught in so called nutrient reduction fisheries in lakes, i.e. removal of fish biomass as remedy for eutrophication (Krinova 2022). Of particular interest today is Common bream, which for a long time has been underutilized both biologically and economically (Sundblad et al., 2020). Common bream is found in freshwater lakes in the southern and middle parts of Sweden and along the coast of the Baltic Sea. It is today mainly caught as by-catch in fisheries targeting freshwater species such as European perch *Perca fluviatilis*, Northern pike *Esox lucius* and pikeperch *Sander lucioperca* and had mainly been discarded or used as bait (Hornborg & Främberg, 2020). Another cyprinid of interest is Ide, which has been used to produce burgers (Blått Centrum Gotland, 2020), and common roach that is today only fished for bait but gaining interest after recent product development in Finland (Järki Särki, 2022). This CS focuses on Common bream from fisheries in Sweden since this currently is the species of highest interest (County Administrative Board of Stockholm, 2022) and because there is only some scattered information on other cyprinids since at the moment these value chains are less developed.

With the renewed interest to utilize cyprinids in Sweden, several initiatives have in recent years started to establish viable value chains based on fisheries. Two main value chains are so far seen for Common bream in Sweden (Figure 1). Bycatch of the species in pikeperch *Sander lucioperca* fisheries in the Stockholm region are being increasingly utilized for human consumption instead of being discarded or used as bait in the fishery for freshwater crayfishes (*Astacus astacus, Pacifastacus leniusculus*). Common bream is sold through the newly established Stockholm Fish auction and processed locally into frozen mince and distributed to wholesalers for further distribution to municipalities and regions to be prepared as fish burgers and served in e.g. schools (Svensk Fiskerinäring 2022). A targeted fishery for Common bream has also been initiated in the northern part of the Baltic Sea since year 2019, with processing into mince in Kalix in the northern Sweden (Guldhaven Pelagiska AB 2022). The mince is formed into burgers that are pre-fried before packaging and distribution. The production of burgers used to take place in the same factory but, due to labour intensity when scaling up production, has recently been moved to an external actor before distribution to hotels, restaurants and public kitchens. Products are sold frozen to optimize shelf life and to be able to offer a steady supply throughout the year since practically no fishing occurs during winter months (Svensk Fiskerinäring 2022). For public kitchens, frozen products are also the most practical option.

Aquaculture production of cyprinids is marginal (producing only a few tonnes) in Sweden. Based on information from the two registered farmers of cyprinids (several species) in Sweden, production costs are higher in Sweden compared to Poland. This is mainly due to different farming conditions, where the grow-out season is longer in Poland (8-10 months in Poland compared to 5-6 months in Sweden), and stocking densities are allowed to be higher (only 100 kg/ha in Sweden, usually 300-1500 kg/ha in Poland). There is still a marginal volume of Swedish farmed cyprinids sold for food in Sweden today, with highest demand from November until Christmas. However, farmers in Sweden require 10-15 EUR/kg to cover production costs whereas wholesalers in Sweden can obtain carp farmed in Poland for 3 EUR/kg. There are, perhaps because of these price differences, indications of illegal import of live carp into Sweden which may risk transfer of disease and poor animal welfare.

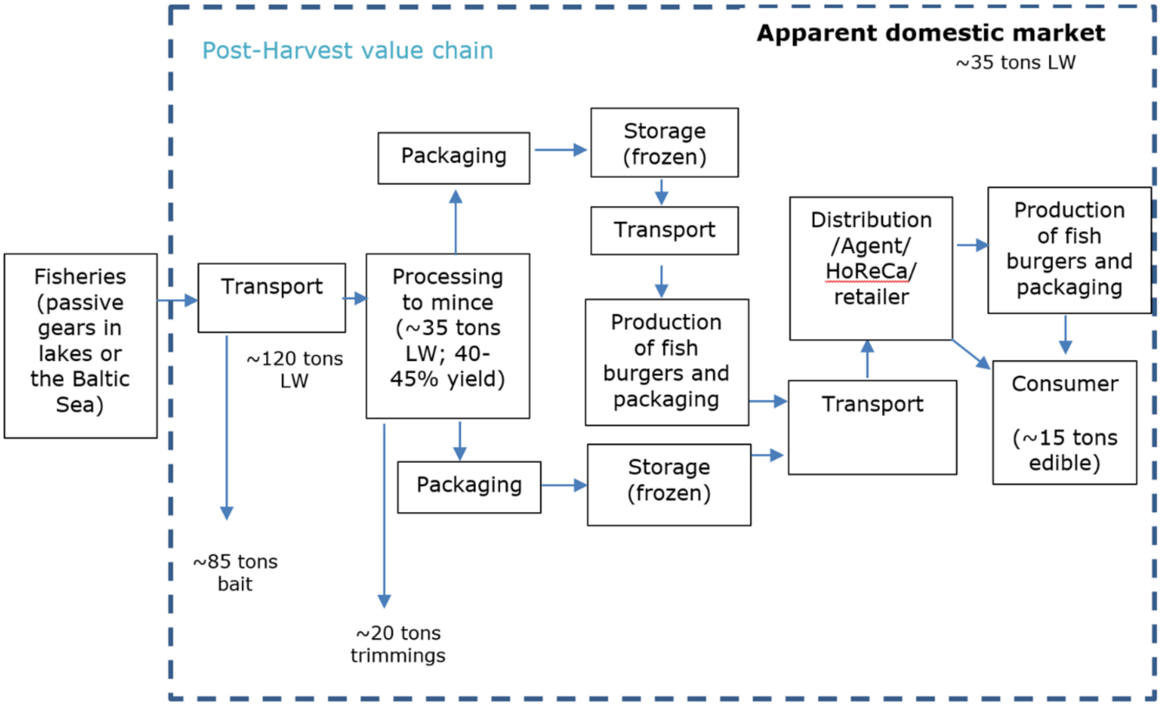

Figure 1. Postharvest value chain of Common bream in Sweden (2020-2021). Source: Andersson (2021), SwAM (2021), interviews.

2.1.2 Poland

Poland is the biggest producer of carp fishes in Europe - Polish aquaculture is dominated by inland production of Common carp *Cyprinus carpio* – 21 150 tons in 2020 (Lirski, 2021). Carp is a traditional product in Poland. Carp consumption is strongly connected to the Polish tradition of Christmas Eve, when fried carp is the main dish. Estimates indicate that about 80–90 % of carps are sold to consumers in November and December. Carp products are usually offered as non-processed goods (whole fish) or fresh fish (gutted). The share of processed fish on the Polish market grows and is done both locally and in few big plants in Poland. The yield of side streams ranges between 40 to 85 % depending on type of processing. Only the surplus of domestic supply goes to industrial processing plants for processed products (fillets). The total production sold amounted about a 40 million EUR turnover per year (Lirski, 2021).

Carp as a raw material is characterized by a favourable nutrient composition. However, carp is consumed out of tradition and the information on positive health values is not communicated to consumers. One portion of 220 g of carp covers an adult's daily need for protein and vitamins, and provides valuable minerals (GIW, 2021; Tkaczewska & Migdał, 2012). The unprocessed product form and relatively natural production is gaining interest among consumers looking for a healthy diet and has increased the interest of processors (Woźniak, 2018).

The structure of the carp value chain in Poland is strongly dependent on the size of the fish farm: farms have different competences, objectives, funds and economics. The big farms (for example "Stawy Milickie" – the biggest centre of carp production in Poland and Europe) sells up to 90 % of their carp production to supermarkets. The small farms usually sell the majority of production directly to the local market (green markets, consumers, local restaurants).

The following actors are important in the carp value chain in Poland:

1. Carp farms – different scale of producers – production volumes from 5 to 1000 tonnes per year. According to Veterinary Poland there are about 1 000 farms specialised in carp production. Large scale farms usually have their own processing.
2. Local market – local consumers, green markets and local processing. Local processing is usually without transportation because it takes place directly on the farm.
3. Local HORECA and retailers – local restaurants and retailers located close to carp ponds sell fish to local consumers (very small scale).
4. Professional processors – big scale processors. There is no processing plant specialised only in carp processing. They only take part in the carp value chain when the supplied quantity is high and live carp is delivered to them. Processors take part also when surplus of supply appears or the process the fish not sold during Christmas. There is no stable supply during the year for processors. The processed product are fillets (in Modified Atmosphere Packaging), cans or jars. The processed products are not popular, mostly because of lack regular offer.
5. Supply integrator – there are two supply organisations (integrators) on the Polish market representing about 40–50 % of the total carp production. The biggest company is "Polski Karp Ltd", representing almost 30 % of total supply in Poland. These integrators negotiate the supply conditions and prices and take provision. The partners of those integrators are mostly supermarkets like Tesco, Carrefour or Biedronka. Integrators coordinates information, financial and physical flows in the value chain. The integrators also sell carp to processing plant for gutting and filleting the fish (about 20 % of production volume). The integrator is not the trader and only coordinates the supply and controls the finance of the supply chain.
6. Supermarkets – responsible for domestic distribution of carp (whole fish). Usually, transportation goes directly from the carp farm to the shop. In the last years, supermarkets prohibited live carp distribution and selling. There are no formal regulations in Poland, but best practice was introduced by supermarkets. As a result, killing of fish needs to take place in the professional plant or plants located nearby the farm.

The following typical supply chains can be identified (Figure 2):

- Short local chains with small scale of delivery (50–100 kg) – oriented mainly at supplying local shops and touristic and gastronomic businesses (Barycz Valley). Carp is transported over short distances (max. 50 km) with small vans or processed/consumed on farm (restaurants).
- National value chains supplying supermarkets in Poland with big scale of delivery (few tons) – seasonally during the Christmas period (the average distance is 200–250 km). This transport takes place with trucks (10–12 tonnes) using containers for keeping live fish in water with oxygen systems. Because of regulations in this value chain, it always takes place in big processing plants.

Recently, there has been an increase in demand for carp (also during rest of the year). This has led to an increase in competition between local and national supply chains.

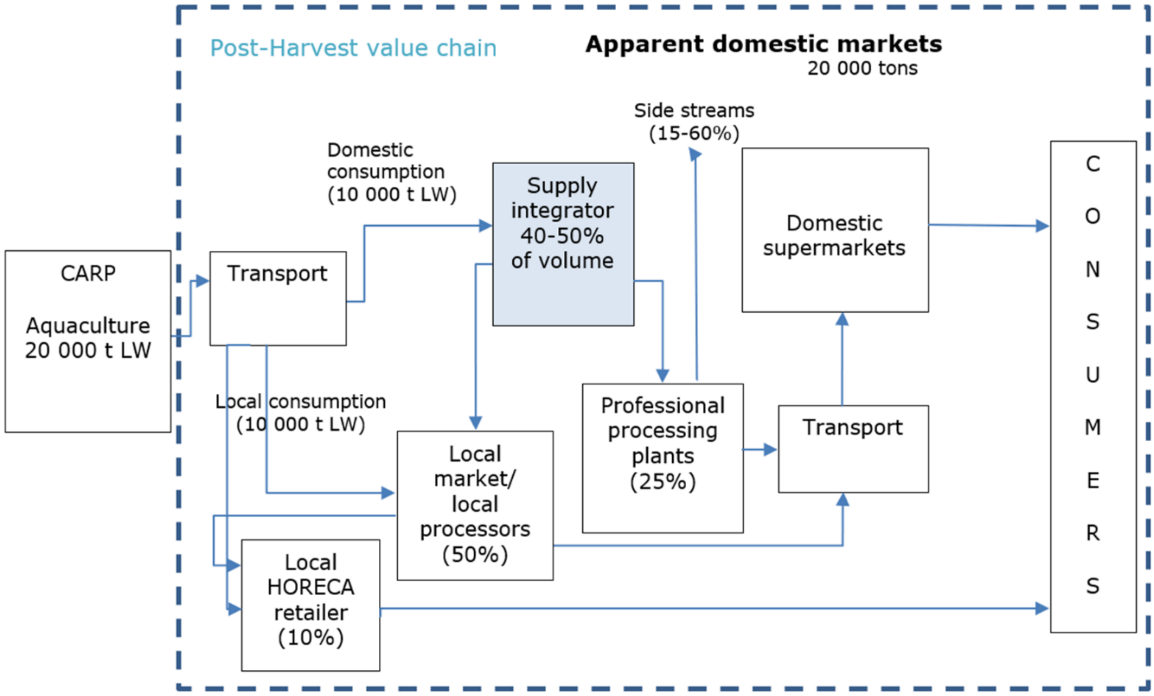

Figure 2. Postharvest value chain of Common carp in Poland (2015-2019). Source: Interviews with industry.

3 Resilience

3.1 Physical and financial resilience

3.1.1 Swedish value chains

In Nordic countries such as Sweden, there is high dependence on a few seafood species, resulting in vulnerability to sudden market changes such as those recently seen due to the covid-19 pandemic and the Russia-Ukraine conflict. According to the Swedish Fishing Industry Association, problems are seen both related to availability of popular species where Russia is an important actor (such as Alaska pollock *Gadus chalcogrammus* and Atlantic cod *Gadus morhua*), and in general from increased costs of imports.

Utilization of cyprinids in Sweden is a recent activity, with value chains being established in the past 2–3 years. Based on interviews, producers of cyprinid products in Sweden want to be able to deliver more broadly to groceries and HORECA. However, they report that the current seafood market structure of major actors in Sweden practically requires MSC-certification. The Swedish WWF consumer guide has given a 'green light' to catches in some lakes, which offers opportunities, but certification is key for many market segments. Restaurants open up other opportunities, where transparent and sustainable value chains are sufficient.

3.1.2 Polish value chains

The Polish carp production sector is highly dispersed – small, family farms dominate, and the total number of facilities is nearly a thousand (Lirski & Hryszko, 2020). Although the production of consumer fish in 2020 amounted to ~20 000 tonnes of carp (data from FAO), it only provided sales values of 40 million EUR. Further horizontal integration aimed at better representation of the bargaining power of carp producers seems to be beneficial for the carp value chain in Poland. The integrator regulates and stabilizes the relationship between supply and demand and optimizes transportation by shipments consolidation and coordination. By assistance of the integrator, integration effects are seen in terms of reduction of transportation distance.

Despite the positive characteristics of the carp raw material, the current model of the fish processing industry is a mismatch between the market, carp processing sector and aquaculture sector. The fish processing industry has specialized in mass production and achieving economies of scale. These plants are used to continuous, systematic deliveries of relatively homogeneous raw materials (most often frozen). This raw material is stored in the plants for a short time due to limited storage conditions and costs. Because of the erratic availability of supply, the number of professional plants specialised in carp in Poland are limited. In current processing systems, innovations and investments in genuinely new markets or products are of little importance. Thus, it can be indicated that the recipients of carp undoubtedly should be enterprises (especially small and medium-sized enterprises), which are able to flexibly adapt production processes and are willing to bear greater risk (Firlej & Kubala, 2017).

4 Major financial constraints and reliability

4.1 Swedish value chains

Experience from recent cyprinid projects in Sweden and Finland (e.g., Resursfisk, 2021; Baltic fish, 2021) show that for professional fishermen, it may be beneficial to catch the fish – but a value chain based on local, small-scale fishing is challenged by current competitiveness (see also Jacinto & Pomeroy 2011; Purcell et al. 2017). It is however possible for small-scale producers to join the market with new niche products, if collaborating along the supply chain with e.g. retailers, and in this way facilitate resilient value chains by creating a consumer demand. For the Swedish value chain, current market competition is tough. If the fisher should be given a reasonable price for the catch (~1.9 EUR/kg), this results in a higher price for cyprinid products for consumers or public procurement than for products such as MSC-certified cod from Norway – a price difference of around 3 EUR per kilo (Svensk Fiskerinäring, 2022).

4.2 Polish value chains

A weakness of the carp value chain in Poland is the high seasonality – 90 % of sales take place in December (Christmas). The seasonality trend is however gradually reduced by the local sale of fish during the year (Goryńska-Goldmann et al. 2016). Seasonality has in turn a negative impact on the global supply of raw material for processing on a larger scale, who wants regular delivery and experience that consumers do not want frozen carp. In addition, carp is also characterized by low yield of edible product (fillets or mince), which decrease the production efficiency of final products. The price of whole carp is about 3-4 EUR and, in the household, it can be used for different purposes (such as soups).

5 Stakeholders' perceptions

5.1 Swedish value chain

Based on two interviews (with one producer of fish mince and burgers, and one authority representative engaged in projects on how to improve utilization of cyprinids), there are difficulties for locally produced, sustainable seafood to get established on the Swedish market due to current price-competition. Cyprinid mince needs to compete with cheap fish mince from filleting of other seafood (such as cod, saithe, salmon), where the valuable fillet most often has already paid the price for the mince. For Common bream, the whole fish is turned into mince; the processing cost is not supported by a valuable fillet. The only way to accept this higher price for cyprinid mince is through environmental awareness of market actors. There is yet not enough specific demand for locally produced, sustainable seafood for environmental reasons, and the products need to either be MSC-certified or have a green light in the WWF consumer guide to get access to important markets. If production costs were to increase as an effect from climate change, the market opportunities would be severely affected.

Related to the issue with certification and consumer guides is the current data gaps concerning sustainable exploitation and potential effects from climate change. There are no constraints from current fishing regulations to utilize by-catch of cyprinids, but for targeted fisheries, monitoring and management objectives need to be established to safeguard long-term sustainable exploitation and feed into certification of evaluations for consumer guides. According to one processor in Sweden, Swedish authorities and research are very positive in increased utilization of cyprinids but the processes are slow, and there is a general lack to take the lead in establishing management plans.

There is also a major challenge with seafood traditions of Swedish consumers. There is a lack of tradition in eating and preparing cyprinids, making targeted marketing actions vital to value chain actors. Export of cyprinid products to other markets where consumer habits include more freshwater fish is challenged by high production costs in Sweden and lower prices for cyprinids in markets such as Poland.

Both interviewees from the Swedish value chain report on these problems and opportunities related to climate change and other important factors that need to be considered for the value chain (Table).

Table 1 SWOT of the Swedish value chain.

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	Strengths • Production is integrated in value chains comprising of other seafood • Diversification allows for more resilience if traditional species are negatively affected by climate change	Weaknesses • Production costly, need to pay fair price to fishermen to deliver the fish • Price sensitive – finding the right price for the right market actor • Handling of catch with higher temperature – more ice or other practices? • Strategies for sustainable growth needed • Knowledge gaps concerning sustainable exploitation levels and effects from climate change on fisheries • Volumes of by-caught cyprinids are dependent on the target species fishery effort which may vary (e.g. pikeperch Sander lucioperca)

External origin (attributes of the environment)	Opportunities • Warmer waters/more nutrients contribute with improved growth and longer fishing season • If demand increases through increased environmental awareness of consumers	Threats • Increase of already high production costs from increasing fuel and energy prices • Inability to phase out of fossil fuels in small-scale fisheries • Maintaining product quality with higher temperatures • More storms and ice cover negatively affect fishing opportunities and thus raw material availability • Potential mismatch between fishing season for target species and bycatch of cyprinids • Competition in fisheries with other more economically valuable species • Ecosystem changes from climate change and fishing

5.2 Polish value chain

For the Polish value chain, other opportunities and challenges were reported on based on two interviews, one carp integrator owner and manager and one Aquaculture Department specialist in Ministry of Agriculture and Rural Development (Table). The integrator represents about 30 % of total supply in the Polish carp market.

Table 2 SWOT of the Polish value chain.

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	Strengths • Flows scheduled, controlled and coordinated by supply integrators. Good economic performance of actors in value chain. • Low level of processing and high nutrient value of product. • Relatively low prices for natural and extensively farmed fish. • Very simple production model – using local grains and manure in feeding and other local resources such as workforce and services. • Strong national market with annual demand correlated with supply. No surpluses identified. • Tradition of carp consumption on domestic market, with short value chain and marginal import and export. • Growing local markets stimulated by tourism.	Weaknesses • Water retention of rivers necessary in production and water use costs, where framers pay a fee to use the water from the river. • Extremely seasonable production, distribution and product availability. • High level of side streams during processing that could be better utilized. • Geographically dispersed production and need of delivery consolidation. • Farm economics supported by subsidies for environmental services. • The regulations of ethically approved killing the fish increased the need of transportation (km/ton). There are only a few (3-4) big scale processing plants in Poland that are specialised in this for carp and makes the distance longer than live fish delivery (directly from the farm to supermarket).

External origin (attributes of the environment)	Opportunities	Threats
	• Increased demand for healthy and sustainable products on the market. Local development strategy based on carp production and consumption (e.g. Barycz Valley) and promotion of local consumption – higher added-value generated in place of production (circular economy).	• Water shortage and water management effect on revenues – supply limited during low water periods. • Decrease in water quality affecting the quality of fish and farming processes. • Increase in losses of fish to predators – mainly cormorants – resulting in growing costs of production. • Potential for outbreak of Koi herpesvirus (KHV) diseases with negative consequences for supply and increase in production cost. • Competition with popular, imported fish species (salmon, seabream).

6 Role of management – lessons learned of adopted strategies

Domestic freshwater resources from capture fisheries are generally given less monitoring and management effort compared to marine species (Arlinghaus et al. 2002; Dudgeon et al. 2006), resulting in poor data availability to determine sustainable harvest levels (Lorenzen et al. 2016; Vehanen et al. 2020). For capture fisheries of cyprinids in Sweden, status of different species and stocks are uncertain but is today generally associated with low utilization (Dahlin et al. 2021). Abundance varies between different fishing areas for species such as Common bream, but overall, reported landings have increased since 2015 (SwAM, 2021). Common bream is a slow growing fish, making it vulnerable to overexploitation. No other species of cyprinids are analysed for commercial fishing opportunities in Sweden.

Despite major data deficiencies, there are already market actors that have initiated sustainability assessments. In the most recent WWF seafood consumer guide in Sweden, Common bream (the only cyprinid included) is communicated to consumers as either a good choice (green light) or to be cautious (yellow light) depending on fishing area (WWF, 2022). Dialogue between market actors is also ongoing in Sweden to create national labelling of locally produced sustainable seafood products from fisheries as has been done in Denmark (NaturSkånsom 2022). These market initiatives are however reliant on sustainable management. Although current fishing pressure on cyprinids is low and increased fishing pressure may offer ecosystem benefits such as remedy of eutrophication (Dahlin et al., 2021), long-term sustainable management needs to develop management models to mitigate potential risks from increased fishing effort (Hornborg & Främberg, 2020; Sundblad et al., 2020) – along the identification of supply chains that are economically viable (Malmström & Waldo, 2021).

The management goal for carp aquaculture in Poland is getting more knowledge about the sector and to collect socioeconomic data. Poland has been obliged to collect, manage and provide upon request a wide range of fisheries and aquaculture data for scientific advice since 2022, following methods and requirements for data collection in Commission Delegated Decision 2019/910 of 13 March 2019. Economic variables that shall be collected by member states are listed in the regulation. The variables are gathered in three main groups: a) economic b) transversal c) social. The economic group contains all variables that are necessary to analyse the economic performance aquaculture sector (i.e., income, labour costs, energy costs, repair and maintenance costs, other operating costs, subsidies, capital costs, capital value, investments, financial position). The transversal variables (water temperature, feed volume, farming technique) supplement the economic variables. The group of social variables contain employment information (number of people employed, unpaid labour and number of hours worked. For aquaculture, the data are collected on segments based on species and production techniques (including carp in ponds).

7 Greenhouse Gas Emissions

7.1 GHG emissions in the value chain

The functional unit of the cyprinid value chain is here 1 kg of edible portion at point of sale. GHG emissions from the Swedish value chains are mainly based on two existing Life Cycle Assessments (LCAs) (Andersson, 2021; Race for the Baltic 2022), complemented with information from contact with value chain actors. For the Polish value chains, GHG emissions from farming are based on insights from an LCA of conventional and organic farming in Germany (Biermann & Geist, 2019) complemented with inventory data from contact with value chain actors. Note that the prior LCA results reported on here are subjected to methodological decisions influencing their absolute values (see Ziegler et al. 2022): results are to be seen as indicative since harmonized methodological decisions (such as allocation, impact assessment method etc.) is required for a proper comparison and mapping of GHG emissions.

Fisheries

The fuel use intensity varies between fishing areas and gears but is between 0.06 to 0.18 litre/LW in current Swedish inland fisheries (Hornborg & Främberg 2020) and between 0.04 to 0.08 l/LW in the northern Baltic Sea (industry data). The estimated range in GHG emission for these fisheries, including production and combustion of fuel (2.94 kg CO_2e/l) and a generic value for non-fuel related emissions based on approach in Ziegler et al. (2021), may thus be between 0.16-0.7 kg CO_2e/kg LW at landing. All fishing vessels use ice for keeping the quality of the fish.

Farming

Carp is produced in earth ponds located mainly in the southern part of Poland. The breeding cycle has been significantly shortened, yet the traditional character of carp breeding has been maintained. This is mainly characterized by a 2–3-year production cycle, only partial dependency on manufactured feeds and a low production intensity (max 1.5 tonne fish per hectare). An important source of feed for carp is plankton naturally occurring in the ponds. Grain feed is added as additional feed and farmers may also use manure to increase plankton production. Farming of carp is thus embedded in an artificially productivity-enhanced pond ecosystem.

Biermann & Geist (2019) performed an LCA of organic and conventional carp farming in southern Germany (traditional pond aquaculture). The typical polish farm conducts the traditional production (2-3 years cycle), similar to what is described in the article. Some carp farmers are also agriculture producers (grain, corn, lupine) and use their own grain as feed for the fish, which cuts transportation distance. For the German carp production, it was concluded that conventional carp farming was associated with higher GHG emissions and water use compared to organic production, and that feed input and pond dredging (i.e., the effort of sludge removal from the pond using machinery) was the driver for both systems; feed input contributed with ~22-27 % of GHG emissions, pond dredging ~40-55 % respectively. The GHG emissions totalled to 5.98 kg CO_2e/kg live carp at farm gate for conventional production, whereas 4.32 kg CO_2e/kg for organic production, respectively. Biogenic carbon was not included. To reduce emissions from the production, feed type and amount should be focussed on, as well as frequency and method for pond dredging. In Poland, there is no use of compound feed, only grains. For higher phytoplankton production, farmers may add manure if the soil is poor quality, but it is not a common practice. No typical cycle of dredging can be established, it is dependent on soil, stock density, type of water source, etc. The goal for optimizing for low GHG emissions in carp farming in Poland now is stock density optimization, focused on maximum usage of natural trophic chains. However, for aquaculture in ponds, potential influence on GHG emissions from release of methane and nitrous oxide requires further investigations (Holgerson & Raymond, 2016; Hu et al., 2012).

<u>Transports</u>

For both Swedish value chains, transport of cyprinid catches to mince production is very short. For example, for the targeted fishery in the northern Baltic, the distance is ~20 km, and is transported either by car with trailer or small truck. No data are available for the Stockholm-based value chain, but they report that transport is efficient through combined delivery with other fish and avoiding empty returns of trucks.

In Poland, half of the production volume has a short distance transport to local markets (restaurants, green markets, direct sales). Average distance is 50 km with typical vehicles of 3.5 tons, delivering on average 50 kg of carp. The other half of the production volume is transported for processing and supermarkets over larger distances, around 230 km with vehicles of 10-12 tons, delivering on average 5-7 tons of carp per trip. Efficient logistics is important. Short distance to local markets, due to the low volume transported and assuming only carp is transported, 50 km transport of 50 kg carp with a smaller lorry (3.5-7.5 t) may emit 0.50 kg CO2e/kg carp (Ecoinvent data), whereas transporting 6 tons for 250 km with a larger lorry (7.5-16 t) emits 0.21 kg CO_2e/kg carp.

<u>Processing</u>

In Sweden, scales are removed with machines and the mince is produced through use of a meat-bone separator. Waste streams are generated from the production of mince, but the meat-bone separator is very efficient in yield; edible yield of common bream is around 40-46 % according to Swedish processing industry. This implies that 2.50-2.17 kg LW common bream is needed to produce 1 kg mince (Andersson 2021, Svensk Fiskerinäring 2022), resulting in 1.5-1.17 kg of side streams. The remains from this process are mainly turned into biogas, but other value chains have been tested or are being discussed, such as use as bait or pet food. Water is used in different stages of the processing but no estimates on volumes are available.

The mince is either packaged in 2.5 kg plastic containers or further processed to 80 g pre-fried fish burgers, packaged in 7 kg boxes (Guldhaven Pelagiska 2022); packaging and production of burgers was not included in the modelling. This production has before been done in the same facility, but due to labour-intensity of burger production by hand, the burger production has now moved to the closest available facility located in northern Finland. Andersson (2021) assumed that the waste was incinerated with energy recovery and the generated electricity and heat was deducted from the potential environmental impact of the minced bream product (electricity: 0.0084 kg CO_2e and heat 0.0081 kg CO_2e). The GHG emissions after minced bream production were not calculated in Andersson (2021) and were based on assumptions.

In Poland, around 7 000 tons out of the total 20 000 tons LW production is processed in factories. During 2017-2020, processing plants produced mostly fresh carp (89 % of processed volume), cans (2 %), smoked fish and marinated (each 1 %) and other products (9 %). EUMOFA provides species-specific conversion factors for Common carp (edible 54 %, skinless fillet 36 %), but based on interviews with Polish actors, yield is between 40 to 85 % depending on product. This results in 15-60 % side streams (head, bones and skin) being generated during processing. Some of this (especially skin) is utilised for medicine or cosmetics purpose. No GHG estimates are available for processing in Poland.

Distribution and storage

For the Swedish value chains, the additional contribution from distribution varies depending on processing location, market, transport mode and average load and is not modelled here since the supply chain is less developed and highly variable. When demand is low, there is also risk of products in storage passing their expiry dates.

For the Polish value chain, contribution of GHG emissions for distribution is included under transports.

Overall GHG emissions

Overall, the total of GHG emissions of the two Swedish value chains has been estimated to be relatively similar. Products from the targeted fisheries in the northern Baltic have been estimated at 0.4 kg CO_2e/kg mince at factory gate (mass allocation; Race for the Baltic 2022) whereas from the Stockholm-based value chain 0.45 kg CO_2e/kg mince (economic allocation; Andersson, 2021) respectively. The fuel use in the fishery is the main driver of the total GHG emissions of the mince at factory gate: 77 % of the total GHG emissions (targeted fishery in northern Sweden) and 58 % of total emissions (by-catch of in the Stockholm area) respectively. Since the fishery is associated with low GHG emissions, transport in the value chain was important: transports contribute with 21 % of total emissions at factory gate (targeted fisheries in northern Sweden), whereas 35 % (the Stockholm-based value chain) respectively. Processing contributed with 1.7 % of total GHG emissions at factory gate.

For the Polish value chain, carp farming in Germany has been estimated to contribute with 4.32–5.98 kg CO_2e/kg live carp at farm gate (Biermann & Geist, 2019). Based on expert opinion, the GHG emissions may be lower for Polish production, but this requires more data collection. For delivery to local markets, an additional 0.5 kg CO_2e/kg LW is added from transports whereas the longer value chain adds 0.21 kg CO_2e/kg LW. Depending on how the carp is sold to consumers (i.e. production form), the edible yield varies between 40-85 %.

7.2 Alternative distribution systems

The trimmings generated during the production of the minced bream in Sweden today is turned into biogas. Waste management had a very small contribution to overall emissions (1.6–13 % of total emissions; Anderson 2021), but the more that is utilized of the raw material, the less input is required per output which decreased emissions per product. Trials have been made to use trimmings for bait to avoid using edible biomass as bait. Discussions are also held with the pet food industry which have shown interested in utilizing the side streams due to low level of contaminants and high nutritional value.

Because fuel use during fishing was identified as a hot spot in the Swedish value chains, sourcing raw material from the most efficient fishery and/or utilizing the full catch of cyprinids offers GHG emission reduction potentials. Findings from utilization of bream in the northern Baltic Sea showed that the fuel use intensity varied between fishers. Utilizing fish from the most fuel-efficient fishery resulted in 0.3 kg CO_2e/kg mince, the least efficient 0.6 kg CO_2e/kg mince respectively – twice the GHG emission levels. The fuel use intensity of the current inland fisheries could decrease with 32 % if all cyprinids that are caught were landed, i.e. improved catch per unit effort in these fisheries (Hornborg & Främberg, 2020). Some efficiency improvements may be achieved PH in Sweden, such as more efficient logistics and higher utilization of side streams, but consideration of a full value chain including fisheries production is vital for managing GHG emissions.

Even within local, domestic markets, efficient logistics are important, especially if the production is associated with low GHG emissions. Contribution of transports to total GHG emissions of products is not only driven by distance, but also transport efficiency (load, mode, etc.). Andersson (2021) found significant increases in the GHG emissions if the minced bream was not locally processed – a potential 160 % increase of total emissions in the in the alternative distribution system studied. Sweden is a long country from north to south, and cyprinid resources are found throughout the country. However, there are very few facilities that can efficiently produce fish burgers; efficient logistics is vital. In Poland, the challenge in carp distribution is logistics at the level of the entire market. Until around 2015, the highly fragmented producers' market was self-organizing, which resulted in excessive transport. The emergence of entities organizing and integrating the flows between farms, processing plants and retail trade contributed (in the respondents' opinion) to the reduction of the average distance of transport of an average ton of fish.

7.3 Limitations for structural improvements in GHG emissions

A general but important transition needed in Sweden, but also other EU member states, is going from highly demanded and scarcer seafood resources to more abundant ones. Eating more cyprinids, from fisheries or aquaculture, offers GHG emission reduction potential of overall seafood consumption (Hornborg & Främberg, 2020; Biermann & Geist, 2019). For future expansion and economically viable value chains, change in preferences and practices is needed, the main drivers of current low interest freshwater fishes in Sweden (Bonow et al. 2013).

Major limitations of cyprinid value chains in Sweden today are however current production costs relative to alternative products and current demand. Higher volumes could be produced, but this is currently hindered by low consumer demand. The availability of Common bream of the right size (over 0.7 kg, or 40 cm) is also a challenge for cost-efficient value chains since most of the by-catch is around 0.5 kg (County Administrative Board of Stockholm, 2022). Utilization of more by-caught Common bream from lakes is also presently challenged due to high competition for bait need in the economically lucrative fishery for freshwater crayfish (County Administrative Board of Stockholm, 2022). Bait resources need to be sourced from the same lake where the fishery takes place due to risks of spread of diseases and parasites. Successful trials have been made to separate cyprinid catches per lake, extract the mince and send back the side streams as bait. If these value chains could be established, it would lessen the competition and allow for increased availability of cyprinid catches for food.

Further improvements of current GHG emissions of cyprinid value chains from capture fisheries in Sweden involves i) creating efficient and long-term sustainable fishing operations, which requires a combination of operational efficiencies (e.g., targeting patterns, gears, utilizing the full catch) and maintaining healthy stock (data collection and management objectives); and ii) efficient processing and logistics of small volumes of product. Efficient logistics in Sweden are challenged by great distances and few market actors that can process the fish raw material into suitable products. New actors with interest in local and sustainable seafood production are however being established, such as a recent investment in Västervik on the east coast (Food Supply 2022). Dialogue between different actors is also ongoing on how to best utilize cyprinid resources from different parts of Sweden.

In Poland, the main limitation in structural improvements for reducing GHG emissions in the PH value chain is the different locations of production and processing. Carp farming takes place mainly in the south of Poland while most of the fish processing plants are in the north. This causes problems in reducing the need for transport.

5 Reducing GHG emissions by technical means

5.1 Trends in technological evolutions and industrial strategies

For the development of cyprinid value chains in Sweden, logistics were already in place based on other species. Challenges that have been in focus in recent years have included finding suitable product forms, provide necessary measurements of potential occurrence of undesired substances, work with the WWF to include Common bream in the consumer guide to open markets and engage fishery management authorities in safeguarding sustainable exploitation (Svensk Fiskerinäring 2021). MSC-certification is important to get access to parts of the Swedish market but is too costly for these small-scale fisheries and volumes. A process has however been initiated to co-certify by-catch of Common bream in the re-certification process of MSC-certified pikeperch from lake Mälaren. This offers a certification opportunity at a much lower cost.

The producers of cyprinid products in Sweden are small-scale and have recently established value chains. They want to grow and are in the process of identifying how to safeguard long-term sustainability. This does not only include the cyprinid resource itself, but also cleaner production technologies such as identifying which energy sources to use, replace single-use plastics and more, which is reported as a strategy for one producer. The perception of this producer is that diversifying their seafood volume adds to resilience and avoid disruptions in the value chain when traditional species such as locally caught cod is not available, i.e. utilizing the same value chains and processes but adding species (see also CS 10). Companies have also tried other species of cyprinids as mince, such as ide which so far has been received even better than Common bream. Ide is however perhaps even more challenging than Common bream in terms of directed fisheries because the current knowledge concerning the species and suitable fishery is even less compared to Common bream. Different companies are however in dialogue on how to utilize cyprinid catches better across Sweden and see increasing interest in cyprinid burgers in public kitchens, restaurants and even retail.

Interesting opportunities exist in initiatives on the Swedish market to minimize food losses. The "Save the Food"-initiative by the wholesaler Martin & Servera is a marketplace where producers can sell their products at lower price if the best before date is approaching (Martin & Servera 2022). This initiative is part of the company's strategy to cut the food waste by half before 2025. One producer reports that when there was a risk for some cyprinid products in storage for not being sold, through this marketplace they were sold out quickly. This may indicate that if the price is lower, there are buyers. Arguably, it could also prove to be an opportunity to try out products for the more hesitant buyers and in the end, create increased interest.

In Poland, aquaculture producers can certificate their farms according to the rules of the "Code of Good Practice in Fish Farming" that was established in Poland in 2015. The code was entered on the list of codes led by Polish Ministry of Agriculture and Rural Development. The idea of the code was the promotion of sustainable farming techniques in aquaculture, implementation the environmentally friendly and socially acceptable standards and promotion of compliance between legislation and customers' expectations. The requirements of the code are based on EU and Polish legislation, other fish standards and recommendations for fish farms such as ASC, FAO, or Blue Growth. Furthermore, use of photovoltaics is according to interviews also a common source of energy in carp production in Poland; the number of installed power has grown dynamically in sector in 2020-2021.

5.2 New processing and logistic techniques and their challenges

To Swedish citizens, many freshwater fish are associated with lack of tradition and knowledge of how to prepare them, and the small bone frequency and different taste (more "fish taste" and possibly taste of mud) can cause dismay. Product development has therefore been essential for establishment of markets, including sensory and texture evaluations with potential customers, as well as designing viable processes and products for producers. Earlier experiences (Resursfisk, 2021; Baltic Fish, 2021) have shown that identifying long-term sustainable solutions require close dialogue with stakeholders, offering opportunities to effectively share project results and increase the possibility for greater interest. When designing new value chains, it is important to start from the market actor's conditions to avoid short-term solutions, and includes, amongst others, both large actors from retail, restaurants, and the public sector. Many of these have goals related to sustainable seafood – but are part of the global food system, which makes changes slow and highly price-sensitive.

When establishing new value chains of cyprinid species in Sweden, experiences from countries with larger consumption of the species such as Poland and Switzerland have been sought for (County Administrative Board of Stockholm, 2022). So far, mainly mince is produced, and the current process could probably improve. For this process, it is extremely important with correct handling of the fish to avoid high fish scent or mud taste in the product. Interestingly, in terms of taste of Common bream, it has been found that this differs between fishing areas – the species has been found to taste muddier in some areas, but may resemble taste of perch, crayfish, mussels or even oysters in other fishing areas. Identifying causes of these differences may offer opportunities. Another challenge is how to handle the occurrence of small bones that dismay Swedish consumers. In other countries, the bones are broken down during processing, which offer one opportunity. Small fish sizes also require certain techniques for filleting. For roach, the fillet is in e.g. Switzerland (also common practice in Germany and Poland) run through a machine with tight-fitting knives that crush the small bones without cutting the skin before the fish is deep-fried and used as snacks. These processing techniques offer opportunities but are associated with costs and current value chain actors may not be viable enough to make these investments. Larger sizes of common bream could be smoked, which would likely be of interest to the Swedish market. However, for public kitchens, demand of smoked fish is low and there is also a challenge in sourcing enough volumes of larger fish. Cutting out boneless parts of Common bream may also be an opportunity, but this form of processing has a very low yield (less than 10 %) and is time-consuming. Further investigations are needed to identify a cost-effective handling of cyprinids in Sweden, offering a so-called double price model for the fish (e.g., producing both smoked boneless product in combination with mince production), which in turn creates the conditions for a low price of a large-scale product.

6 Conclusions

- Demand and production costs of new seafood with low GHG emissions is today challenging sustainable growth in Swedish and Polish value chains based on different cyprinids.
- From a positive side, integrating more species in a value chain is by industry in Sweden seen as an opportunity to increase resilience when traditional species are negatively affected from e.g., climate change.
- Climate change challenges reported by actors in Sweden refer to both uncertainties related to effects on ecosystems and species and fishing opportunities and increasing production costs.
- For Polish value chains, one challenge is to optimize for a stable volume of carp production and to continue logistic improvement made by market integrators.

- There is a scarcity of value-adding processing facilities in Sweden which makes efficient logistics important to GHG emissions.
- There are data deficiencies for inland fisheries and species with national management for defining sustainable exploitation levels requiring fishery management actions.

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SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

European plaice (*Pleuronectes platessa*)
Photo: Henk Heessen, WUR

Common sole (*Solea solea*)
Photo: Oscar Bos, WUR

Hoekstra, G., Deetman, B., Turenhout, M., Van den Burg, S., Vernooij, V., Broeze, J. & Guo, X.

LIST OF ABBREVIATIONS

Term	Description
GHG	Green House Gas
PH	Postharvest
CS	Case Study
MS	Member States of the EU
USP	Unique Selling Point

1 Background

The PH value chain of European plaice (*Pleuronectes platessa*) starts at several EU fish auctions where first sales take place after fresh plaice is landed by the demersal trawler fleet (bottom trawling and twin rig). In addition to the EU landings, plaice are imported from third countries. The most important third countries are UK, Russia and Iceland. Primary production comes entirely from wild capture fisheries. The British, Dutch and Danish flatfish vessels dominate the plaice landings within EU. The largest fish auction for plaice within Europe is Urk (Netherlands). Most of the plaice is processed here as fillets and exported frozen to Italy (Table 1). In particular market size category 4 is in high demand by the Italian retail and catering market. Larger market size categories are often sold fresh to HORECA. Increasingly, fresh fillets are exported to Germany and Scandinavian countries being less price competitive markets with higher added value (quality perception) compared to the Italian retail market for plaice. As the landings of plaice by the European fishery fleet have decreased in the last 5 years, imports of European plaice from third countries are increasing mainly from fisheries in northern cold waters such as Icelandic Waters and the Norwegian Sea where Norwegian and Russian fishing trawlers catching plaice. Substitutes for European plaice are Yellowfin sole (*Limanda aspera*) caught at the coast of Canada, Japan and Bering Sea and Rock sole (*Lepidopsetta bilineata*) caught in the waters of Alaska and Bering Sea. Especially when EU plaice landings are low these substitutes are of high importance for the EU processing industry to guarantee the supply of (frozen) flatfish fillets in the EU. By importing these substitutes of the European plaice by EU processors, these companies could still continue their production activities even during months when there are hardly landings of plaice by EU vessels. To process a whole European plaice in a fillet, on average 38-50 % of the whole fish is used (Figure 2). At this moment, most of the side products are collected and used for animal feed or bioenergy.

Four Dutch specialized flatfish processors were interviewed in person. One retailer that sells processed flatfish products in the Netherlands and Belgium was interviewed via an online meeting.

2 Value Chain

2.1 Value chain description

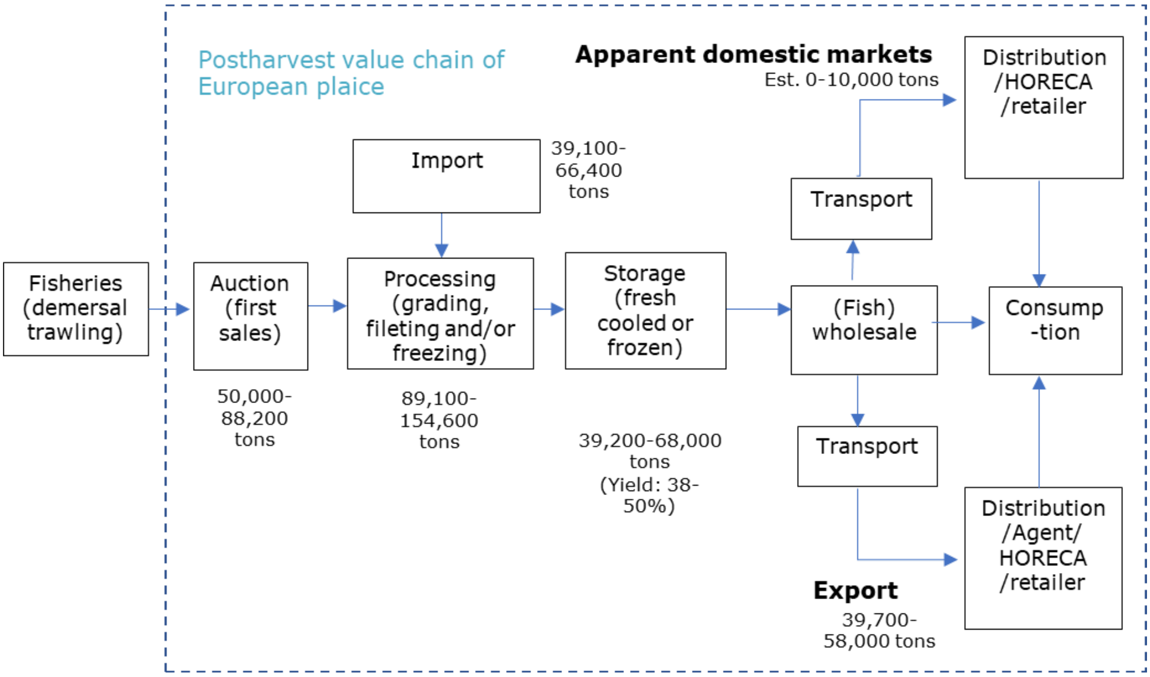


Figure 1. Postharvest value chain of European plaice (2015-2019). Source: EUMOFA

Table 1: Numbers of the postharvest value chain of European plaice (2015-2019). Sources: EUMOFA, European Commission (2021)

Main primary production	Top 5 EU countries (landing volume)	Volume first sales (annually)	Value first sales (annually)	TAC (quota) in 2021 (tonnes)	Main first sales locations
Wild capture (Demersal, bottom trawling)	1.Netherlands 2.Denmark 3.Belgium 4.UK 5.France	50,000-88,200 tons	121,100-145,500 thousand EUR	1.UK (24 %) 2.Netherlands (20 %) 3.Denmark (17 %) 4.Norway (6 %) 5.France (5 %) Total: 180,700 tonnes (EU incl. UK and Norway)	Urk (NL) IJmuiden (NL) Hirtshals (DK) Thyboron (DK) Oostende (BE)

Market size category to be analysed	Preservation & presentation	Top 5 EU countries (import value) of fillets + total import value EU (2019)	Top 5 EU countries (export value) of fillets + total export value EU (2019)	Dominant sales channel
Category 4: length between 27 cm and 31 cm	Fresh and frozen, fillets.	1.Italy (59 %) 2.Germany (13 %) 3.Belgium (7 %) 4.UK (7 %) 5.Netherlands (5 %) Total: 93.900 thousand EUR (EU incl. UK and Norway)	1.Netherlands (87 %) 2.Belgium (9 %) 3.Germany (1 %) 4.Poland (1 %) 5.Italy (1 %) Total: 101.700 thousand EUR (EU incl. UK and Norway)	Retail (supermarkets)

3 Resilience

3.1 Physical and financial resilience

In literature, no climate change events were found describing specifically impacts on financial or physical resilience for the PH value chain of plaice and sole. The only impact mentioned during interviews and found in literature (CERES, 2020), is that plaice is moving more to northern waters in the North Sea by rising water temperature. Grey literature showed that in 2002 there was a lower share of annual financial turnover with sales of sole and plaice among Dutch flatfish processors compared to 1996 (Kamer van Koophandel, 2004). In 1996, the total turnover consisted of 52.5 % plaice and 26.4 % sole. In 2002, this was 43.1 % and 18.4 % respectively (Kamer van Koophandel, 2004). Based on stakeholder consultation, this decreasing trend was confirmed. The underlying reasons mentioned were quota cuts and decreasing catchability of the plaice and sole. Based on literature, it could not be confirmed or denied that climate change results in lower catchability of sole and plaice in the North Sea. There are no direct climate change driven events in the PH chain of sole and plaice affecting the physical or financial resilience of the industry.

From the interviews and literature review it became clear that the PH fish value chain is mostly impacted by climate change driven events of:

- Displacement of plaice to more northern waters of the North Sea (Perry et al., 2005; Engelhard et al, 2011). This results into more days at sea (at the same amount of fishing days) due to increased miles to steam (float) before reaching fishing area at sea. This means increased fuel and energy consumption and higher GHG emissions. In response to this, fishing vessels could decide to land their plaice at fish auctions nearby the fishing grounds instead of the conventional fish auctions. If the fish are landed in more northern countries, a disadvantage could be that the quality and freshness of the fish decreases if transport to processing site takes long.

- Extreme weather events. These impact the PH chain as several events have targeted with particular intensity fishery areas and coastal zones (Aghakouchak et al., 2020). Increased frequency of storms during winter seasons results into fewer fishing days and therefore decreased landed volumes of caught fish. Floods may hinder activities at fish auctions or processing factories close to sea. Storms could hinder transporting trucks to distribute the fish products via EU highways. During summer seasons more heat waves are expected. This could be overcome by investing state-of-the-art cold storage capacity to maintain high quality of fish products. However, not every enterprise has the financial buffer to invest into new cold storage capacities. Another challenge is the discrepancy of willingness to generate renewable energy as enterprise via solar panels and the overloaded capacity of the energy infrastructure. Overloaded energy infrastructure has resulted into frequent power failures. This demotivates the PH enterprises to invest into the transition from fossil fuels into renewable energy.
- Due to climate change European plaice is decreasing in size and length since spawning seasons and other biological processes are affected (Queiros et al, 2018).

During the interviews, the following insights were provided by the stakeholders about their financial and physical resilience. Not all of the provided insights are (directly) related to climate change. Some of the insights are more market-driven.

- Flatfish processors in the Netherlands have a long track record and experience of flatfish processing. Their knowledge about processing techniques and the flatfish product is a Unique Selling Point (USP).
- Processors could become more self-sufficient for energy (in particular if climate change will affect the availability of energy) by generating renewable energy via solar panels.
- Increasingly, PH companies are reducing packaging materials (less plastics, more recycling).
- Processors are recycling rest warmth from production machines to reduce electricity usage and therefore reduce their carbon footprint.
- Locally landed flatfish is important to the PH chain since added value is brought to the products by own processing in EU, compared to outsourced processing to third lower-cost countries of fish products.
- Many PH companies have acquired ecolabels and sustainable certificates in order to act upon EU climate policy (Green Deal) and sustainable needs of their customers, often stimulated downstream by EU retailers.
- Vertical integration between fisheries and processing ensures sufficient flows of raw materials. It enables a better prediction between supply and demand in PH chain.
- Frozen fish products are often transported via sea freight and therefore less GHG emissions compared to airplane freight.
- Investments in renewable energy (solar panels) are not always possible due to overloaded capacity of the energy infrastructure.
- Difficult to renovate existing buildings. New buildings are more efficient for renewable facilities such as heat pump.
- Diversification to other species such as salmon, seabass and cod, sourced and imported from outside EU is a strategy to continue PH production, as EU landings of flatfish are decreasing due to displacement of plaice (by rising sea water temperature).
- Importing substitutes is another mitigating management strategy such as Yellow tail flounder from third countries in case of lacking supply by decreasing landing volumes of flatfish in the EU.

- New species (e.g. squid, red mullet, gurnard, see CS8) introduced to market is a third mitigation management strategy.
- Since the COVID-19 pandemic, it is more reliable to not outsource processing of flatfish to China due to challenges with transport and customs due to Chinese zero-tolerance COVID policy. Customs and border control procedures in Chinese harbours could delay embarking of fish products that is problematic for these perishable products. Therefore, it is an opportunity to process within EU, providing more reliability and less food miles (and therefore less GHG emission by transport).
- Sustainability could be utilized as an USP in the EU market.
- Scarcity of raw materials (unprocessed fish), resources (ingredients like flower, sunflower oil but also fossils, energy, fresh water etc.) within the EU is a threat for PH chains, which could harm existing supply to EU markets.
- Labor shortage makes it difficult to process flatfish in time.
- Displacement of fishing stocks to northern waters are a risk to the supply for PH chain. More efforts and costs are needed to relocate caught fish to PH activities in EU.
- Decreasing landed volumes of flatfish in EU is a threat to PH chain of flatfish.
- Energy and fossils costs are increasing as a result of the Ukraine war.
- Higher dependency on imports from third countries of raw materials (fish to be processed) and therefore decreased self-sufficiency.
- Processing activities like freezing, glacing and breading including baking are intensively energy (electricity and gas) consuming. If energy prices are increasing even more than currently occurs due to the war in Ukraine, it will be loss given to process the flatfish.
- Retail supply contract often fixed prices for one year-round. It is difficult to increase contract prices in case of cost inflation during the contract period.
- Many business-to-business customers and end-consumers in Southern EU MS less prone to value sustainability.

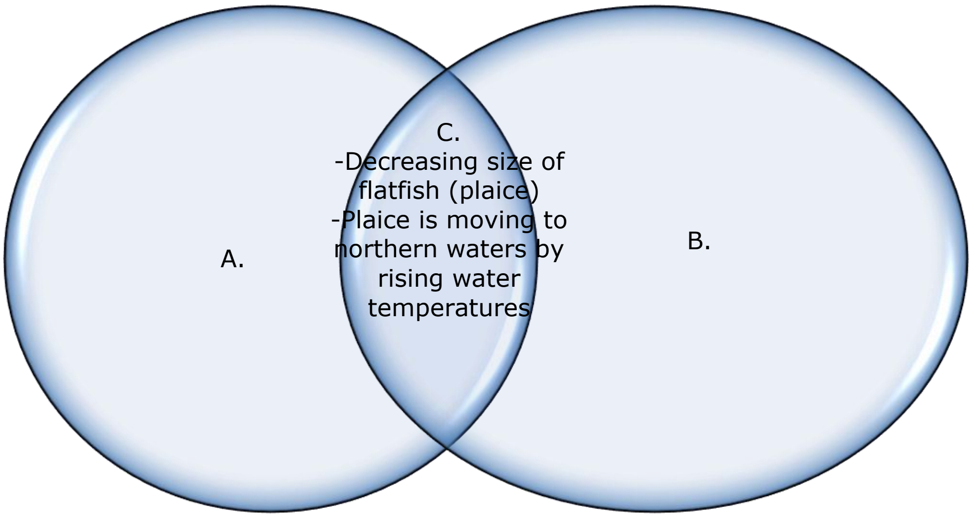
3.2 Major financial constraints and reliability

No major financial constraint was found in the scarce relevant literature related to plaice and sole for the PH chain. Based on the stakeholder consultation, a summary of SWOT of the PH value chain for plaice and sole was created.

3.3 Stakeholders' perceptions

	Helpful	Harmful
Internal origin (attributes of the organizations)	Strengths • Self-sufficiency to certain extent by generating renewable energy via solar panels • Reducing packaging materials (less plastics, more recycling) • Recycling rest warmth from production machines. • Ecolabels and sustainable certifications acquired by PH enterprises to enable supplying EU retailers. • Vertical integration between fisheries and processing ensures sufficient flows of raw materials. • Frozen fish products transported via sea freight and therefore less GHG emissions compared to airplane freight.	Weaknesses • Investing into renewable energy (solar panels) not always possible due to overload capacity of the energy infrastructure. • Difficult to renovate existing buildings. New built is more efficient for renewable facilities such as heat pump.
External origin (attributes of the environment)	Opportunities • Diversification to other species such as salmon, seabass and cod, sourced and imported from outside EU. • Importing substitutes such as Yellow tail flounder from third countries in case of lacking supply by decreasing landing volumes of flatfish in EU. • New species (e.g. squid, red mullet, gurnard) introduced to market. • After COVID-19 it is more reliable to not outsource processing of flatfish to China due to challenges with transport and customs due to Chinese zero-tolerance COVID policy. Therefore, it is an opportunity to process within EU that provides more reliability and less food miles (and therefore GHG emission by transport). • Sustainability as USP in storytelling to EU market	Threats • Scarcity of raw materials (unprocessed fish) within EU, resources (ingredients like flower, sunflower oil but also fossils, energy, fresh water etc.) which could harm existing markets • Displacement of fishing stocks to northern waters. More efforts and costs to relocate fish to PH activities in EU. • Higher dependency on imports from third countries of raw materials (fish to be processed) and therefore decreased self-sufficiency. • Processing activities like freezing, glacing and breading including baking are intensively energy (electricity and gas) consuming. If energy prices are increasing even more than currently occurs due to the war in Ukraine, it will be loss given to process the flatfish. • Many business-to-business customers and end-consumers in Southern EU MS less prone to value sustainability.

3.4 (Mis)Fits between literature review and stakeholders' perceptions



A. = From literature review
B. = From stakeholders' perception
C. = Overlapping as found both in literature and stakeholders' consultation

3.5 Role of management – lessons learned of adopted strategies

Due to lower catchability and therefore decreasing landing volumes of flatfish in the Netherlands, the PH chain diversified to other species like salmon from aquaculture and wild captured cod. The diversification strategy to more species than only flatfish has been successful as the revenues of these fish processors have been growing while the financial turnover from processing and selling North Sea species as plaice and sole did rather decrease than stabilize or grow.

4 Greenhouse Gas Emissions

GHG emissions in the post-harvest chain are related to transportation (fuel use), processing and refrigeration (mainly energy use; with phasing out refrigerants with high GHG impact the contributions from leaking refrigerants is marginalized) and packaging. Also food losses (indirectly) induce additional GHG emissions since losses induce extra demand for catch and related post-harvest chain emissions. The GHG emissions are estimated for typical post-harvest chains for the products of this case study: typical transportation distances, refrigerated storage durations and packaging solutions.

GHG emissions in the postharvest chain are related to transportation (fuel use), processing and refrigeration (mainly energy use; with phasing out refrigerants with high GHG impact the contributions from leaking refrigerants is marginalized) and packaging. Furthermore, food losses (indirectly) induce additional GHG emissions since losses induce extra demand for catch and related postharvest chain emissions. The GHG emissions are estimated for typical postharvest chains for the products of this case study: with typical transportation distances, refrigerated storage durations and packaging solutions. Results show that especially consumer packaging material use and effects of losses in postharvest chains (which induce extra catch) are dominant hotspots.

Below the following cases are analysed:

- fresh sole, marketed in NW-Europe,

- frozen glazed sole, exported from the Netherlands to South Europe
- frozen breaded plaice fillets, exported to South Europe

4.1 GHG emissions in the PH chain for fresh sole

Fisheries

Understanding GHG emissions for catching the seafood is relevant for this study since losses along the postharvest chain indirectly induce extra demand (thus extra catch).

Fisheries for flatfish consume around 2 liter fuel oil per kg fish (www.visserijincijfers.nl). Since fuel use induces around 96% of the GHG emissions (Sandison et al., 2021). From the fuel use we derive a typical GHG emission intensity of 8 kg CO2-eq. per kg landed fish. This value is quite in line with the range provided by the 'Seafood Carbon Emissions Calculator' (http://seafoodco2.dal.ca/).

Transport from auction to processor

Typical transportation distance is 50km. For a large truck, based on data from www.ecotransit.org and EcoInvent GHG emissions associated to this type transport are estimated at 0.20 kg CO2-eq, per ton product per km. Result: 0.01 kg CO2-eq. per kg

Processing, packaging and storage

The whole fish is delivered with ice flakes in eps boxes.

Ice flake use is estimated at 0.5kg ice per kg fish. Production of ice flakes requires about 0.02kWh per kg ice flakes (Amiadji et al, 2017). Based on average European GHG emission intensity of electricity[32], producing 0.5kg ice flakes induces 0.002 kg CO2-eq GHG emissions.

The eps package weight varies around 60 gram eps per kg fish fillet. Based on typical GHG emission intensity of packaging eps (3.7 kg CO2-eq per kg material, ETC-WMGE, 2021) the net climate impact of plastic use is 0.22 kg CO2-eq. per kg fish.

Transport

For transportation to a distribution centre and retail outlet large trucks are used. Transportation distances vary amongst the markets, from typically 50km to 500km. Based on 0.20 kg CO2-eq, per ton product per km, the distribution transport contributes 0.01 to 0.10 kg CO2-eq. per kg fish product.

Energy use for refrigeration in the retail display cabinet

Typical electricity use of 0.06kWh per kg per day was derived from a set of direct measurements for various product categories; the actual value however will largely depend on technical design, loading degree and operational use.

Assuming typical shelf period of 2 days follows total refrigeration electricity use of 0.12kWh per kg fish, which induces 0.03kg CO2-eq. per kg product.

[32] The actual GHG emission intensity of electricity differs amongst countries because of varying energy mixes; we used the EU-average in the calculations.

Effects of losses in retail

Losses in retail are estimated at 7.5% (retail interview). Emissions associated to catching, processing and transporting these lost products are allocated to the actually sold products.

Summary of climate impact

Table 1. Summarized climate impact of described post-harvest chains

Chain stage	GHG emissions kg CO2-eq. per kg fish
transport from auction to processor	0.01
refrigeration + ice flakes production	0.002
eps packaging	0.22
transport	0.01 to 0.10 (average 0.06)
energy use in retail	0.03
effects due to losses	0.61
TOTAL post-harvest	0.93

Remark: the total GHG emissions in the PH chain are dominated by the (indirect) effect of losses. Be aware that the denote loss percentage (7.5%) was provided by only one stakeholder; others could give estimates. The percentage is an estimated average for a broad group of products in one situation. Consequently, above result should be considered as an indicative value.

4.2 GHG emissions in the PH chain for glazed plaice

Frozen glazed plaice is marketed in South Europe.

Processing, packaging and storage

In processing the fish is first gutted (weight loss around 15%, https://www.chefs-resources.com/seafood/seafood-yields/). Next the fish is glazed (typically 0.3kg ice/glaze added per kg fish). For energy use of the of the processing step including glazing/freezing no information was provided; as a work-around we estimate it from data found in literature on meat and fish freezing, increased by a factor 50% because of the glazing. Consequently the GHG emissions related to processing/freezing are estimated around 0.06 kg CO2-eq per kg fish.

The fish is packaged at the processor and/or in the distribution centre or retailer. For typical consumer package on average around 30 gram plastic per kg fish fillet is used. Based on GHG emission intensity of packaging plastics (3 kg CO2-eq per kg plastic, ETC-WMGE, 2021) the net climate impact of plastic use is 0.09 kg CO2-eq. per kg fish fillet.

Frozen storage in processing, wholesale and storage: product storage period varies; here typically 3 months is assumed. Based on typical electricity use for refrigerated storage (Evans et al., 2014) follows climate impact of storage around 0.07 kg CO2-eq. per kg product (0.09 kg per kg fish).

Transport

Transportation to a distribution centre and retail outlet goes through large trucks. Transportation distance to South Europe is estimated at 1200km. Based on 0.20 kg CO2-eq, per ton product per km, the distribution transport contributes typically 0.24 kg CO2-eq. per kg product, that is around 0.3kg per fish.

Energy use for refrigeration in the frozen retail display cabinet

Energy use of frozen retail display cabinets strongly depend on type of freezer and filling degree and operational use. From Evans et al. (2014) a typical electricity use of 0.06kWh per kg per day was derived from a set of direct measurements for various product categories.

Assuming typical shelf period of 20 days follows total refrigeration electricity use of 1.2kWh per kg fillet, which induces 0.27kg CO2-eq. per kg product, that is around 0.33 kg CO2-eq. per kg fish.

Effects of losses in retail

Losses in retail are estimated minimal for frozen product and neglected here.

Summary of climate impact

Table 2. Summarized climate impact of described case

Chain stage	GHG emissions kg CO2-eq. per kg gutted fish	GHG emissions per kg gutted fish
transport from auction to processor	0.01	0.01/0.85=0.01
processing/freezing		0.06
consumer packaging		0.09
frozen storage		0.09
transport		0.30
energy use in retail		0.33
effects due to losses		0.0
TOTAL postharvest		0.88

4.3 GHG emissions in PH chain for frozen breaded plaice

Frozen breaded fish products are composed of typically 50 to 60% fish fillet, around 10% oil (for instance rapeseed oil) and batter (composed of starch bread crumbs, water and some minor ingredients). The production chain consists of the following essential steps: filleting, battering, frying, freezing, frozen storage, frozen (international) transport and frozen storage in the retail channel. In below elaboration GHG emissions of the processing steps including contributions of the batter and (frying oil) are derived

Processing, packaging and storage

The filleting yield is estimated at 50%.

Effects of adding bread crumb layer and processing are derived from Vazquez-Rowe et al. (2013), who analyzed GHG emissions related to fish sticks production (like for breaded plaice fillets, the fish stick consists of about 50% fish fillet and 50% bread layer). The bread layer is composed of various ingredients amongst which bread crumbs, flour and oil. Total GHG emissions related to processing, freezing and bread crumb ingredients are estimated by Vazquez-Rowe et al. at 0.7 kg CO2-eq. per kg edible product, that is 1.4 kg CO2 eq. per kg fish ingredient.

Packaging related GHG are also derived from Vazquez-Rowe et al. (2013): typically 0.04 kg CO2-eq. per kg edible product (0.08 kg CO2-eq. per kg fish ingredient).

Frozen storage of the frozen product varies; here typically 3 months is assumed. Based on typical electricity use for refrigerated storage (Evans et al., 2014) follows climate impact of storage around 0.07 kg CO2-eq. per kg product (0.14 kg per kg fillet).

Transport

Transportation to a distribution centre and retail outlet goes through large trucks. Transportation distance to South Europe is estimated at 1200km. Based on 0.20 kg CO2-eq, per ton product per km, the distribution transport contributes typically 0.24 kg CO2-eq. per kg product, that is 0.48 kg CO2-eq. per kg fish fillet ingredient.

Energy use for refrigeration in the frozen retail display cabinet

Energy use of frozen retail display cabinets strongly depend on type of freezer and filling degree and operational use. From Evans et al. (2014) a typical electricity use of 0.06kWh per kg per day was derived from a set of direct measurements for various product categories.

Assuming typical shelf period of 20 days follows total refrigeration electricity use of 1.2kWh per kg product, which induces 0.27kg CO2-eq. per kg product (equivalent to 0.54 kg CO2-eq. per kg fish fillet component).

Effects of losses in retail

Losses in retail are estimated minimal for frozen product and neglected here.

Summary of climate impact

Table 3. Summarized climate impact of described case

Chain stage	GHG emissions kg CO2-eq. per kg fish	GHG emissions kg CO2-eq. per kg fillet-equivalent
transport from auction to processor	0.01	0.01/0.5=0.02
processing, breading and freezing		1.4
consumer packaging		0.08
frozen storage		0.14
transport		0.48
energy use in retail		0.54
effects due to losses		**0.0**

Remarks:

- A significant part of the PH emissions are related to ingredients in the bread crumb. This increases the total nutritional value and it is questionable whether this should be allocated to the fish.
- Since the GHG emissions related to freezing and frozen storage in the PH chain are not dominant, it is expected that the PH GHG emissions for breaded place are comparable to those for e.g. fresh breaded pre-cooked chicken products.

5 Conclusions

The flatfish PH chain is mainly affected by climate change with decreasing landing volumes and smaller sized plaice according to literature. Consulted stakeholders perceive the displacement of plaice (due to rising sea water temperature) to outside EU waters and therefore less supply by decreasing landings of EU vessels is problematic for the resilience of PH chain. Another concern of consulted PH stakeholders is the rising energy costs due to Ukraine war. Despite the cost inflation, the rising energy costs stimulates PH companies to invest into renewable energy and to reduce their footprint as freezing processing activities requires high energy and gas consumption. Unfortunately, due to a limited energy infrastructure capacity it is not always possible to implement solar panels. Another problem is that insurance companies are not willing to insure solar panels at the roofs of processing factories due to risk of burn (with too large capital value of the factory to insure that is at risk). Management interventions to mitigate the effects of climate change or other market driven threats to the resilience of PH chains are:

- Importing substitutes such as plaice from third countries
- Introducing new species like squid (see CS8)
- Diversifying to other species like aquaculture, such as salmon or seabass and seabream.

GHG emissions in the post-harvest chain strongly vary amongst the final product types.

The first product considered is fresh common sole, traded regionally. For this product type the emissions are estimated around 0.9kg CO_2-eq. per kg fish (with a high uncertainty: the actual value strongly depends on the actual losses along the PH chain, which are poorly known).

For products traded in southern Europe, the estimated emissions highly depend on the product type: varying from 0.9 kg CO_2-eq. per kg (glazed) sole to 2.7 kg CO_2-eq per kg fillet for breaded plaice. Note that the value for the breaded product is relatively high because of bread layer ingredients, baking step and because the bread layer weight is added to the fish product in frozen storage and transport.

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CASE STUDY 13: DEMERSAL FISH – INVASIVE SPECIES (*SIGANUS LURIDUS*, *SIGANUS RIVULATUS* AND *PTEROIS MILES*) – SMALL-SCALE FISHERIES OF GREECE AND CYPRUS

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Stelios Katsanevakis

LIST OF ABBREVIATIONS

Term	Description
CPUE	Catch Per Unit Effort
IAS	Invasive Alien Species
NIS	Non-Indigenous Species
SSF	Small-Scale Fisheries
SST	Sea Surface Temperature

1 Background

The small-scale fisheries (SSF) fleet in the Mediterranean and the Black Sea dominates the regional fishing fleet and has a significant social and economic role, supporting livelihoods in coastal communities and local economies. SSF in the Mediterranean and the Black Sea represent 84 % of the fishing fleet, 44 % of fishing capacity, 62 % of the workforce aboard, and 24 % of total landing value from capture fisheries (FAO 2021). However, they have been suffering from serious challenges in recent decades as a result of overexploitation, unsustainable fishing practices, degraded habitats, pollution, biological invasions and climate change. The cumulative impacts of such stressors and inefficient management have put the profitability and viability of the SSF sector at risk (Said et al. 2018; Tzanatos et al. 2020; Ünal and Ulman 2020). SSF fishers and their families are a highly vulnerable population susceptible to important risks due to their low incomes (FAO 2019). Securing the environmental, economic and social sustainability of SSF and the related supply chain has been the main goal of the Regional Plan of Action for Small-Scale Fisheries in the Mediterranean and the Black Sea (FAO 2021). The proliferation of thermophilic invasive species in the eastern Mediterranean may provide opportunities for introducing new species to the market, thus contributing to the viability of the SSF sector and the resilience of the linked supply chains.

Invasive alien species (IAS) may have important negative impacts on biodiversity, infrastructure, human health, and ecosystem services (Mazza et al. 2014; Katsanevakis et al. 2014; Bellard et al. 2016). However, IAS may also have positive impacts, through the provision of food and shelter, the creation of novel habitats or through securing ecosystem processes and functions (Hobbs et al. 2009; Schlaepfer et al. 2011; Katsanevakis et al. 2014; Rilov et al. 2020; Tsirintanis et al. 2022). Within the Mediterranean Sea, the majority of IAS introductions and subsequent increases in population abundance has been associated with increasingly warming waters. Importantly, within the European Union, when examining the role of such species, Katsanevakis et al. (2014) showed that food provision was the predominant ecosystem service impacted by IAS, including both positive and negative impacts. To develop effective management strategies for adaptation and resilience to the effects of climate change on fisheries, the impacts of climate-change-assisted IAS need to be seen from a holistic perspective and as a multifaceted process, inclusive of societal perceptions and implications (Goodenough 2010; Simberloff et al. 2013).

In the Mediterranean, many thermophilic species introduced through the Suez Canal continuously expand their range northwards and westwards as sea temperatures increase (Dimitriadis et al. 2020). Some of these species, such as rabbitfishes and lionfish, have massive negative impacts on both biodiversity and ecosystem services (Katsanevakis et al. 2014; Tsirintanis et al. 2022). However, in land-locked seas such as the Mediterranean Sea, the loss of temperature-sensitive native species might compromise food provision, as species shifting their range from southern latitudes are absent to fill the gap. In such cases, thermophilic alien species are more likely than native species to persist and could be beneficial overall by fulfilling the lost ecological roles and providing a novel exploitable source for fisheries (Katsanevakis et al. 2018). Currently, in the Levantine Sea, where alien fish dominate today in the shallow shelf communities and the commercial catches (Edelist et al., 2013; Katsanevakis et al. 2018), food provision and the income of the fishers would have seriously declined if there were no alien species. The present situation in the Levantine Sea (Figure 1) represents a ‘forecast’ of the future situation in the EU countries of the eastern Mediterranean due to the continuous sea warming.

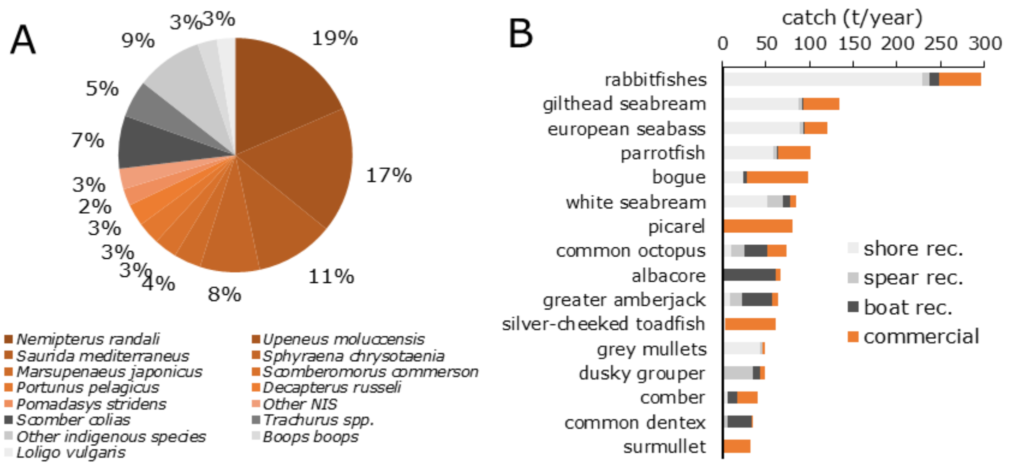


Figure 1 (A) Catch composition in 78 commercial trawl hauls along the Israeli coast between May and December 2017 in depths 30-60 m. Brown shades refer to NIS, whereas grey shades to native species (adapted from Katsanevakis et al., 2018); (B) Species composition of the Cypriot recreational (rec.) and commercial fisheries. Rabbitfishes, which rank first, include the IAS *Siganus rivulatus* and *S. luridus* (adapted from Michailidis et al. 2020).

Two alien rabbitfishes, the dusky spinefoot *Siganus luridus* and the marbled spinefoot *Siganus rivulatus* dominate fish communities in the coastal reefs of the eastern Mediterranean (Sini et al., 2019), causing detrimental impacts on the reef communities due to overgrazing (Rilov et al., 2018). However, both rabbitfish species have acquired a commercial value at local fish markets in many eastern Mediterranean countries (Carpentieri et al. 2009; Katsanevakis et al. 2014; Kalogirou et al. 2012; Michailidis et al., 2020; Shakman et al. 2019; Soykan et al. 2020), e.g., reaching the value of 25 euros/kg in Cyprus. While in Cyprus, rabbitfishes currently constitute the main target species of recreational fisheries and are one of the main target species of commercial fisheries (Fig. 2B; Michailidis et al. 2020), in southern Greece where the species are also very abundant (Sini et al. 2019; Katsanevakis et al. 2020), they are mostly discarded or attain very low values, e.g., 3 euros/Kg in the Dodecanese Islands (Roditi and Vafidis 2022). Nevertheless, their increased abundance in certain islands in south-eastern Greece has contributed to their marketing at much higher prices in some localities, e.g., 10-15 euros/Kg in Rhodes Island (Corsini-Foka et al. 2017).

The lionfish *Pterois miles* is a successful Lessepsian invader, rapidly spreading in the eastern and central Mediterranean (Dimitriadis et al. 2020), and gradually becoming a dominant predator along the eastern Mediterranean coasts (Kleitou et al. 2021). Lionfish are voracious opportunistic ambush predators and their establishment in Mediterranean ecosystems has the potential to significantly disturb local food webs (D'Agostino et al. 2020; Savva et al. 2020). The species is edible and is currently found in fish markets in the eastern Mediterranean. Promoting its fishery and marketing has been suggested as a way to control its populations and mitigate the ecological impacts of population increases (Kleitou et al. 2021). However, its potential inclusion in the EU list of IAS of Union Concern (as defined by Regulation 1143/2014) might complicate its marketing. This is because Article 7 of the IAS Regulation specifies that species of Union concern should not be intentionally placed on the market and that buying, selling, using, and exchanging of IAS shall be prohibited. A reform of the IAS Regulation to allow for dead specimens to be marketed in order to incentivize a targeted fishery has been proposed by Kleitou et al. (2021).

As climate change drives the continuous increase of thermophilic invasive species and the decline of native commercial species in fish communities of coastal areas in the eastern Mediterranean, this CS will investigate the potential of *S. luridus*, *S. rivulatus,* and *P. miles* to contribute to the sustainability of small-scale coastal fisheries in Greece and Cyprus. These species, as the vast majority of small-scale fisheries catch, are directed to the consumers fresh without any processing (other than cleaning), either through wholesalers or retailers (fish markets) or even directly to consumers or restaurants. As these species have become both a new resource and a threat to native commercial species and ecosystems, their exploitation and marketing can be promoted as a win-win strategy to contribute both to the resilience of small-scale fisheries and related value chain, as well as in providing sustainable conservation and IAS impact mitigation policies, by controlling IAS populations. The adaptation of the supply chain to the introduction and dominance of new thermophilic invasive species is a major issue for the sustainability of small-scale coastal fisheries. The CS will assess the resilience of small-scale fisheries in Greece and Cyprus to climate change, and the adaptation of the supply chain to the dominance of IAS.

2 Value Chain

2.1 Value chain description

Small-scale fisheries (SSF) in the eastern Mediterranean are characterized by low levels of investment throughout the value chain, including pre-harvest, harvest, and PH stages. Products are mostly marketed fresh without any processing (other than fish cleaning). There is none, or minimal, product differentiation through processing, improvement of existing products, exploitation of by-products, canning or packaging, with little or no labelling. The value chain (Figure) is short (in particular in remote insular areas in Greece), spanning from direct sales at the place of landing or within the producer's shop (i.e., without any middleman between the producer and the consumers) to direct sales to retailers (fish markets or supermarkets), or restaurants/hotels predominantly in the same area where the catch was landed (Maniopoulou et al. 2020). In many localities, part of the catch is traded through wholesalers or fish wharves (Roditi and Vafidis 2022). A recent study in the insular region of northern Cyclades (Aegean Sea, Greece) based on interviews with 92 fishers from five Greek islands, reported that SSF products are primarily sold to local restaurants (36 %), and then to local wholesalers or retailers (27.4 %), directly to local consumers (24.1 %), distant consumers away from the islands (9.7 %), and distant retailers (2.8 %) (Maniopoulou et al. 2020). These percentages may substantially differ seasonally, e.g., sales to restaurants are much more important during the summer months. In contrast to Cyprus, rabbitfishes and lionfish are not targeted and are often discarded in Greece and official data on their catches are not available.

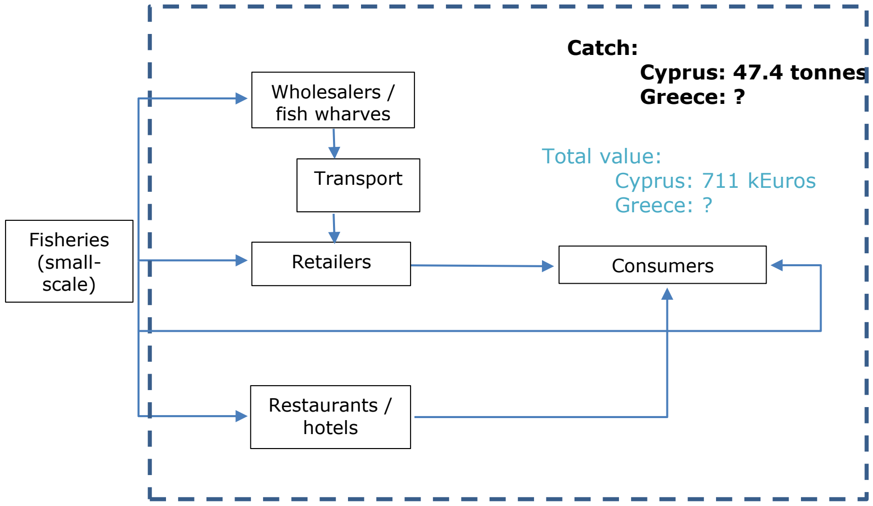


Figure 2 Postharvest value chain of rabbitfishes and lionfish in Greece and Cyprus.

3 Resilience

3.1 Physical and financial resilience

The sustainability of SSF in the Mediterranean is impeded by the existing organisation of value chains and market structures, dominated by a lack of product traceability and underappreciation of the value of SSF products, as well as limited influence over the price (Penca et al. 2021). The value of SSF products as a quality service (local production, fresh, culinary varied nature) is not adequately recognized and separated from industrial, farmed, and imported products (Pascual-Fernandez et al. 2019), such as farmed salmon, seabass, and seabream, or imported tuna that are common across the Mediterranean markets and tend to diminish local SSF products (Penca et al. 2021). Important reasons for the marginalization of SSF products in consumer preferences are the failure of policies for ensuring their visibility in the markets, the poor public education about the seafood trade and sustainability (Lawley et al. 2019; Penca et al. 2021), and the fact that supply is not steady as it seasonally varies and is greatly affected by weather conditions and the availability of target species (Roditi and Vafidis 2019; Maniopoulou et al. 2020; Penca et al. 2021), all conditions that are expected to be intensified due to climate change. In addition, small-scale fishers face competition from industrial fishing and aquaculture and the illegal marketing of fish by recreational fishers, which are marketed at competitive prices (Maniopoulou et al. 2020).

Climate change affects SSF through the increased frequency and intensity of bad weather restricting days-at-sea, proliferation of invasive species (e.g., *Lagocephalus sceleratus*) that cause extensive damage to gear and catches, and increased frequencies of algal blooms affecting fishing activities (present study, interviews). The most pronounced impact of climate change in the eastern Mediterranean SSF has been changes in catch composition (Katsanevakis et al. 2018; Michailidis et al. 2020; present study, interviews & questionnaires). Native species (e.g., sparids and striped red mullet) have declined in catches, while alien species populations (e.g., rabbitfishes, pufferfishes, and lionfish), especially in the easternmost regions of the Mediterranean, have increased and now dominate catch biomass.

Increases in sea surface temperature (SST) combined with decreased precipitation and river runoff may increase stratification, reduce productivity, and increase fish energetic costs, (e.g., Triantafyllou et al. 2019), and invasive jellyfish are predicted to further expand due to climate change (e.g., Stergiou et al. 2016) affecting several fish stocks. The cumulative impacts of overfishing and climate change have been identified as a major threat to SSF resources throughout the Mediterranean Sea (Fortibuoni et al. 2015; FAO 2018). The supply of traditionally fished SSF target species within the Mediterranean (e.g., groupers, sparids and striped red mullet) has become more irregular or interrupted. This has negatively affected the supply chain for such species, causing a shift of customers, e.g., restaurants that need to have a constant menu, to other fish products from industrial fisheries (e.g., sardines, anchovy), Mediterranean aquaculture (European seabass, gilthead seabream) or other international aquaculture (salmon) whose supply is more stable. In Cyprus, alien species such as rabbitfishes have already replaced traditional catches becoming the species with the highest catches and value (Figure 1), substantially contributing to fishers' income (Michailidis et al. 2020). In Greece, this shift has yet to come, but consumers seem to be receptive to changing their feeding habits, especially when properly informed about the high quality of rabbitfishes and lionfish and that their consumption contributes to mitigating their negative impacts (see Supplement 1). Invasive alien species marketing provides an opportunity to improve the resilience of the SSF supply chain, in particular where this involves a species with very high abundance and biomass such as the rabbitfishes in Cyprus (Michailidis et al. 2020) and the southern Aegean (Corsini-Foka et al. 2017; Sini et al. 2019; Katsanevakis et al. 2020; Crocetta et al. 2021), as well as such products having a marketable taste.

3.2 Major financial constraints and reliability

Overfishing and the decline of fish stocks targeted by SSF in the eastern Mediterranean is the main threat to the viability of the sector. Low income combined with hard working conditions and safety concerns has led to a low attractiveness of the SSF sector, in which employment trends are negative (Maravelias et al. 2018). At present, SSF often cannot provide a sustainable livelihood, which leads fishers to engage in additional activities to support their families (e.g., tourism and X?). Broadening fishing activities by aiming at innovation and diversification, e.g., through fishing tourism, has been proposed as the way to increase fishers' income and improve the viability of the sector (Kyvelou and Ierapetritis 2020). As stressed by interviewed stakeholders, the major issue of SSF in the eastern Mediterranean is the decline of fish stocks and reduced CPUE, attributed to a combination of stressors but mostly to overfishing and in Greece also to bad fisheries management. The impacts of climate change are less pronounced and have much less effect on the viability of the sector and securing the supply chain. Priority should be given to the protection of fish stocks and proper management.

Fuel prices represent a major financial constraint, in particular due to their recent abrupt increase due to the Ukrainian war. Stakeholders are concerned that due to climate change mitigation measures, e.g., by abolishing the tax-free fuel policy for SSF or imposing additional green taxes on vessels of low energy efficiency and high emissions energy costs will further increase. As stated by Greek fishers, despite funding opportunities by the state, to improve vessel energy efficiency or promote SSF products, most of the small-scale fishers could not take advantage of these opportunities. This is for two main reasons: (1) the financial state of small-scale fishers is already bad. To apply for these funding opportunities, fishers needed to submit a tax clearance certificate and a social security certificate, but a large percentage of fishers are unable to get such certificates because of their debts; (2) for large investments, e.g., for improving the energy efficiency of vessels, fishers need to pay first for the expenses, which are often many tens of thousands of Euros, and they get reimbursed after many months or more than a year. They do not have the capital to do so and it is very difficult to get bank loans to manage to pay in advance for such investments.

Some IAS substantially contribute to increasing SSF catches and income, thus improving the viability of the sector and sustaining the supply chain. This has been noticeable in

Cyprus, where rabbitfishes have become the most important target species in terms of both landings and value, attaining very good market prices. Lionfish have been also promoted for consumption in Cyprus and gradually gain share in the market. Greece still lags behind, but it seems that with the increasing abundance of IAS (especially in south-eastern Aegean) marketing of IAS, in good terms for the fishers, is gradually established (Kleitou et al., 2021). In the list of species which have a Greek brand name and may be available for sale in the Greek market, as provided in no. 1750/32219/19-03-2015 (B'475) Ministerial Decision (last amendment no. 138/71708/17-03-2022 (B' 1375)), alien species such as *Siganus* spp. have been included. Soon, it is expected that other alien species, such as the lionfish, will be included in this list.

3.3 Stakeholders' perceptions

The main perceptions of stakeholders on the most influential climate change impacts and the major consequences to financial and physical resilience are depicted in Table . These perceptions were based on interviews with selected stakeholders. These were an official of the Department of Fisheries and Marine Research, Ministry of Agriculture, Rural Development and Environment of Cyprus; scientific advisor of the Pan Cypriot Association of Professional Coastal Fishers; the former president of the Small-Scale Fishers of the southern Aegean; two officials of the General Secretariat of Fisheries, Ministry of Rural Development and Food of Greece; and an official of the decentralized Department of Fisheries in the Perfecture of Chania, Greece.

To achieve the objective of SSF adapting to climate change to secure the value chain, the only strength of SSF in comparison to competition was that many new (alien) species are thermophilic, shallow-water species that are predominantly targeted by small-scale fisheries, and less so by competitive fisheries, hence the main benefit from the introduction of such new species in the market will be received by SSF. On the other hand, SSF have many inherent weaknesses such as the ageing fleet (old technology and high fuel consumption), low market share and high vulnerability to increased production costs, high vulnerability to the increased frequency of bad weather, local operations and thus higher difficulty of adaptation through changing fishing grounds, lack of proper training to new fishing methods, low degree of organization through fishers' associations, low profitability and viability, and ageing of fishers with thus reduced adaptive capacity.

According to stakeholders, increased threats for SSF because of climate change include the decline of native stocks, reduced acceptance of new species by some consumers, high negative impacts by some invasive species that damage gear and catches, knowledge gaps on the effects of climate change on stocks and fisheries that may lead to inappropriate management, increased forest fires related to the degradation of coastal essential fish habitats, and increased frequency and intensity of bad weather.

Table 1 Main perceptions of stakeholders on the most influential climate change impacts and the major consequences to financial and physical resilience

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the	Strengths Many alien species are thermophilic, shallow-water species that are predominantly targeted by small-scale fisheries, and less so by industrial fisheries. Hence, the competition for these species	Weaknesses The small-scale fleet is old and the engines are of old technology and of high fuel consumption with high emissions. Increased restrictions on emissions will lead to the need for substantial investments for renovations, which unless subsidized, will not be affordable by the majority of the low-income small-scale fishers.

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
	could be lower than for other native species.	The landings by small-scale fishers cover only ~10 % of the market in Cyprus. Due to their low market share, small-scale fisheries can be more vulnerable to increased production costs, as other sectors (aquaculture, imports of frozen fish etc) could easily outcompete them (if these other sectors obtain better energy efficiency). Small-scale fishing fleet is more vulnerable to bad weather conditions than other sectors (industrial fisheries, aquaculture, imports, etc). Most SSF vessels operate locally and thus it is difficult to change their fishing grounds following species shifts due to climate change, contrary to industrial fishing vessels. Lack of proper training. The fishers need to be trained in different and more selective fishing methods and abandon nets, which are highly vulnerable to damage by *L. sceleratus* and potentially other species. For example, the invasive lionfish attain very good market prices but are not easily targeted with the currently applied fishing methods. The fishers need to be better organized through their association to obtain better prices for their catches. Currently, in the absence of auctions, each fisher separately negotiates prices with retailers or restaurants, which restricts their share of the final market price. SSF are only marginally viable, as many stocks and fishers' income have greatly declined, disproportionally more than in other fisheries and aquaculture. Hence, any additional negative impacts of climate change will impose great risks to the viability of SSF. Ageing of small-scale fishers leads to reduced adaptability to the needed changes in fishing tactics and accepting climate change adaptations.
External origin (attributes of the environment)	Opportunities Due to climate change, an increase of alien species that have commercial value and can be gradually included in people's diet and restaurant menus is expected. It is unclear if the competitive sectors will be affected less or more. Maybe aquaculture will be affected more by climate change as they operate in shallow waters and thus cannot confront seawater warming, whereas many wild fishes can find refuge deeper. If this is the case, SSF may have a competitive advantage in comparison to aquaculture.	Threats Reduction of native species (but overall this is balanced by the biomass increase of alien species) Although the market can adjust to new species, a percentage of consumers do not easily accept changes in their habits, and thus better awareness and information campaigns would be helpful to promote marketing and consumption of new species. SSF are especially impacted by certain alien species such as *Lagocephalus sceleratus* that cause important damage to the gear and catches. Mitigation measures are needed. Gaps in knowledge and inadequate management can negatively affect SSF. It is difficult to understand the role of climate change in the observed changes in fish stocks as many stressors are acting simultaneously. Reality is complex, and more research is needed to understand how climate change affects fish stocks. Climate change should not be used as a scapegoat to cover the effects of bad management and other human activities. The great decline of native fish stocks in the

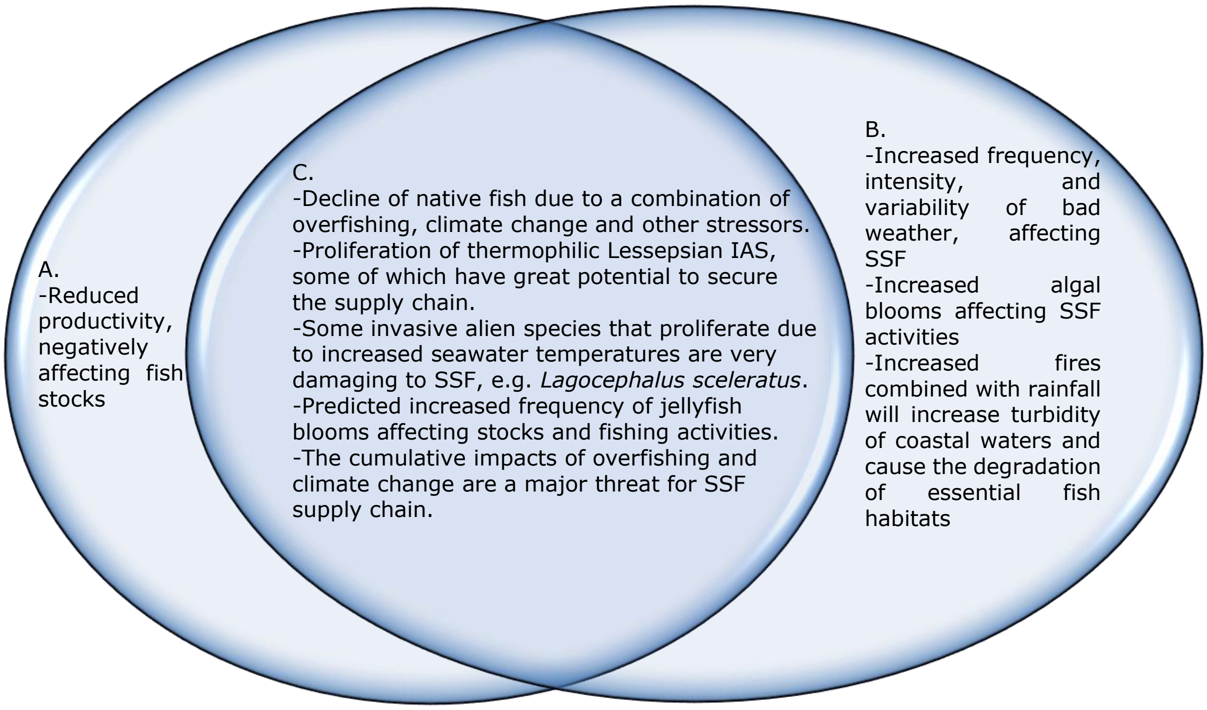
	Helpful (to achieving the objective)	Harmful (to achieving the objective)
		Aegean has been partly attributed to climate change but the effective protected area of Gyaros island (southern Aegean) proved that with proper enforcement many fish stocks can recover and thus their decline was not because of climate change but rather because of overfishing and bad management. Both fishers and the public considers overfishing as the major cause of stocks' decline, with climate change ranking third. Increase in forest fires combined with heavy rainfalls is expected to lead to an increase of turbidity in coastal waters and degradation of essential fish habitats, which will further negatively impact fish stocks. Increased frequency and intensity of bad weather results in a decrease of days-at-sea, and thus loss of income for SSF.

Furthermore, the perceptions of consumers were analysed based on an online questionnaire. For the consumers' questionnaire, an online google form (https://forms.gle/Qe7D9FBoXx1ex7ieA) was created (in Greek) and disseminated in Greece and Cyprus. This questionnaire targeted consumers, aiming to understand consumer preferences and market demand, and assess the potential of invasive species to replace declining native species in the market. Overall, 1324 questionnaires have been replied to (87.9 % from Greece and 12.1 % from Cyprus). The main outcomes of the consumers' questionnaires are (see also Supplementary 1):

- The majority of consumers (both in the past and at present) consume fish 1-5 times monthly. In the past, European pilchard, European anchovy, European hake, gilthead seabream, European seabass, and red mullets dominated consumers' preferences in Greece, whereas gilthead seabream, European seabass, red mullets, tuna, and European hake dominated in Cyprus. At present, the same species remain on top of consumers' preferences but those produced within aquaculture (i.e. seabream and seabass) have gained a higher share.
- Rabbitfish have had a low share in consumers' preferences in Greece both in the past and at present (S. luridus and S. rivulatus were consumed by 2.8 % and 1.2 % respectively of the respondents in the past, and 2.3 % and 0.8 % of the respondents at present, respectively), while in Cyprus their share has been substantial (17.5 % and 4.4 % in the past, and 16.3 % and 3.1 % at present). Lionfish is currently consumed by 1.5 % of the respondents in Greece and 8.1 % of the respondents in Cyprus.
- About a quarter of the respondents have stated that some species have become rare or no longer available in the market, mostly mentioning the striped red mullet, groupers, the white seabream, and swordfish in Greece, and red mullets, groupers, salema, red porgy, parrotfish, and swordfish in Cyprus.
- According to consumers, the dominant reasons for the decline of native fish are overfishing (72 %), pollution (11 %) and climate change (9 %) in Greece, and overfishing (37 %), invasive species (37 %), and climate change (13 %) in Cyprus. As thermophilic invasive species are much more abundant in Cyprus than in Greece, the high ranking of invasive species contrary to Greece (4 %) is expected, and is closely related to climate change impacts.
- Rabbitfishes are much more appreciated and have become much more a part of consumers' preferences in Cyprus than in Greece, but a high percentage of consumers that haven't yet tried rabbitfish in both countries responded that they would likely consume them in the future
- It is generally difficult to find rabbitfish in the Greek fish markets, substantially less so in Cyprus
- Lionfish have been consumed by approximately a quarter of consumers in Cyprus but only by 6.2 % of the respondents in Greece. Nevertheless, a high percentage of consumers that haven't yet tried lionfish responded that they would likely consume them in the future. The great majority of those that consumed lionfish were satisfied.
- It is generally difficult to find lionfish in the Greek fish markets, less so in Cyprus.
- The majority of consumers are willing to change their feeding habits and start consuming new species, such as rabbitfishes and lionfish, in particular when considering that in this way they also contribute to mitigating their negative impacts on biodiversity.
- The great majority of consumers (75 % in Greece and 81 % in Cyprus) replied that if, in the future, fish that they used to consume become less available and of higher cost, they would be willing to try new invasive species that may become abundant due to climate change. Hence, alien species have important prospects as new commodities, securing the SSF supply chain.

3.4 (Mis)Fits between literature review and stakeholders' perceptions

There was a general agreement between the literature and stakeholders' perceptions on the major impacts of climate change on SSF and the opportunities for the exploitation and marketing of new species. Both the literature and the stakeholders recognise the decline of native fish due to a combination of stressors, including climate change; the spread and increase in abundance of thermophilic invasive species, which is more pronounced in Cyprus and the south-eastern Aegean Sea and remains negligible in the northern Aegean; the damages of certain IAS to fishing activities; and the predicted increase of jellyfish and harmful algal blooms. Predictions of lower productivity due to climate change impacts that will affect fish communities have been stated in the literature but do not seem to be foreseen by stakeholders. The Greek fishers mentioned a reduced fishing effort because of increased bad weather and increased algal blooms that affect their activities, whereas these issues do not seem to have yet attracted the attention of scientists and are not reflected in the literature for Greece and Cyprus. Nevertheless, both the increased frequency of harmful algal blooms in certain locations in recent decades or the future, assisted by climate change (e.g. Lewitus et al. 2012; Glibert et al. 2014; Anderson et al. 2015; Townhill et al. 2018) and the disruption of fishing effort due to increased storminess (e.g. Sainsbury et al. 2018) have been reported in the international literature, beyond the CS area. A Greek official of the General Secretariat for Fisheries mentioned the increase in forest fire frequency combined with heavy rainfalls as another climate change impact that is expected to lead to an increase of turbidity in coastal waters and degradation of essential fish habitats, further negatively impacting fish stocks. No such study of the effects of forest fires on marine ecosystems in the study area has yet appeared in the literature. On the other hand, international studies highlight that forest fires can lead to increased productivity in marine pelagic ecosystems by providing an increase in Fe and other nutrients (e.g. Ito 2011; Xiao et al. 2020).



D. = From literature review
E. = From stakeholders' perception
F. = Overlapping as found both in literature and stakeholders' consultation

3.5 Role of management – lessons learned of adopted strategies

Despite measures to improve the energy efficiency of fishing vessels both in Cyprus and Greece, the total funds invested are too low to make a marked impact, while administrative restrictions (see 3.2) have made these funds largely inaccessible to most small-scale fishers. Hence, the majority of SSF vessels remain old with high CO_2 emissions and high operational costs, rendering SSF more vulnerable to climate change impacts than industrial fisheries.

In Cyprus, a policy of state reimbursements for landing and disposing of *Lagocephalus sceleratus* has been implemented, aiming to control its population and limit the damages it causes to SSF gear. Furthermore, for certain periods this measure provides an important income to fishers who target mainly this IAS and land large quantities. Nevertheless, the scientific advisor of Cypriot SSF mentioned that substantial delays in payments (often for many months) discourage fishers to be engaged in pufferfish fishing for long periods, compromising the effectiveness of the measure to mitigate the species' impacts. An improved policy for targeted *L. sceleratus* removals, especially during the reproduction period, coupled with a better and quicker payment scheme would substantially improve the effectiveness of the measure.

Promoting the marketing of new species has been successful in Cyprus and if organized smartly has a great potential to contribute to changing consumers' habits and improving the consumption of new alien species that are currently not targeted or discarded in many locations, especially in Greece. Rabbitfish and lionfish are promising new species due to their high abundance. Rabbitfish have successfully entered the Cypriot market, indicating important prospects also for the Greek market, contributing to increasing fishers' income and securing the SSF supply chain. The project RELIONMED in Cyprus has been successful in training fishers on how to handle lionfish and promoted new market opportunities for both lionfish consumption (mainly large individuals) and using the patterned spines, rays, skin, and tails of small specimens in handcrafts. Lionfish were discarded in 2016-2017 by Cypriot fishers but by 2021 a new market had emerged and lionfish dishes in restaurants obtained prices between 12-22 Euros per dish (Kleitou et al. 2022). Promoting the consumption of IAS is a win-win strategy as it brings multiple benefits: increased income for the fishers; controlling IAS populations and mitigating their impacts, and contributing to securing the SSF supply chain. Currently, IAS are not managed as a fisheries resource, and thus no MSY targets or other management measures aiming for the sustainability of the stocks have been implemented.

4 Conclusions

The main conclusions of this CS are:

- Small-scale fisheries in the eastern Mediterranean are already in a bad state. Suffering historical overfishing and bad management, the sector is now in dire straits, independently of any climate change impacts, which are secondary in magnitude.
- The main climate change impacts on SSF are changes in species composition (decline in traditional native target species and increase of IAS); lost days at sea due to the increased frequency of bad weather conditions; extensive damages to fishing gear, and thus increased maintenance costs, by certain thermophilic IAS such as Lagocephalus sceleratus; an increase of jellyfish and harmful algal blooms that impact gear and catch; and reduced productivity of marine ecosystems.
- IAS such as rabbitfishes and lionfish have already been successfully marketed in Cyprus, less so in Greece. Their increased abundance can provide opportunities for SSF in both countries, as they can obtain high demand in a short time, and thus their targeted fisheries contribute to securing fishers' income and the SSF value chain.

- The role of management has been inadequate to secure the viability of the SSF sector and the related supply chain. Removing administrative barriers for measures to improve energy efficiency and control IAS, and coordinating active promotion campaigns of new alien species to the market would substantially contribute to the viability of the sector.

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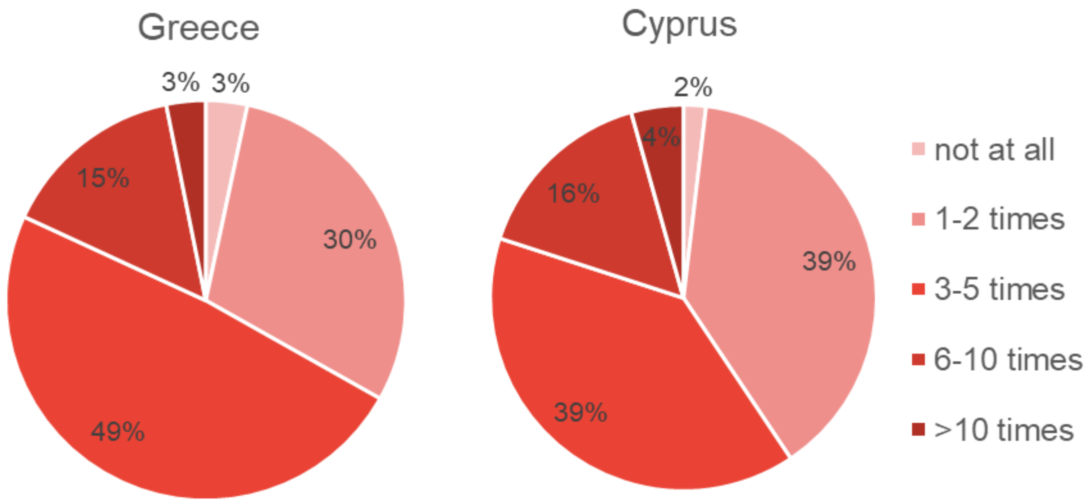
Supplementary 1: Consumer questionnaires

For the consumers' questionnaire, an online google form (https://forms.gle/Qe7D9FBoXx1ex7ieA) has been created (in Greek) and disseminated in Greece and Cyprus. This questionnaire targeted consumers, aiming to understand consumer preferences and market demand, and assess the potential of invasive species to replace declining native species in the market. Overall, 1324 questionnaires have been replied to (87.9 % from Greece and 12.1 % from Cyprus).

Part 1: Consumer behaviour in the past

1.1 How often did you use to consume fish monthly in the past (15-25 years back)?

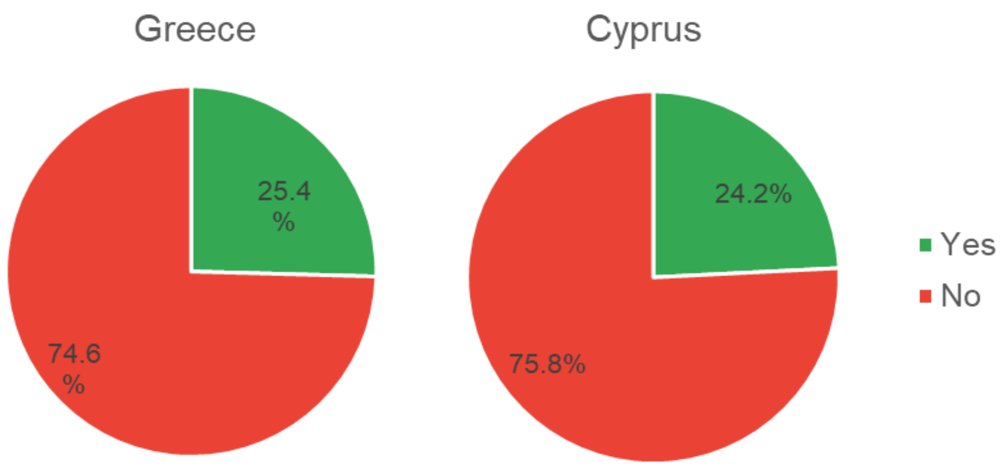


1.2 Which fish species did you use to consume in the past?

The most common replies for Greece were *Sardina pilchardus* (72.0 % of the respondents from Greece), *Engraulis encrasicolus* (71.7 %), *Merluccius merluccius* (68.8 %), *Sparus aurata* (65.5 %), *Mullus surmuletus* (54.9 %), *Mullus barbatus* (49.7 %) and *Dicentrarchus labrax* (36.9 %). *Siganus luridus* used to be consumed in the past by only 2.8 % of the respondents and *S. rivulatus* by 1.2 %.

The most common replies for Cyprus were *Sparus aurata* (79.4 % of the respondents from Cyprus), *Dicentrarchus labrax* (66.3 %), *Mullus surmuletus* (58.8 %), *Thunnus* spp. (46.9 %), and *Merluccius merluccius* (35.0 %). *Siganus luridus* used to be consumed in the past by 17.5 % of the respondents and *S. rivulatus* by 4.4 %.

1.3 Have some of these species become rare or no longer available in the market?



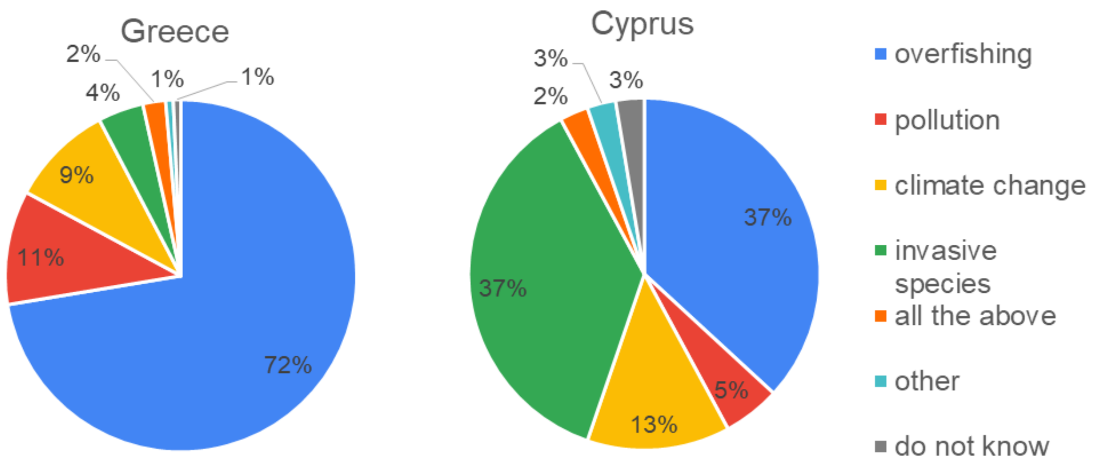
There was no substantial difference in the response between Greece and Cyprus. About a quarter of the respondents consider that some species have become rare or no longer available.

1.4 [If yes in 1.3] Which are those species that have become rare and are not easily found in the market?

In Greece, the species that have been reported to have become rare by most interviewees that responded 'yes' in the previous question include *Mullus surmuletus* (26.6 %), *Epinephelus marginatus* (26.2 %), *Diplodus sargus* (20.6 %), *Epinephelus aeneus* (17.8 %), *Xiphias gladius* (16.8 %), and *Epinephelus costae* (16.4 %).

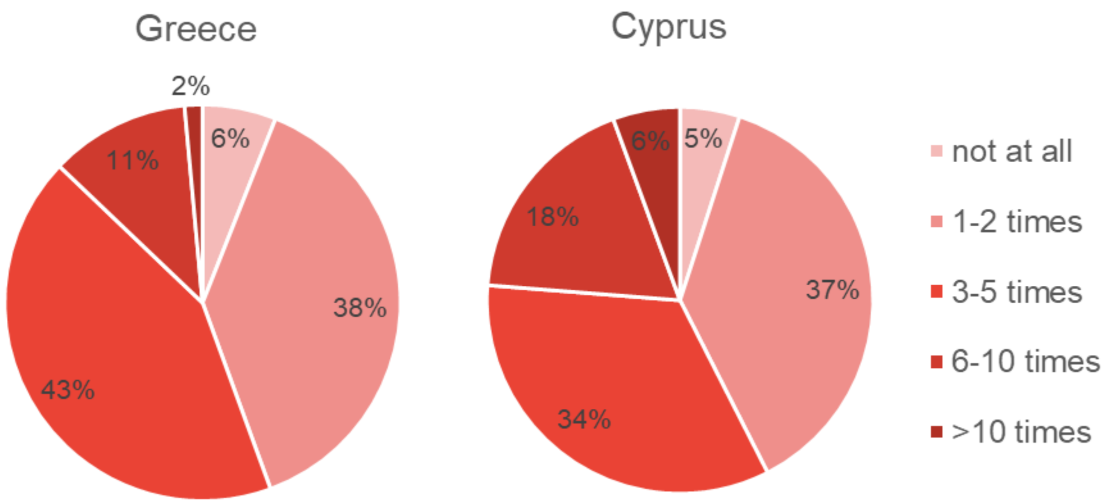
In Cyprus, the species that have been reported to have become rare by most interviewees that responded 'yes' in the previous question include *Mullus surmuletus* (39.5 %), *Epinephelus marginatus* (23.7 %), *Sarpa salpa* (15.8 %), *Mullus barbatus* (15.8 %), *Pagrus pagrus* (13.2 %), *Epinephelus costae* (13.2 %), *Epinephelus aeneus* (12.5 %), *Sparisoma cretense* (13.2 %), and *Xiphias gladius* (13.2 %).

1.5 Which do you believe is the main reason that these species have become rare?



Part 2: Consumer behaviour at present

2.1 How often do you currently consume fish monthly?

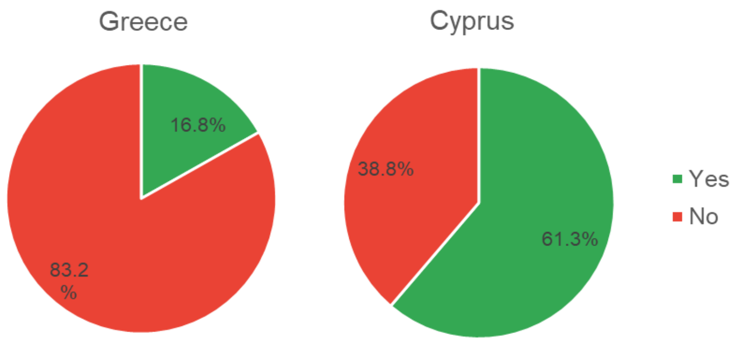


2.2 Which fish species do you currently consume?

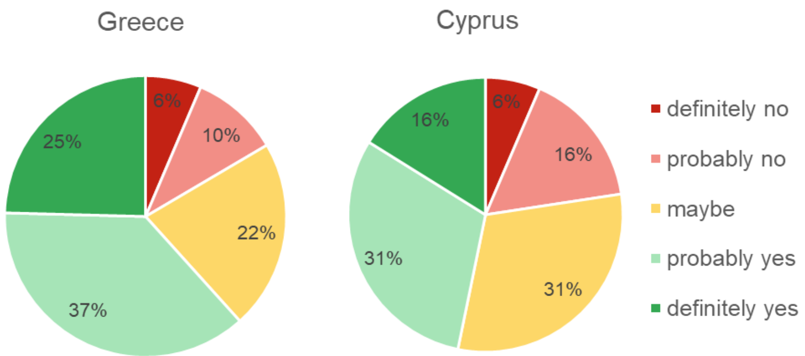
The most common replies for Greece were *Sparus aurata* (60.4 %), *Sardina pilchardus* (55.2 %), *Merluccius merluccius* (54.2 %), *Engraulis encrasicolus* (50.1 %), *Dicentrarchus labrax* (33.8 %), and *Mullus barbatus* (33.4 %). *Siganus luridus* is consumed by only 2.3 % of the respondents, *S. rivulatus* by 0.8 %, and *Pterois miles* by 1.5 %.

The most common replies for Cyprus were *Sparus aurata* (80.0 %), *Dicentrarchus labrax* (60.6 %), *Thunnus* spp. (38.8 %), *Mullus surmuletus* (35.6 %), *Merluccius merluccius* (27.5 %), *Pagrus pagrus* (26.9 %), *Siganus luridus* (16.3 %, ranking 7th), and *Sardina pilchardus* (16.3 %). *Siganus rivulatus* is consumed by 3.1 % of the respondents and *Pterois miles* by 8.1 %.

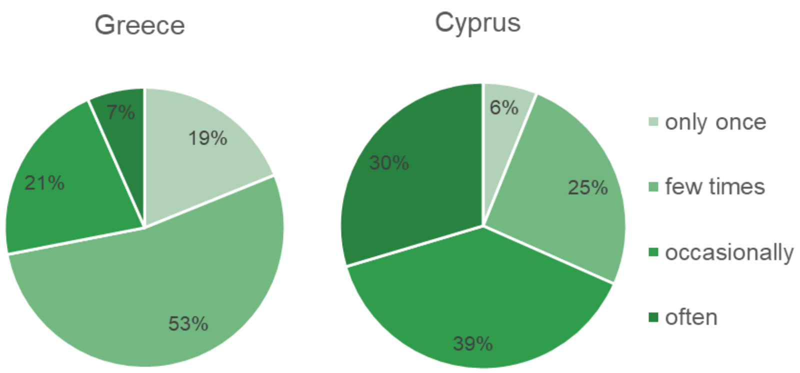
2.3 Have you ever consumed rabbitfishes (*Siganus luridus* or *S. rivulatus*)?



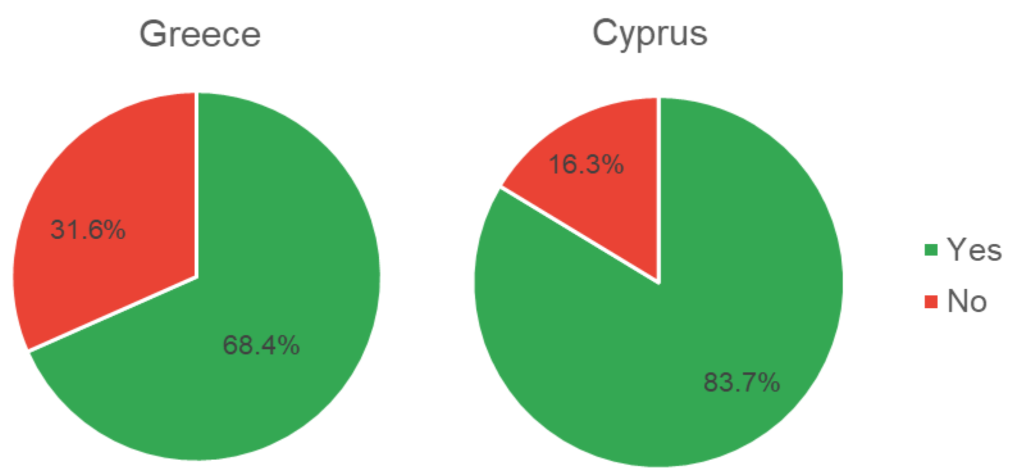
2.4 [if no in 2.3] Would you try to consume rabbitfishes, being aware that they are considered high-quality fish?



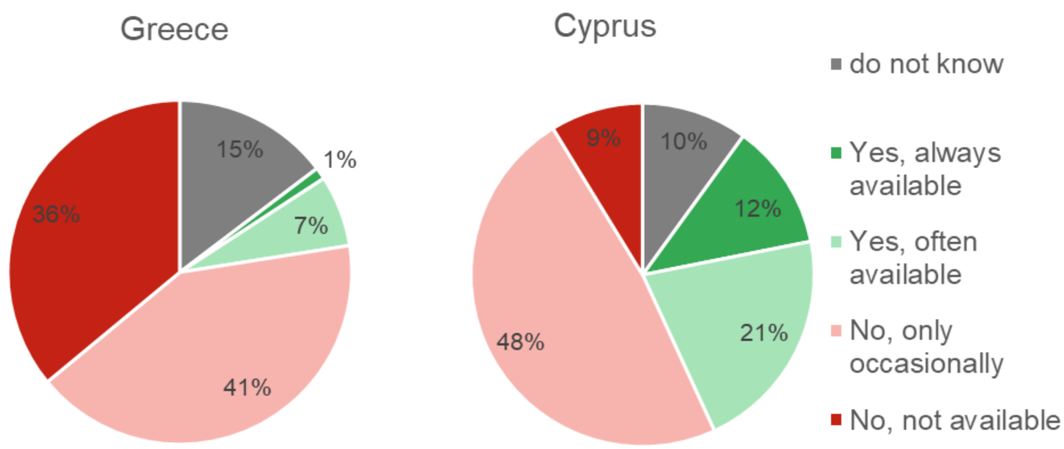
2.5 [if yes in 2.3] How often do you consume rabbitfishes?



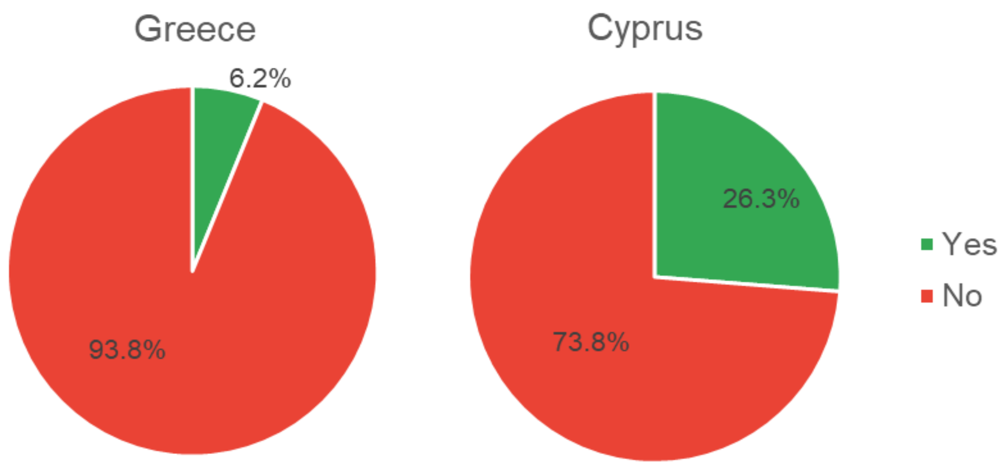
2.6 [if yes in 2.3] Have you been satisfied by consuming rabbitfishes?



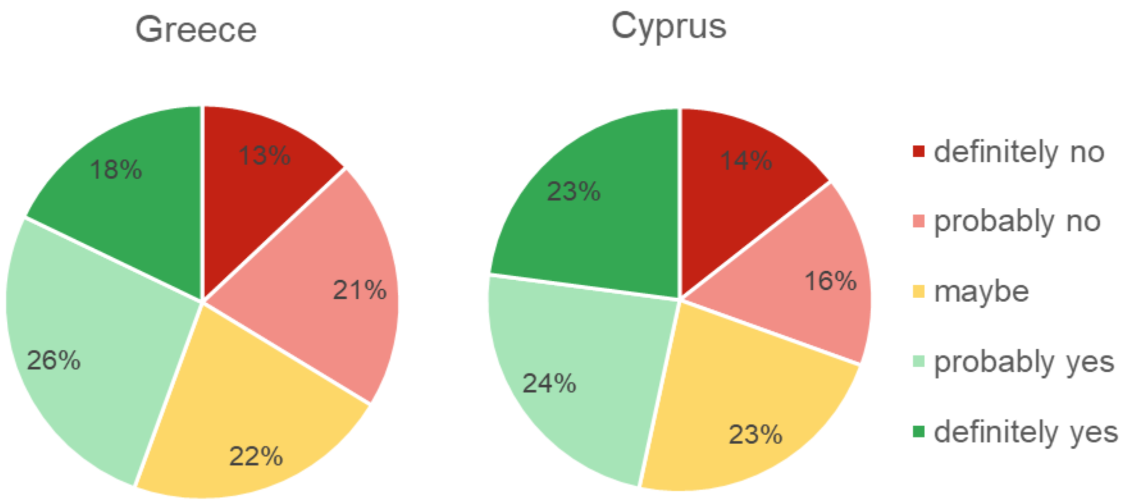
2.7 Is it easy to find rabbitfishes in the market?



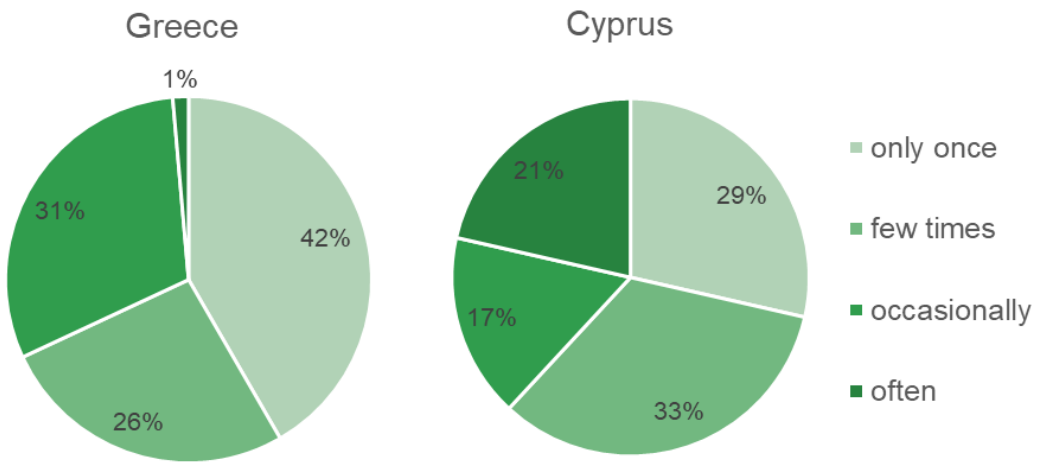
2.8 Have you ever consumed lionfish (*Pterois miles*)?



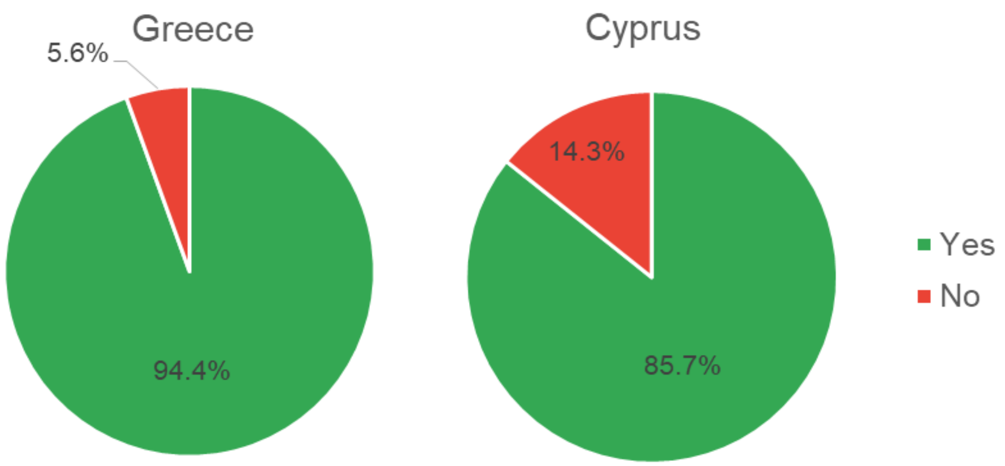
2.9 [if no in 2.7] Would you try to consume lionfish, being aware that they are considered high-quality fish?



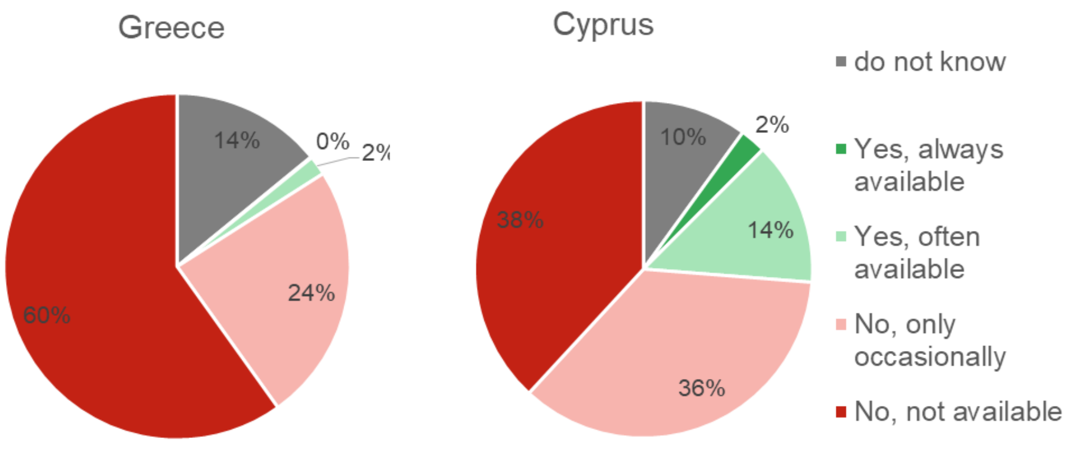
2.10 [if yes in 2.7] How often do you consume lionfish?



2.11 [if yes in 2.7] Have you been satisfied with consuming lionfish?

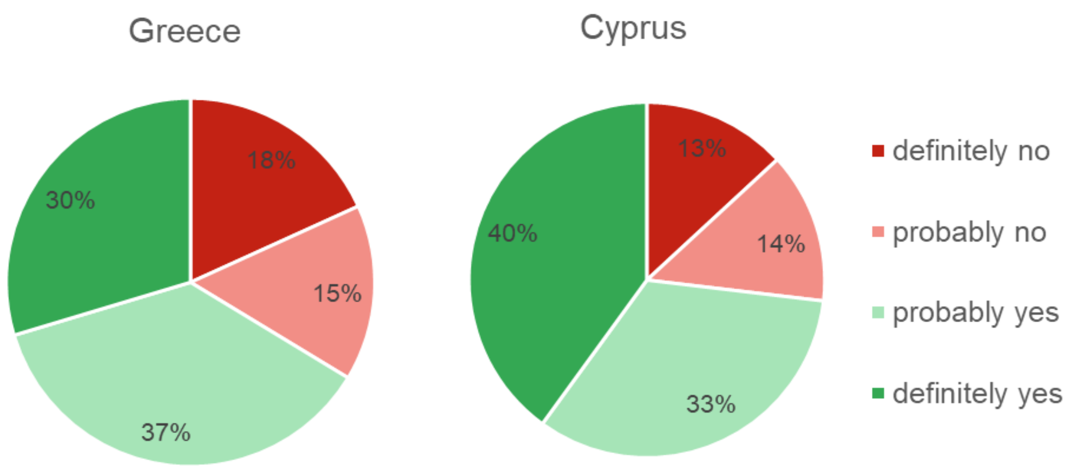


2.12 Is it easy to find lionfish in the market?

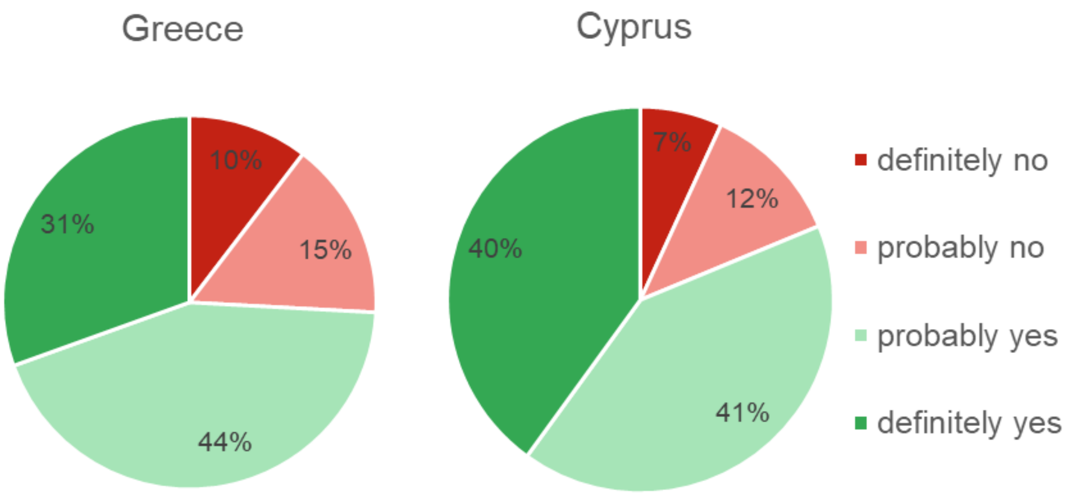


Part 3: Consumer behaviour in the future

3.1 Considering that consuming invasive alien species could be a means to control their populations and mitigate their impacts, would you consider starting/increasing the consumption of invasive alien species such as rabbitfish and lionfish replacing some of your commonly consumed native fish?

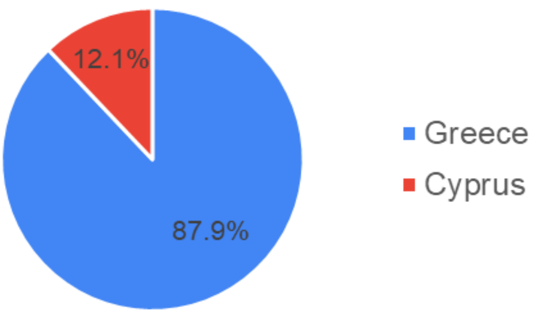


3.2 If in the future, fish that you used to consume become less available and of higher cost, would you be willing to try new invasive species that may become abundant due to climate change?

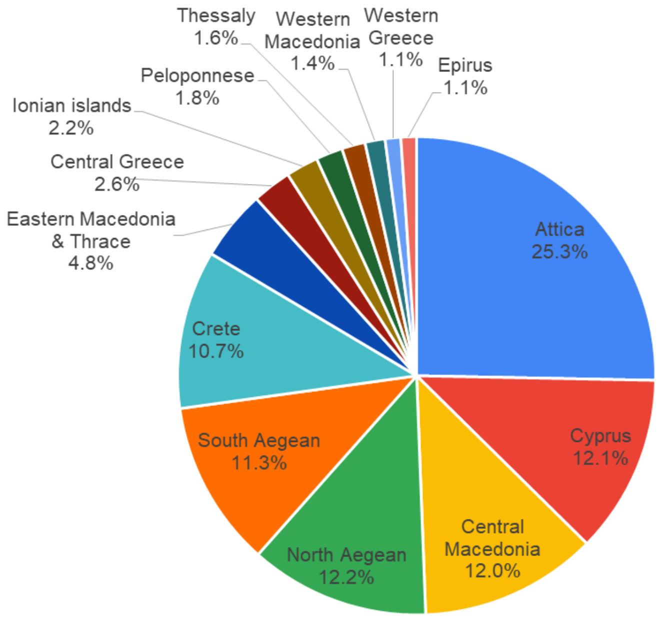


Part 4: Profile of respondents

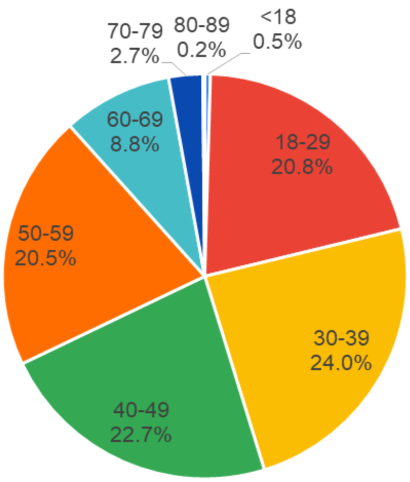
4.1 Country



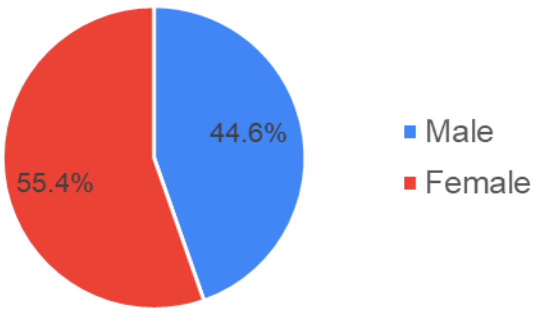
4.2 Region (NUTS2)



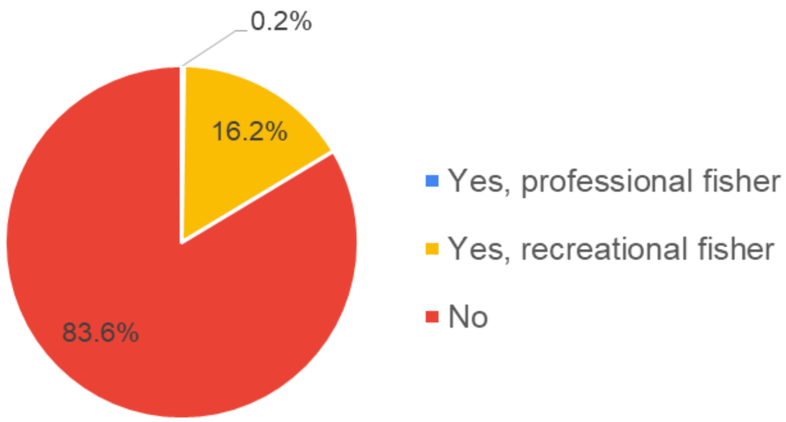
4.3 Age



4.4 Sex



4.5 Do you fish?



CASE STUDY 14: INVERTEBRATES – BLUE MUSSEL (*MYTILUS EDULIS*), AND OYSTER (*OSTREA EDULIS* AND *CRASSOSTREA GIGAS*) - NETHERLANDS, GERMANY, BELGIUM AND FRANCE

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Blue mussel (*Mytilus edulis*)

European flat oyster (*Ostrea edulis*)

Japanese oyster/Creuse (*Crassostrea gigas*)

Hoekstra, G., Deetman, B., Turenhout, M., Van den Burg, S., Vernooij, V., Broeze, J. & Guo, X.

LIST OF ABBREVIATIONS

Term	Description
GHG	Green House Gas
MAP	Modified Atmosphere Packaging
CS	Case study
PH	Postharvest

1 Background

For this CS six stakeholders were consulted:
- Four processors/traders from the Netherlands (in person)
- One retailer from Belgium (via online meeting)
- One transporter from originally Netherlands but that has many divisions and offices in Belgium and Germany (in person)

The shellfish PH chain in the Netherlands could be divided into two main supply flows:
1. Supply of live blue mussel *(Mytilis edulis*) for in particular the Northern European Retail market and HORECA.
2. Supply of live European flat oyster (*Ostrea edulis*) and live Japanese oyster/creuse (*Crassostrea gigas*) for in particular the Northern European HORECA.

Beside the supply of live mussels and oysters, the Netherlands produce and process other shellfish products like razor clams, cockles and winckles. However, the volumes of these products are low and excluded from this CS.

The shellfish PH chain from the Netherlands is dominated by companies located in Yerseke (Zeeland). The live shellfish are purified during processing with Oosterschelde water pumped with a special fresh water pipeline ("*pijp van Bliek*") to the existing processing plants. These processing plants are located in the same street along the Oosterschelde coast.

Invasive species (among others due to rising water temperature) like starfish, Japanese oyster borer and oyster herpes virus threatened the production of mussels and oysters. New techniques have been introduced to reduce the negative effects of these invasive species. For instance, oysters are cultivated at off-bottom tables to avoid Japanese oyster borer harming the oyster production.

2 Value Chain

2.1 Value chain description

In the Netherlands, blue mussel seed is traditionally fished from wild beds in the Wadden Sea and Oosterschelde delta and transplanted to the culture plots. Last two decades more and more mussel seed is produced using mussel seed collectors next to the traditional technique of fisheries using bottom trawls. To collect mussel seed suspended mussel seed collectors are used. Substrates in the forms of ropes and nets are deployed in the water column for the summer period, and natural settlement of mussel larvae provides considerable amounts of mussel seed on the substrates. Continuous long lines or systems with dropper lines are also in use but in a marginal extent. Long lines is only a few percentages of the total volume. In 2020, the harvested and landed production was 32000 tonnes of blue mussels by Dutch aquaculture in the coastal waters, representing EUR 45 million for the mussel farmers and fishers in total. Blue mussels were imported with a volume of 25000 tonnes in 2020, mainly from Ireland and Germany and Denmark (Sylt area). In 2019, import volumes were much higher (40000 tonnes).

Oyster production in the Netherlands was around 22 million pieces of Creuses (Japanese oysters) and 4 million pieces of flat oyster in 2020. Import was marginal with 1300 tonnes in weight.

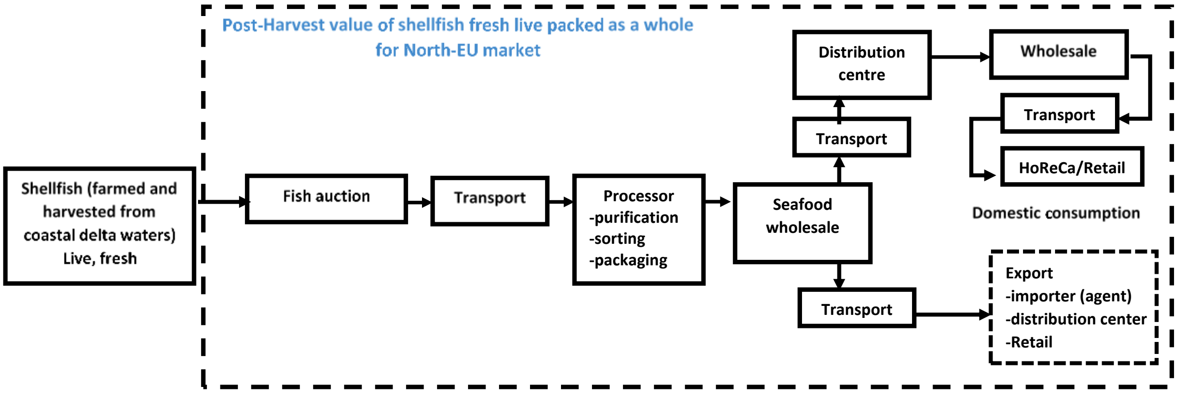


Figure 1. Postharvest value chain of live and fresh Blue mussel and oyster. Source: CBS (edited by Wageningen Economic Research)

The biggest volume of sold shellfish in the Netherlands consists of blue mussel. Depending on the season, Dutch or non-Dutch (German, Danish, Irish) mussels are used for processing. Blue mussels produced in German and Danish waters are often growing stronger in the early season (from April onwards), while Dutch blue mussels are often harvested around June. To extend the length of Dutch production season, blue mussels are imported from Germany, Denmark and Ireland.

Mussels are collected from mussel farmers directly or via the shellfish auction in Yerseke. During mussel processing, the shellfish are cleaned using brushes, followed by the removal of the Byssus filaments[33]. Empty shells are removed in the process by blowing air through the mussels; stones and heavy other materials are removed manually. After a final physical check, the mussels are sorted by size and packed in plastic airtight containers or jute bags. Depending on the establishment, mussels are cooled on conveyor belts used in the product process or before packing in refrigerating tanks.

Tarra, wastage in mussel processing, is around 10-15 percent of the total weight. This product is collected by a specialized company and used as substrate in the oyster production.

The main market for blue mussels is Belgium, as 60 % of exports (in value) is destined to the Belgian market. Most of the blue mussels are sold in EU supermarkets (70 % of volume) for home consumption. HORECA is the most important out-of-home market where (especially the bigger mussels) are consumed.

For oyster processing, the majority of the oysters are the Japanese oyster. Oysters are bought from oyster farmers and stored in oyster puts in or around the factories (wet storage). Oysters are collected for processing from the oyster puts and packed on simple sorting tables into wooden baskets or jute bags.

The main export market for oysters is France. 95 % of shellfish species are processed and sold as a fresh live product to Retail or HORECA (CBS, edited by Wageningen Economic Research).

[33] Byssus filament is a bundle of filaments secreted by many species of bivalve mollusc that function to attach the mollusc to a solid surface such as rocks or seabed. The inedible byssus are often known as the 'beard' of the mussel which are removed before consumption.

3 Resilience

3.1 Physical and financial resilience

Mussels are produced in shallow coastal waters where they aggregate into beds. This makes the farming vulnerable for climate events like heavy winds. Bivalves are sensitive to climate change-induced changes in temperature and salinity which affect behaviour, physiological rates and the immune system (Matozzo and Marin, 2011). Blue mussel production is currently dependent on natural recruitment which, in turn, is affected by environmental factors such as food supply and water temperature and salinity. Climate change is expected to directly influence the health and growth performance of farmed blue mussels via physiological responses, immuno-biological performance and acclimation to the new environmental conditions. Climate change could indirectly affect the health and growth performance of farmed blue mussels via potential pressure from harmful algal blooms and diseases (CERES, 2020a).

Oysters are expected to be affected by climate change with regards to the health and growth performance directly via physiological responses, immuno-biological performance and acclimation or adaptation to the new environmental conditions. Indirectly climate change influence production of oysters via changes in the frequency of harmful algal blooms, jellyfish outbreaks, invasive species and/or diseases. Expansion of the distribution range of non-native species such as the Japanese oyster drill (*Ocenebra inornata*) can cause mortality among juveniles. The most important potential effects of climate change on oyster production concern more frequent occurrence of diseases and toxic algal blooms (CERES, 2020b).

3.2 Major financial constraints and reliability

For blue mussel and oyster it is expected that climate change will negatively affect the growth performance and mortality rates. This effect in the primary production (pre-harvest) will negatively impact the financial resilience of PH bivalve processors in the Netherlands (CERES, 2020a; 2020b). If quality (smaller sized) will decrease and spoilage (higher mortality) will increase, the profitability of processors will be negatively be affected as the financial return to the market per kilogram blue mussels or oysters are expected to be on a lower level.

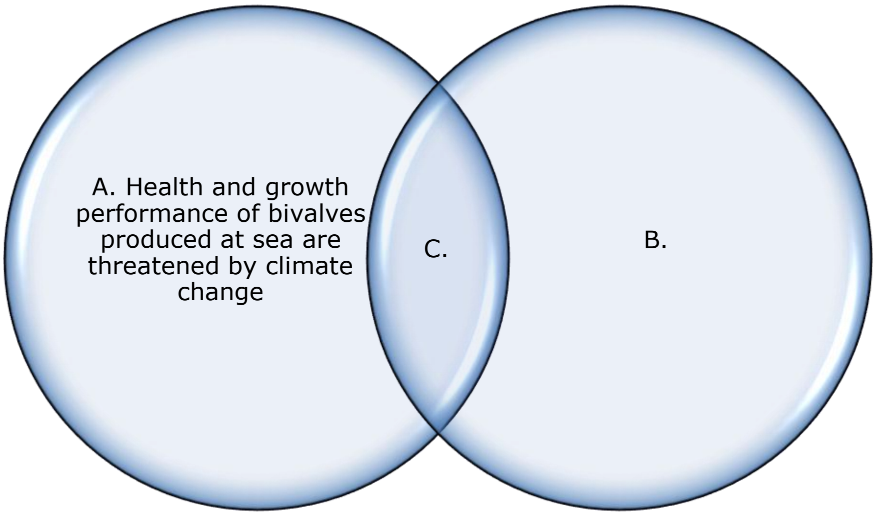
3.3 Stakeholders' perceptions

The insights from consulted stakeholders are summarized in the SWOT matrix below.

	Helpful	Harmful
Internal origin (attributes of the organizations)	Strengths • Potential to carbon (CO2) sequestration by filtering and capturing it into the shells. • Own production in local areas in the Oosterschelde and EU Wadden Sea area and therefore able to monitoring effects by climate change in time • No feed is needed for aquaculture of mussels and oysters. Mussels and oysters feed themselves with algae, resulting in a low carbon footprint • Vertical integrated companies. Processors acquired mussel/oyster farming producers. Therefore, better resilience regarding supply and logistics	Weaknesses • Intensive fossil fuels consuming mussel fishing vessels in Natura-2000 area. It is expected that by 2030 only low-emission vessels are allowed to enter these areas. Similar holds for reduction of nitrogen compound emissions in 2030. However, for fishers from 2023 on they already need to prove reduction of nitrogen emissions by their fishing activity to acquire the license to fish in Nature-2000 waters.
External origin (attributes of the environment)	Opportunities • Generate own renewable energy via solar panels. • Further expansion of mussel seed collectors can optimize the farming of market sized mussels. As climate change (rising water temperature) could negatively affect the growth performance, mussel seed collectors are more stable in production performance compared to seabed seed production techniques	Threats • Natural ecosystems (Wadden Sea, Sylt) are essential for mussel/oyster production. In case of climate change or water pollution this could have large impact on financial and physical resilience of mussel processors. • New invasive species can negatively impact the production of produced oysters and mussels

3.4 (Mis)Fits between literature review and stakeholders' perceptions

Not applicable as there is not any literature (mis)fitting the perceptions of stakeholders.



G. = From literature review
H. = From stakeholders' perception
I. = Overlapping as found both in literature and stakeholders' consultation

3.5 Role of management – lessons learned of adopted strategies

As climate change affects the growth performance and health (higher mortality rate) of blue mussels, it is important to the PH chain to be able to minimize the risk of higher costs (lower quality and waste among landed mussels by fisheries) and reduced landing volumes locally of mussels by fisheries. Among Dutch bivalve processors there is a trend of vertical integration and joint ventures. These processing companies acquire mussel fisheries companies to ensure sufficient supply volumes from primary production into the PH chain. Another management intervention to be more resilient as mussel processor is sourcing blue mussels from other regions with less climate change impacts. Often this could be done by importing blue mussels from other regions if local quality of Dutch mussels is low and mortality is high among produced mussels. Other regions for blue mussel production are currently Ireland, Denmark and Germany. This intervention is only successful if climate change impacts are less impactful than in Dutch local waters.

For oysters new techniques have been introduced to reduce the negative effects of invasive species. For instance, oysters are cultivated at off-bottom tables to avoid Japanse oyster borer could harm the oyster production. For mussels, imports of raw materials (live, fresh mussels to be processed) by the Dutch shellfish processors from other EU MS such as Germany, Denmark and Ireland are increasing in order to compensate decreasing production volumes in Dutch waters. By the introduction of the mussel seed collectors by Dutch mussel farmers the predictability of mussel seed production and there landings of mussels improved in recent years. Still more than half of the total mussel productions by Dutch processors is coming from other countries for origin of harvest (mainly from Germany, Denmark and Ireland).

4 Greenhouse Gas Emissions

GHG emissions in the post-harvest chain are related to transportation (fuel use), processing and refrigeration (mainly energy use; with phasing out refrigerants with high

GHG impact the contributions from leaking refrigerants is marginalized) and packaging. Furthermore, food losses (indirectly) induce additional GHG emissions since losses induce extra demand for catch and related post-harvest chain emissions. Estimated GHG emissions for typical mussel and oyster PH chains are elaborated in following sections.

4.1 GHG emissions in the value chain for shellfish: mussels

Transport from producer to processor

Typical transportation distance is 50km. For a large truck, based on data from www.ecotransit.org and EcoInvent GHG emissions associated to this type transport are estimated at 0.20 kg CO2-eq, per ton product per km. Result: 0.01 kg CO2-eq. per kg

Processing, packaging and storage

In processing, a "cleaning" step is applied and the products are packaged. In cleaning, about 12.5% (in terms of weight) is removed/rejected. For typical consumer package on average around 50 gram plastic per kg mussels is used. Based on typical GHG emission intensity of packaging plastics (3 kg CO2-eq per kg plastic, ETC-WMGE, 2021) the net climate impact of plastic use is 0.15 kg CO2-eq. per kg mussels.

In interviews, a typical specific energy use was mentioned: around 0.25kWh per kg product. Based on average European GHG emission intensity of electricity[34], this induces 0.06 kg CO2-eq GHG emissions per kg product.

Transport

Transportation to a distribution centre and retail outlet is done by means of large trucks. The total transportation distance covers typically 100km. Based on 0.20 kg CO2-eq, per ton product per km, transport contributes 0.02 CO2-eq. per kg product.

Energy use for refrigeration in the retail display cabinet

(Electricity use of refrigerated retail shelves were estimated at typically 0.06kWh per kg per day from a set of direct measurements for various product categories; the actual value however will largely depend on technical design, loading degree and operational use).

Assuming a typical shelf period of 3 days follows total refrigeration electricity use of 0.2kWh per kg shellfish, which induces 0.05kg CO2-eq. per kg product.

Effects of losses in retail

Losses in retail are estimated at 7.5% of the supplied volumes (retail interview). Emissions associated to production, processing and transporting of these lost products are allocated to the actually sold products, and consequently the losses indirectly induce 7.5% extra GHG. For this the GHG emissions of production were derived from www.dierenwelzijnscheck.nl/klimaatcheck/schelpdieren: 1.3 kg CO2-eq. per kg product.

[34] The actual GHG emission intensity of electricity differs amongst countries because of varying energy mixes; we used the EU-average in the calculations.

Summarized climate impact of mussels PH chain

Chain stage	GHG emissions kg CO2-eq. per kg landed mussels	GHG emissions per kg CO2-cleaned mussels
transport from auction to processor	0.01	0.01
processing + refrigeration electr. use		0.06
packaging		0.15
transport		0.02
energy use in retail		0.05
effects due to losses		0.12
TOTAL post-harvest		**0.41**

4.2 GHG emissions in the value chain for shellfish: oysters

Transport from producer to processor

Typical transportation distance is estimated at 50km or shorter, as for mussels. Associated GHG emissions are relatively small: 0.01 kg CO2-eq. per kg.

Processing, packaging and storage

With lack of primary data, but with the notion that energy use is lower than for mussels, the specific energy use is estimated at half the value for mussels: 0.125kWh per kg product. Based on average European GHG emission intensity of electricity[35], this induces 0.03 kg CO2-eq GHG emissions per kg product.

Packaging of oysters are very different from other seafoods:

- Traditionally oysters are packed in wooden boxes. The amount of packaging wood per kg oysters varies amongst packaging size; here 0.2kg wood per kg oysters is assumed. Often, wood is considered climate-neutral; however the post-harvest processing and supply do induce GHG emissions[36]. Since soft wood is used in this type of packaging, here it is assumed that the emission factor is at the lower range: 0.5 kg CO2-eq. per kg wood.
  Altogether the packaging adds 0.1 kg CO2-eq. per kg product.
- For oysters traded in supermarkets, increasingly plastic packaging is used. With typical plastic use of 0.06kg plastic, the contribution of the packaging is estimated at 0.2 kg CO2-eq. per kg product.

[35] The actual GHG emission intensity of electricity differs amongst countries because of varying energy mixes; we used the EU-average in the calculations.

[36] Total GHG emissions of wood supply varies amongst wood types; values found between 400 and 2000 kg CO2-eq/MT. https://www.idhsustainabletrade.com/publication/carbon-footprint-of-tropical-timber/#chapter-2.

Transport

Transportation to a distribution centre and retail outlet is done by means of large trucks. The total transportation distance covers typically 150km. Based on 0.20 kg CO2-eq, per ton product per km, transport contributes 0.03 CO2-eq. per kg product.

Energy use for refrigeration in the retail display cabinet

Average shelf period is estimated shorter than for musselsl: 2 days. From that follows total refrigeration electricity use of 0.1kWh per kg shellfish, which induces 0.03kg CO2-eq. per kg product.

Effects of losses in retail

Losses in retail are estimated at 7.5% of the supplied volumes (retail interview). Emissions associated to production, processing and transporting of these lost products are allocated to the actually sold products, and consequently the losses indirectly induce 7.5% extra GHG. For this the GHG emissions of production were derived from www.dierenwelzijnscheck.nl/klimaatcheck/schelpdieren: 2.6 kg CO2-eq. per kg product. Because these emissions are substantially higher than for mussels, also the loss-related GHG emissions are higher.

Summarized climate impact of oysters PH chain

Chain stage	GHG emissions per kg oysters
transport from auction to processor	0.01
processing + refrigeration electr. use	0.03
packaging	0.1 to 0.2 (average: 0.15)
transport	0.03
energy use in retail	0.03
effects due to losses	0.2
TOTAL post-harvest	**0.5**

5 Conclusions

For bivalves (blue mussels and oysters) the most impact by climate change to the PH chain is the lower quality and produced volumes by fisheries (higher mortality and decreased growth performance of mussels). It is expected that lower quality result into decreasing financial result to the market for the PH chain. A management intervention by the PH chain to mitigate or adapt to the impacts of climate change is to lower the risk of locally lower quality of produced mussels by vertical integration or joint ventures. Another management intervention is to source blue mussels from other regions (e.g. Ireland or Denmark and Germany) by Dutch processors to guarantee production throughout the year.

GHG emissions in PH chains are estimated around 0.4 kg CO2-eq per kg mussels. This is low compared to other seafoods, which is related to absence of freezing step and mostly moderate transportation distances. The packaging is – as for most other seafoods – a hotspot in terms of GHG emissions. For oysters, although energy use in processing are somewhat lower than for mussels and the packaging is considered more sustainable, the total GHG emissions induced by the PH chain end somewhat higher. The wooden packaging has substantial higher weight than plastic packaging, and the processing/supply of the wooden packaging still induces substantial emissions. Furthermore, because of somewhat higher GHG emissions in the production phase, the effect of losses along the chain is higher. Altogether, the GHG emissions along oyster PH chain is estimated at 0.5 kg CO2-eq. per kg oysters. .

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CASE STUDY 15: INVERTEBRATES – MUSSELS (MYTILUS EDULIS, MYTILUS GALLOPROVINCIALIS) - FRANCE

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Photo: Oscar Bos (WMR)

Sébastien Metz, Marie-Pierre Mommens

1. Background

Mussels within France are available wild or farmed, however the national supply comes predominantly from aquaculture. For example, the French mussel aquaculture industry sold in 2018 and 2019, 48,844 tons and 60,255 tons, respectively (i.e., consumption excluding sales between producers). In comparison, only 379 tons and 486 tons of mussels were landed from dredge fishing in 2018 and 2019, respectively (EUMOFA).

The national production of mussels is approximately half of the yearly French fresh mussel consumption. Imports of mostly fresh mussels (43,992 tons of fresh mussels over a total of 59,068 tons of imported mussels in 2018 (FranceAgrimer)), come from Spain and the Netherlands, while low levels of imports are sourced from Ireland, Italy, the UK and Denmark. Mussels imported from Spain and Italy are Mediterranean mussels (*Mytilus galloprovincialis*), while imports from the Netherlands, Ireland, Denmark and the UK are blue mussels (*Mytilus edulis*), also known as the common mussel. Danish mussels are mainly fished mussels (i.e., non-aquaculture) while Dutch mussels are mainly bottom farmed. Most imports occur when national production is low to satisfy market demand or to supplement domestic production during periods of high consumption. The Dutch mussel, which is cheaper than other imports or national production, is substantially used in catering. A low volume of French mussels is exported, 3392 tons in 2018 (FranceAgrimer).

The blue mussel (*Mytilus edulis)* is the main French farmed species, with 44,192 tons sold in 2018 (AGRESTE). Bouchot-type culture (i.e., ropes fixed to wooden piles, see Figure) is the main culture technique (producing 37,554 tons of *M. edulis* in 2018). Bouchots are spread throughout the Atlantic coast and the Channel-North Sea. The second technique used along the Atlantic coast is the submerged longline. The Mediterranean mussel (*M. galloprovincialis*) (4,652 tons in 2018, 9.5 %) is farmed mainly on Mediterranean shores using longline culture and suspended cultures (rafts).

As bouchot are installed in the intertidal zone, bouchot mussels are regularly emerged, which has an effect on the shelf life, as mussels learn to close their shell while being outside waters. Longline mussels

Figure 1: Bouchot culture in French Normandie (close to Granville). Poles are set in intertidal areas (right) and mussels are attached on these poles (left)

2. Value chain description

The marketable size for mussels within France is 4 cm, with *M. edulis* reaching 10 cm and *M. galloprovincialis* 15 cm. Market weights of *M. edulis* and *M. galloprovincialis* are different (10,4 g and 26 g in average respectively) as well as their geographical distribution as *M. edulis* prefers colder waters than *M. galloprovincialis*.

There are important differences in the availability, cost and access to market between *M. edulis* and *M. galloprovincialis*. *Mytilus edulis* is sold from June to January, as this species has a spawning season within the spring (and therefore is likely to have low or no gonadal tissues during this time period). In comparison, *M. galloprovincialis* is sold throughout the year, as there is no seasonal spawning within this species. There is also stronger interest in mussels grown using bouchot (i.e., *M. edulis*), which regulates differences in prices between species, with a farm price difference (in 2018) of approximately 0.4 EUR/kg between *M. edulis* and *M. galloprovincialis*. In this respect, there is also differentiation by certification and development of trademarks (i.e., origin and cultural practices).

Most French farmed mussels are covered by a public label:

- Almost all the mussels raised in a bouchot-type culture in France are certified under traditional speciality guaranteed (TSG, "Moules de bouchot") registered since 2013 (24 786 tons in 2018).
- In 2018, the Protected Designation of Origin (PDO) of "Moules de bouchot de la Baie du Mont-Saint-Michel" (translated as 'Bouchot mussels from the Bay of Mont-Saint-Michel') produced 9 790 tons
- 383 tons were produced under the French public quality "Label Rouge" and "Moules de filières élevées en pleine mer" (translated as 'mussels raised in the open sea'), of
- 1 666 tons of organic mussels.
- Some of these labels impose higher commercial size and/or meat yield

French name of the quality program	Quality program type	Wild catch or aquaculture	Minimal meat yield (Lawrence & Scott index)	Simplified meat yield (IS)	Minimal size
AOP Moules de Bouchot de la Baie du Mont Saint Michel	Protected Designation of Origin (PDO)	Aquaculture (bouchot)	>= 120	>= 25,5 %	40 mm
STG "Moules de bouchot" (M. edulis and M. galloprovincialis).	Traditional Speciality Guaranteed (TSG)	Aquaculture (bouchot)	>= 100		Shell thickness 12 mm
Label Rouge "Moules" LA 03/16 (M. edulis)	French quality certification "Label Rouge"	Aquaculture	>= 151	>= 27 %	40 mm
Label Rouge "Moules de filières élevées en pleine mer"	French quality certification "Label Rouge"	Aquaculture (Rope)	>= 160	>= 28 %	45 mm
Barfleur	Quality pledge	Wild catch		>= 23 %	40 mm
Dredge fishing		Wild catch		>= 17 à 30 % (indicative)	40 mm

Bouchots mussels can be mechanically harvested with in-boat hydraulic machinery, scraping all wrapped mussels (which are contained in a circular net) at once from the piles and depositing them into inboard containers. The submerged longlines will be towed on boats with a hydraulic winch. Contrarily to bouchot mussels which are always installed in the intertidal area, longline mussels may be installed in places where mussels are permanently submerged, which impacts the PH chain. Mussels that regularly experience emersion (ie bouchot mussels) learn to close their shell, while mussels that are always submerged do not. The main consequence is a higher level of water loss during storage and transport for constantly submerged mussels. All farmed mussels are declumped, cleaned with seawater and placed in bins directly on the deck.

Dredged mussels are washed, pre-selected and bagged on board the boat. Stones, broken and small mussels (under 4 cm) were until recently discarded directly into the sea. Now these mussels must be specifically treated as they constitute an organic waste which can't be disposed directly on the shore. The harvested and bagged mussels are then placed in degritting pools (i.e., freshwater pools, which makes the mussel evacuate any sand/grit they have taken in during filtering) for 2 to 6 hours.

Mussels preprocessing is determined by a specific water quality classification, based on regular tests for microbiology (E. coli) and chemical residues. The classification system is comprised of four classes, from A (cleanest) to D. The mussels from a 'Class A' shellfish production area can be sold directly without any further processing for human consumption. For farmed mussels from 'Class B' shellfish production areas, a purification/depuration step is mandatory before mussels can be marketed. In this process, mussels are placed within a tank of clean water with a high flow of clean seawater. During this temporary storage, mussels will empty their gastrointestinal tracts, reducing the amount of mud and grit within their valves. This process also promotes the purging of some bacteria and viruses, leaving a cleaner product. Farmed mussels from 'Class C' areas need a longer depuration process or a heat treatment to be commercialised. Certification label regulations may limit the purification (optional) and duration of storage in inland plots. Depending on the certification label, this purification process may be from 48h for Label Rouge mussels, to a maximum of 15 days for TSG "Moules de bouchots".

Following harvest and purification, to guarantee their quality prior to marketing, mussels pass through different mechanized steps:

1. **De-clumping**: a de-clumper machinery is employed to reduce groups of mussels down to individuals (mussels not still attached to one another with byssus threads) and to remove nets used to maintain mussels (capelage). This process should generate a minimum of broken shells (less than 2 or 3 percent);
2. **Washing, size grading**: After declumping, mussels are washed and pre-sorted. Naturally present impurities and epibionts are removed by mechanical rubbing, "undersizeds" (very small non-saleable mussels) are also removed. Certification labels define a minimum size usually above the minimal market size (notably the Label Rouge products);
3. **Removing the byssus thread**: Mussels sold as "ready-to-cook" on the market are debyssed. Byssus thread, although edible, is an undesirable part of the mussel that the animal uses to attach itself to a substrate. The debyssing machine uses a set of narrow cylinders that rotate, counter to one another, to grasp the byssal threads (the 'beard') and pull them from the mussel. This leaves a cleaner and more palatable product. However, this procedure reduces their lifespan as they are now unable to completely close their shell. As a result, they will gradually lose their shell liquors, so special care must be taken for the mussels to retain their fluid. Byssus weight is estimated by professionals between 5 and 8 % of the mussel total weight (FranceAgrimer).
4. **Grading**: The last step in the processing is grading, to ensure the marketed product has a uniform size. Mechanical graders use rolling bars placed nearly parallel to one another, but with an increasing distance between them along their length. Mussels

travel over the rolling bars, and the smallest mussels drop out first, based on the width of the mussels.

Cleaned mussels, individually separated, with byssus thread removed and grouped by size are ready for packaging. French mussels are mostly sold alive even if they can be purchased as processed products (canned, pre-cooked and processed with dressing, frozen, etc.). Fresh mussels may be sold as "traditional mussels": packed into mesh or perforated plastic bags, from usually 2 Kg up to 15 kg for bulk sales, while mussels can also be sold as 'ready to cook', chilled mussels without byssus threads. These are packed into trays (vacuum or Modified Atmosphere Package (MAP)) from 0,5 up to 2 kg, for direct consumer use. Lastly, mussels can also be sold 'raw' in bulk, directly out from sea, unclean and not degritted (ie still with sand), to wholesalers for a price that is much lower than that for direct sales.

After harvesting, mussels gradually lose water during packaging and transport. The water losses vary during the season (10 % at the beginning and end of the season and 5-7 % in the middle). Such water loss is anticipated by processors who are filling bags with more weight than labelled, so that the product reaches the desired weight at the consumer level.

Farmed mussels can be marketed directly, through a regional wholesaler-shipper (most often another producer) or through producer groups that also provide packaging and shipping (producers' cooperative, for example, the Mytilimer, Cultimer, Groupement des producteurs Mytilicoles de Pénestin in Brittany). The majority of farms produce and sell their products.

The distribution channels for mussel producers (all types of production combined) are:

- Wholesalers, fish merchants and traders: privileged circuit for "bouchot" mussels consumed in out-of-home catering and sold at specialized retailers (fishmongers) outside coastal areas;
- Direct sales to restaurateurs, fishmongers, caterers, scalers: common in the production regions (Channel and Atlantic coast);
- Supermarket chains: directly from store buyers, especially in coastal areas or to the central purchasing offices of distribution groups;
- Direct sales to the consumer and tasting: Some producers have developed a boutique service, and/or tasting, all year round or during the tourist season; and
- Export: Most exports are made via exporting wholesalers. Direct exports by producers remain in the minority.

The main distribution channel to consumers is through national wholesalers/fish merchants, which account for 50 % of sales in value (50.9 million EUR in 2018). Sales to supermarket chains and direct sales to restaurants and fishmongers account for 40 % of the sales (39.9 million EUR) (AGRESTE).

It is estimated that around 39 % of the production of mussel bouchot (approximately 15,000 tonnes) is processed by producer groups (FranceAgrimer). This group sells mainly to supermarket chains (between 50 and 70 % of the sales) because they specialise in ready-to-eat packaging, representing up to 60 % of mussels' sales in this retail.

In France, households mainly consume fresh mussels compared to frozen, 38,982 tons and only 1,451 tons in 2018, respectively (Kantar Worldpanel). Approximately 81,3 % in volume of household purchases are made in supermarkets, making this retail far ahead of the specialized retailers (e.g., fishmongers), which encompass only 7,8 % of sales in value.

Mussel processing generates by-products composed mainly of undersized mussels. Except for dredged mussels sorted before landing, part of the production is excluded before packing, due to a minimum size needed for marketing mussels under the different labels and trademarks. Variation in growth between individuals is mainly due to breeding techniques (difference in the growth of mussels according to their positioning on the bouchot or on the longline) and are linked to environmental conditions. Such variation in growth can represent more than 20 % of production according to practices, sectors, and environmental conditions (15 – 25 % in Normandy-North Sea and North Brittany, 15 - 50 % in the other basins). The percentage of the population that is undersize is larger in catchment basins, as new spat will attach to adult mussels, reducing the total number of large sized individuals.

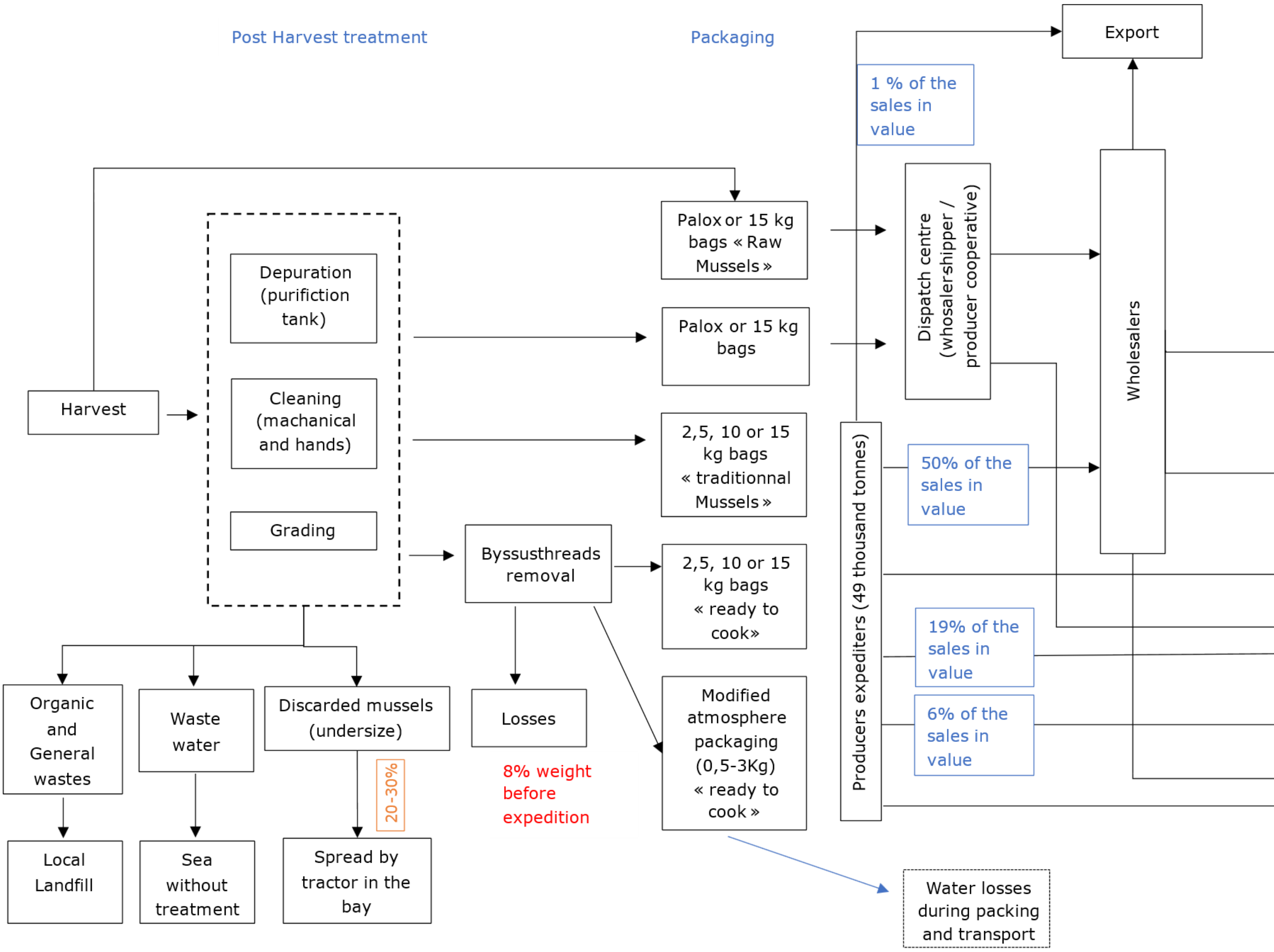


Figure 2. Postharvest value chain Mussels in France. Source: FranceAgrimer

Table 1: Numbers of the postharvest value chain of Mussels in France. *Sources: Agreste DPMA (Annual survey - Enquete aquaculture 2018), France Agrimer (Commerce exterieur des produits de la pêche et de l'Aquaculture 2018, Key figures 2019, Key figures 2020, Consommation des produits de la pêche et de l'aquaculture 2020), EUMOFA.*

Main primary production	French production, quantities sold for consumption (annually, commercial size)	Volume importations / Volume exportation	Top 5 Import countries (Volume)	Value of sales (annually)	Top 5 Export locations (volume)
Bouchots culture Longline Rafts	48,844 tons (37,554 tons M. edulis bouchots culture)	Import (live, fresh or chilled): 43,992 tons Export (live, or fresh	1. Spain (43 %) 2. Netherlands (32 %)	101 million EUR	1. Spain (70 %) 2. Switzerland (13 %)

Main primary production	French production, quantities sold for consumption (annually, commercial size)	Volume importations / Volume exportation	Top 5 Import countries (Volume)	Value of sales (annually)	Top 5 Export locations (volume)
	379 tons landing	chilled): 3,382 tons	3. Italy (12 %) 4. Ireland (5 %) 5. Denmark (4 %)		3. Belgium (5 %) 4. Germany (3 %) 5. Italy (2 %)

Dominant sales channel (in value)	Average annual consumption per capita (Equivalent live weight, estimation)	Households purchases for home consumption (fresh)	Households purchases for home consumption sales channel (volume) 2020
1. Whosalers: 50 % 2. Restaurant, other specialised retailers: 21 % 3. Retail (supermarkets): 19 % 4. Direct sales: 6 % 5. Other: 3 % 6. Export: 1 %	2017: 2.4 kg 2013 to 2015: 3 kg	2017: 39,691 tons 2018: 39,603 tons 2019: 37,141 tons 2020: 36,510 tons	1. Retail (supermarkets); 79.7 % 2. Fishmonger: 7.1 % 3. Open Market: 6.9 % 4. Others: 6.3 %

3. Resilience

3.1 Physical and financial resilience

Traditionally, farms' facilities have been settled very close to the shore, sometimes a few metres from the foreshore. The processing units are usually located on the farms' premise, which makes them highly vulnerable to any changes in sea level or any intense storms, despite the physical protections (dykes mainly) that have been erected to protect them from strong weather.

The different hypotheses of sea rise by 2010 adding 50 cm to 1 metre compared to current levels would cause issues for many processing units. The strengthening and the increasing frequency of storms that are forecasted in the various global warming scenarios may impact directly the PH operations. In recent years, several cooperative structures have emerged, with the aim of grouping the processing steps for several producers, to gain efficiency and improve the technical capabilities of companies. These cooperatives have tended to settle inshore (mainly due to the lower costs for the land), thus improving the physical resilience of primary processing operations.

Several research projects have also highlighted that ocean acidification and global warming may have a significant effect on the growth of marine species, notably mussels (see Waldbusser et al 2014 Vargas et al 2017). Pirone et al (2019) indicate that changing conditions may modify the bioaccumulation of heavy metals and pollutants, which may, in certain circumstances, be detrimental to the sector as mussels wouldn't be suitable for human consumption and that no treatment could modify that. Other authors studied the effect of climate change on growth rates, which may increase towards an optimal temperature, while additional stressors as ocean acidification may have the potential to narrow the thermal window to grow mussels (see notably Fitzer et al 2015 and Lassoued et al. 2021). Climate changes may create conflicting demands on energy (increased host metabolic activity, homeostasis maintenance) that would be detrimental to mussel growth. Moreover, higher temperatures could affect mussel larvae availability, the dynamics of all pathogens, the distribution and abundance of nutrients and could also modulate the susceptibility of organisms to pollutants. Ocean acidification is detrimental to shell quality, which may cause issues in terms of the availability of the sector to produce mussels that can handle transport.

All these factors combined could lower the quality of mussels produced by the French sector: softer shells and smaller mussels. In a catastrophic scenario, the French sector would have to rethink entirely its approach, notably if the current commercial size couldn't be reached.

4. Major financial constraints and reliability

Mussels' farmers have experienced sudden mortalities in recent years (since 2014) that have affected several regions along the Atlantic coast, limiting production in subsequent years. These mortalities are associated with the detection of a new pathogen in France, *Francisella halioticida*, which was previously identified as the main cause of mortalities in Japan (abalone production) and Canada (mussel production) (Charles 2020). Stakeholders commented that these episodes had reduced the cash flow of most farms, affecting their ability to resist future shocks but also to invest in more energy-efficient equipment and participate in research projects to adapt their practices to reduce GHG emissions and improve their resilience to climate change.

5. Stakeholders' perceptions

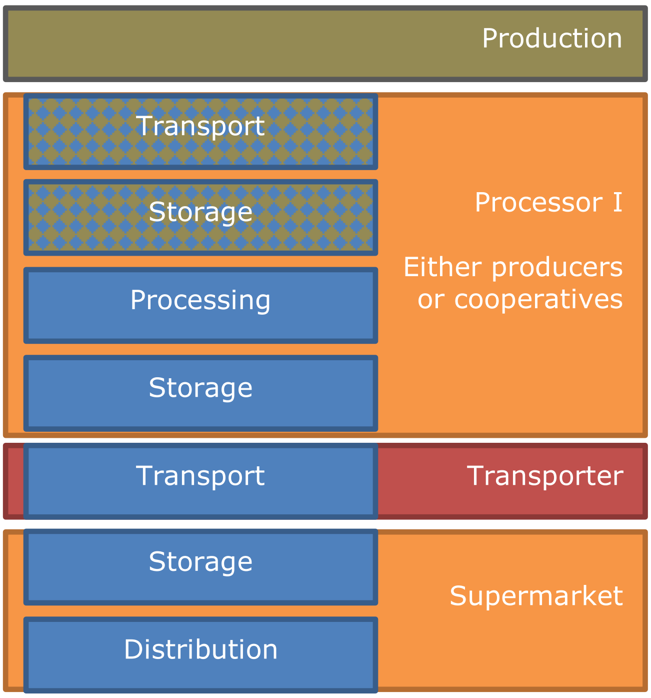
	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	***Strengths*** • Development of a coordinated approach for PH activities, by the creation of cooperatives	***Weaknesses*** • Most operations are situated on the coastline: sea rise, stronger winter storms • Shellfish farming relies on monocultural practices in France, which means that most farmers are highly vulnerable to higher mortality rates and low levels of larval recruitment • A lot of SMEs are farming and processing mussels, with limited staff availability to look into climate change issues
External origin (attributes of the environment)	***Opportunities*** • Emerging marine activities may provide new areas to produce mussels, like offshore windfarm • *M. galloprovincialis* may replace *M. edulis* in areas not suitable for edulis as they face warmer conditions in their distribution area.	***Threats*** • Climate change may trigger new pathogens which start new mortality episodes

6. Greenhouse Gas Emissions

6.1 GHG emissions in the value chain

The mussel supply chain is relatively short, involving only a few actors:

1- Producers (the production is outside the PH chain) which are either vertically integrated or organised in coop to perform all the processing steps (cleaning, declumping, debyssing, packaging)
2- When producers are organised in cooperatives, there are additional steps in the value chain (ie transport and storage before the processing)
3- Transport from the processing units to the supermarket networks, with potentially several stops in grouping/degrouping platforms
4- Storage and distribution in supermarkets.



6.2 Transport from production to the primary processor

Mussel farmers are usually vertically integrated, performing all processing steps on their farms before shipping the products to supermarkets, wholesalers, and fishmongers. However, there is a tendency for producers to regroup in cooperatives to increase their collective capabilities to invest and develop new processing techniques (ready-to-eat mussels notably).

When producers are regrouped in a cooperative, there is a need to transport mussels to the cooperative facility before processing. In this case, there are one to two additional steps in the value chain: transport and storage. The cooperatives own the trucks and are organising the collecting routes, which means that trucks are solely used for mussel transport, which doesn’t allow for the optimisation transport companies are performing as the trucks may be empty before loading the mussels at the farms. There is no systematic record of the distance travelled nor the load factor of the trucks used, which would allow the evaluation of the GHG emissions associated with this transport.

6.3 Primary processing

On arrival in the primary processing unit, mussels are stored in cold storage. Mussels are then quickly processed before being packed (cleaned, declumpsed, sorted). Companies contacted do not record the energy consumption associated with each processing step. In vertically integrated operations, little distinction is made between the energy and material used for the production steps and the one needed for the PH steps.

6.4 Transport companies

Mussels are usually transported by the same companies transporting fresh seafood in France. These transport companies usually report GHG emissions ratios combining all their activities at an annual level, which doesn’t help understand the exact contribution of transportation to the mussel GHG emissions. The high mussel season (from July to October) doesn’t correspond with the high season of seafood transport (usually the end of the year), which means there is a trade-off between productions from the transporters’ perspective.

As for the fresh seafood and the cooked shrimp supply chains, there is a difference between the long hauls and the last kilometres that are not operated by the same trucks. Long hauls tend to be operated with 18-tonne refrigerated trucks, while the last kilometres are more and more handled by smaller low-emission vans due to increasing restrictions on emissions and noise in urban and sub-urban areas, where most supermarkets and fishmongers are located.

There is no systematic record of the distance travelled nor the load factor of the trucks used, which would allow the evaluation of the GHG emissions associated with this transport.

6.5 Supermarkets and fishmongers

In stores, the mussels are either sold

- within 2 days from arrival on fresh counters,
- or within 5 to 7 days on self-service fresh counters for the Modified Atmosphere Packaging range.

7. Alternate distribution systems

In recent years, mussel farmers have developed new packaging to offer ready-to-eat options to shoppers. These products have been widely distributed by supermarkets but less by fishmongers who relied more on bulk bags. They are slowly picked by some e-commerce specialists, but the volumes entering those chains are not allowing the development of a specific alternative model to distribute mussels.

Stakeholders mentioned that the supermarket chain distribution organisation dictated how mussels were shipped from the PH units.

8. Limitations for structural improvements in GHG emissions

Despite the potential link between climate change and the recent epizootic touching mussel farms, stakeholders converge to indicate that global warming and environmental issues related to PH are at the bottom of the list of priorities for most operators in the sector. Despite the organisation in cooperatives which helped increase the number of support staff that the mussels farms could afford to hire collectively, long-term environmental issues are still in the remit of the regional associations of shellfish farmers, which have lots of difficulties engaging with their members on climate change issues.

9. Reducing GHG emissions by technical means

9.1 Trends in technological evolutions and industrial strategies

In recent years, prepacked live mussels in modified atmosphere packaging (MAP) appeared on supermarket shelves. They consist of portions packs of ready-to-eat mussels that are cleaned and debyssed. Mussels sold on fresh counters are usually not debyssed because this step dramatically reduces the shelf life of the live mussels. These packs are adding more plastic weight per kg of mussels than the 5 kg bags used by supermarkets to supply their fresh counters and are filled with specific gas combinations to extend the shelf life of the mussels by reducing the development of aerobic bacteria and

The organisation in cooperatives is fostering developments that couldn't be undertaken by individual farmers: prepacked live mussels are an example of new techniques permitted by the grouping of PH capabilities.

10. Conclusions

For live mussels, the impact of climate change is twofold:

- Structural: most of the sector is located on the coastline, in areas that are at risk of being submerged (sea rising) and more frequently impacted by rough weather. Operations happening in the intertidal zone are also affected by these changes, which may disrupt further the operations of businesses that are mostly vertically organised (production and primary processing).
- Resource: warming waters may have profound impacts on the ability of mussels to grow at the current commercial size, which may dramatically change the ability of the sector to offer any product without a complete rethink of the product range that may be offered to consumers.

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CASE STUDY 16: INVERTEBRATES – NORTHERN SHRIMP (*PANDALUS BOREALIS*) - SWEDEN

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Photo: Fresh, boiled Northern shrimp *(Pandalus borealis)* for direct human consumption. Photo credit: Sara Hornborg

Sara Hornborg, Yannic Wocken and Kavitha Shanmugam

LIST OF ABBREVIATIONS

Term	Description
GHG	Greenhouse gas
HORECA	Hotels, Restaurants and Cafés
LW	live-weight
CO_2e	carbon dioxide equivalents (i.e., combined GHG emissions)
SwAM	Swedish Agency for Marine and Water Management
t*km	tonne kilometre, i.e., transport of one-ton material for one km

1 Background

Northern shrimp *Pandalus borealis* is fished with demersal trawls throughout the northern Atlantic, north Pacific and Arctic Sea (FAO areas 18, 21, 27, 61, 67; EU COM, 2022). In Sweden, Northern shrimp is often perceived as a locally produced seafood by consumers and is associated with important cultural values and traditions including small-scale coastal fisheries, tourism, consumption during weekends and holidays. However, the dominating volume consumed in Sweden is imported (Hornborg et al., 2021). The imported shrimp may have long and complex supply chains. They are predominantly based on fisheries from around Greenland and Canada or in the Barents Sea and could be processed in a variety of countries (e.g., Poland, Norway, Bulgaria) before it reaches Swedish consumers. The most locally occurring shrimp stock in the Skagerrak (the Northeast Atlantic) is shared between Swedish, Danish, and Norwegian fisheries.

Fisheries for Northern shrimp are generally relatively fuel intensive compared to fisheries for finfish due to use of demersal trawls and lower catch per unit effort (e.g., Ziegler et al., 2018) and therefore belongs to the category with a higher range of greenhouse gas (GHG) emissions amongst seafood (Gephart et al., 2021). The full GHG emissions of Northern shrimp products have so far been identified to be driven by the fishing phase (Ziegler et al., 2021). Therefore, when focusing on the PH opportunities to reduce GHG emissions, higher utilization of the biomass that is caught during fishing offers improvement potentials because it contributes to lower input of fuel per output of product. Side streams of peel could be valorised for improved resource efficiency in the form of production of chitosan, broths, etc. Furthermore, problems with high grading of catch occurs in the shrimp fishery in the Skagerrak area – smaller sizes of shrimp are discarded back to sea due to low value for fishermen although a landing obligation is in place (Ziegler et al., 2016; Hornborg & Mann, 2019). In 2020, the share discarded is associated with uncertainties and varied between countries but was in the range ~3 % of total catch (ICES 2021). The main driver is that the quota is limited for the number of vessels active in the fishery. However, if improved market opportunities would exist for these volumes of smaller sizes (such as higher value), further incentives to comply may be achieved. This would contribute to decreasing the fuel use intensity (l/kg landed) of the fishery and in the end GHG emissions of shrimp products. There may also be other species of cold-water shrimp caught as bycatch in the Northern shrimp fishery that could be utilized more (Appelqvist & Lindegarth 2019).

With this background, this CS focuses on the value chain of Northern shrimp in Sweden. Through interviews with value chain actors and exploration of scenarios through basic Life Cycle Assessment (LCA) calculations, potential emission reductions through supply chain interventions are explored of a seafood product in the higher range of GHG emissions.

2 Value Chain

2.1 Value chain description

Northern shrimp is the most common species of shrimp on the Swedish market (Bua shellfish, 2022). Imported Northern shrimp enters wholesalers either as frozen (shell-on or peeled) or fresh in brine (peeled) to be distributed to HORECA or retailers. There are differences in preferences in product form between markets where the Swedish market prefer shrimp with shell on (Royal Greenland, 2022). There are many different fisheries supporting the value chains of imported Northern shrimp. Fisheries around Canada, Greenland and Norway could either be coastal or offshore, and could be dedicated to species-selective shrimp trawling, target a mix of species where shrimp comprise of various shares of the total volume or target shrimp during certain trips (Ziegler et al., 2018; Winther et al., 2020; Royal Greenland, 2022). The shrimp catch may either be boiled and frozen directly onboard the fishing vessel or put on ice for processing on land. Imported Northern shrimp that is peeled has either been processed by hand or machine, predominantly in Poland, Latvia and Norway or Greenland (e.g., Orkla, 2022a; Feldts, 2022; Winther et al., 2020; Royal Greenland, 2022).

There is also a fishery for Northern shrimp in Skagerrak (the Northeast Atlantic) where Swedish commercial fisheries are active together with Denmark and Norway. These landings enter fish auctions in Göteborg and Smögen on the Swedish west coast or are delivered by trucks from Norway. Landings comprise of two fractions: larger sizes of fresh shrimp that have been boiled on vessels for direct consumption and smaller sizes of raw shrimp for fresh processing on land or direct delivery to HORECA. The larger, boiled shrimp (main volume) is directly sold fresh (shell on) for distribution to HORECA or retail. Raw shrimp landed by Swedish fisheries, and a small volume of raw shrimp caught in Norwegian fisheries entering Sweden by trucks, are processed, boiled and peeled by machine in one processing facility south of Gothenburg and put in brine before further distribution to wholesalers (Bua shellfish, 2022). A smaller volume of raw shrimp is also sold directly from the fish auction to wholesale and HORECA (approximately 100-150 kg per week). There is also one mechanical processing plant for shrimp in Denmark and two in southern Norway. According to the Swedish shrimp processing industry, 400 tonnes of raw shrimp is processed on land by machine each ear.

There is a price difference for the fisher between the larger boiled shrimp compared to the smaller size of raw shrimp, with the small, raw shrimp generally generating a lower value (Figure 1). The magnitude of difference in price varies over the year and between years; it could amount to a tenfold difference (Ziegler et al., 2016). The raw processed shrimp from the Skagerrak fishery only supply the Swedish market. The main destination of shells from the processing industry is feed or biogas (Orkla, 2022a; Bua shellfish, 2022) but also broth may be produced (Feldts, 2022).

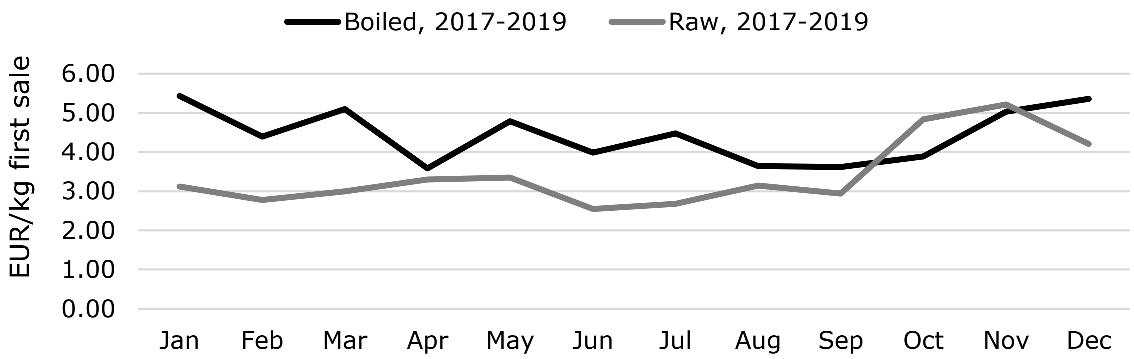

Figure 1 Average price at first sale for larger, boiled shrimp and smaller, raw shrimp during 2017-2019 (data from SwAM; Blomquist et al. 2021).

The volumes in the PH value chain of Northern shrimp on the Swedish domestic market are complex to describe because i) trade flows contain different product forms (frozen, peeled, combined products); ii) EUMOFA statistics do not distinguish between different species of cold-water shrimps (they also include Common shrimp *Crangon crangon*); and iii) they may be processed and/or repackaged at different locations. A rough sketch of the value chain in Sweden is illustrated in Figure 2 and volumes at EU level in

Table . According to FAO statistics on *Pandalus borealis*, the five top countries by landing volume are Canada, Greenland, Norway, Russia and Estonia – combined contributing with over 92 % of landing volume during 2015-2019.

Based on information of one major wholesaler from Northern shrimp in Sweden, the main volume sold is frozen shrimps with shell. It is reported that these frozen shrimps are bought directly from the fishing vessels (fisheries around Canada, Greenland), brought to Denmark by boat for storage before road transport by fully loaded trucks to factories where they are processed by hand (predominantly in Poland) and transported fresh in brine to central storage in Sweden by fully loaded trucks (~ 7 000 tons of peeled shrimp). The same actor reports on only smaller volumes of smaller shrimp being processed by machine (from raw shrimp landings) in Sweden or Norway from fisheries in the Skagerrak or Norway (~5 % of their total sales volume); this part used to be larger before.

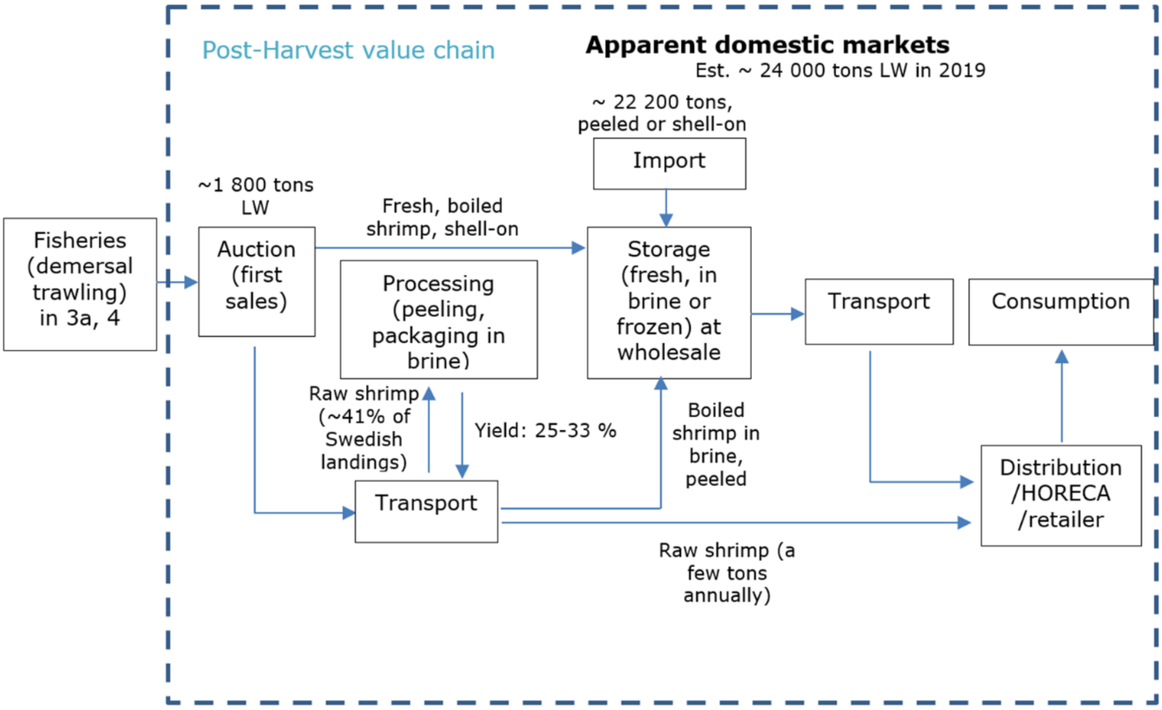

Figure 2 Postharvest value chain of Northern shrimp *Pandalus borealis* in Sweden (2019). Note that figures are subjected to rounding and total domestic volume may contain also other species of shrimp since EUMOFA product categories may include more species. LW = Life Weight. Source: EUMOFA, Statistics Sweden

Table 1 The postharvest value chain during 2015-2019 for all of EU of Northern prawn, or all cold-water shrimps when further details are not available (may be combined with other cold-water shrimp, *Crangon crangon*).

Main primary production	Volume first sales of cold-water shrimp (annually)[1], excluding Iceland, Norway and UK	Value first sales of cold-water shrimp (annually)[1], excluding Iceland, Norway and UK	TAC (quota) for Northern shrimp in 2021 (tonnes) in 3a, 4 + 2a (UK waters), 4 + 14 (Greenland waters)[2,3]	Main first sales locations of cold-water shrimp (harbours with largest landing volumes)[1]
Wild capture (Trawls)	3,700-5,100 tons	28,700-32,300 thousand EUR	1.Denmark (43 %) 2.France (20 %) 3.Norway (26 %) 4.Sweden (10 %) 5.UK (2 %) Total: 9,674 tonnes	Hirtshals (DK) Skagen (DK) Göteborg (SE) Smögen (SE) Hanstholm (DK)
Market size category to be analysed	**Preservation & presentation**	**Top 5 EU countries (import value) + total import value EU + UK and Norway (average 2015-2019 for cold-water shrimp)[1]**	**Top 5 EU countries (export value) + total export value EU (average 2015-2019 for cold-water shrimp)[1]**	**Dominant sales channel**
All sizes	Fresh boiled (shell-on or peeled in brine), frozen boiled (shell-on or peeled)	1.Denmark (50 %) 2.Sweden (10 %) 3.Iceland (6 %) 4.Norway (5 %) 5.Spain (4 %) Total: 825,600 thousand EUR (EU incl. UK)	1.Denmark (59 %) 2.Iceland (17 %) 3.Netherlands (5 %) 4.Estonia (5 %) 5.Spain (4 %) Total: 459,000 thousand EUR (EU incl. UK)	Retail, HORECA

Sources: [1]EUMOFA, [2]NAFO, [3]European Council

3 Resilience

3.1 Physical and financial resilience, constraints and reliability

Northern shrimp can be fished all year round, but fishing opportunities are affected by ice conditions in some areas (Royal Greenland, 2020). As a consequence of climate change, ice cover in the northern hemisphere is dramatically decreasing. From a Northern shrimp value chain perspective, one wholesaler reports that this has contributed with increasing problems with drift ice in shrimp fishing areas around Greenland and Canada that have not had ice challenges before. It is therefore unclear if the melting of the Arctic will have a negative or positive effect on shrimp fisheries. Ocean acidification has also been found to have a negative effect on survival, development and growth of the larval stage of Northern shrimp (Arnberg et al., 2018).

According to one wholesaler, the value chain is and has also been affected by increasing fuel and energy prices. This is despite of fisheries already being exempt from fuel tax; perhaps they are even more sensitive to further increases in oil price because they are already dependent on financial support. In fact, with the sudden increase in fuel costs due to the Russia-Ukraine conflict, Swedish shrimp fisheries required extra financial support to be able to continue fishing. Prices for Northern shrimp have however increased in recent years due to high demand in combination with decreased quotas (Royal Greenland, 2022). Furthermore, during the covid-19 pandemic, disruptions in seafood value chains occurred due to lower demand from HORECA. According to Swedish processing industry, this resulted in increased competition between shrimp processed by machine or by hand in remaining markets, negatively affecting the price for machine-peeled shrimp. Retailers have however experienced a sharp increase in demand in particular for frozen seafood. According to one wholesaler, the value chain of Northern shrimp is in this sense generally affected by changes in demand from different markets. However, compared to other shellfish such as Nephrops (*Nephrops norvegicus*), price at first sale for Northern shrimp was less affected since these volumes are also distributed through retail (Blomquist et al., 2021). Having multiple sales channels and a diverse product portfolio thus seems to add resilience to disruptions in the supply chain.

Peeling of shrimp by hand is preferable in terms of yield, an important parameter for both economy and GHG emissions of the final product, but according to one wholesaler, there are problems with lack of work force. From a wholesaler perspective, it is also preferable to have processing in the vicinity, and not in e.g. Morocco, because it facilitates e.g. quality control and minimises the need for transportation (for which costs have increased and which poses a risk when disrupted). According to the machine processing industry in Sweden, the hand-peeled shrimp sets the price for Northern shrimp on the market; the market perceives hand-peeled shrimp to be of better quality and is sold at higher price.

3.2 Stakeholders' perceptions

This SWOT is based on interviews with one wholesaler and one processor, both important to the Swedish market (Table).

Table 2 SWOT for the Northern shrimp value chain in Sweden based on interviews with one wholesaler and one processor of shrimp.

	Helpful	Harmful
Internal origin (attributes of the organizations)	Strengths • Large volumes are fished at a time and most of the processing happens onboard (fewer steps in the PH value chain)	Weaknesses • Uncertainties on what is most efficient – process onboard fishing vessels or on land? • Different efficiencies between fishing vessels – older, smaller fishing vessels may have higher fuel use intensities • Affected by demand (which varies and differs between markets) • Affected by resource availability (which may vary and is limited) • Fuel costs in fisheries – some vessels are now not fishing due to high fuel costs and demand higher price for their products
External origin (attributes of the environment)	Opportunities • With more knowledge on different drivers behind current GHGs, the production process may improve • Implement sourcing strategies for raw material allowing for resource efficiency, given the variability between fisheries	Threats • Drift ice – how will this affect fishing opportunities? • Predation – shrimp is affected by e.g. cod abundance, unclear if this may be affected by climate change • Shrimp availability – uncertain availability, effected by climate change, rising fuel costs, quotas (decreasing)

3.3 Role of management – lessons learned of adopted strategies

High-grading of shrimp catches in the Northeast Atlantic has not been resolved through fishery management nor eco-certification by the Marine Stewardship Council (Hornborg and Mann, 2019). When quotas are limited, and with current price difference between different size fractions, change in practice will arguably be difficult to achieve. However, the reduction of number of fishing vessels in the Danish fishery through introduction of an individual tradable quota system has affected the fishing pattern; Danish fisheries is now more fuel-efficient (in l/kg) compared to Swedish and Norwegian fisheries on the same stock (Ziegler et al., 2016). In part, this reflects different limitation of the quota (number of vessels involved) and utilization of the catch – a larger proportion of smaller sizes of Northern shrimp is landed in Danish fisheries which improves catch per unit effort in the fishery and thus fuel use efficiency. The same change in practice for Sweden and Norway offers reduction potentials of GHG emissions of Northern shrimp but would also lead to change in value chains where more shrimp is processed on land. According to one wholesaler, this also needs shift in demand – there is generally a higher demand for larger shrimp. At the time of year when demand is highest (summer months), higher shares of smaller sizes of shrimp are caught; there is thus a mismatch between when demand is higher compared with the season when the smaller sizes are more abundant.

The current value chain thus causes problems. The main problem is illegal discards of smaller sizes of shrimp (high grading), with cannot be quantified for the Norwegian fishery and estimates are based on assumptions (ICES, 2021). There are also problems with estimating catches when shrimp is boiled on the vessels, because loss in landed weight compared to live weight needs to better be accounted for. A Northern shrimp value chain with increased boiling on land and higher utilization of the full catch (including small sizes) may decrease uncertainties about volumes caught in the Skagerrak, and as a bonus, decrease current uncertainties in stock assessment and contribute to GHG emission reductions.

Utilizing other shrimp species that are caught as bycatch in the fishery in the Skagerrak for human consumption – e.g. *Pasiphaea tarda, P. multidentate, P. sivado, Pandalus montagui, Lebbeus polaris* (Appelqvist & Lindegarth 2019) – may also offer opportunities for reductions of GHG emissions of the fishery; improved utilization of actual catches decreases fuel use per landing. However, these species have no fisheries advice today and thus requires management actions to safeguard a sustainable exploitation and avoid risk for overfishing. There is also a need for establishing a market for these products. One wholesaler also reports on variable quality of these shrimps, where in particular *Pandalus montagui* are landed together with Northern shrimp, but that they may be used for salads.

4 Greenhouse Gas Emissions

4.1 GHG emissions in the value chain

The product studied (or functional) unit of the Northern shrimp value chain here is 1 kg edible product at wholesaler. Most data related to PH emissions are based on background data for Northern shrimp production in Norway (Winther et al., 2020) – the 'base case'. Complementing information on different fisheries and input from Swedish value chain actors is used in this chapter to inform on variability and GHG emissions of alternative value chains and processes of the Northern shrimp supply chain in Sweden.

4.1.1 Fisheries

For Norwegian production on Northern shrimp, the base case shrimp was caught by coastal shrimp trawlers landing 25 % shrimp catch or more, with an average fuel use intensity of 1.48 /kg LW. However, the estimates by Winther et al. (2020) for fuel use for different shrimp fisheries in Norway shows a large variability and experienced difficulties in modelling in suitable detail; depending on fishery and modelling choice, emissions could vary between 1.2-7.2 kg CO2e/kg LW at landing.

The fuel consumption of fisheries for Northern shrimp in the Skagerrak area varies between countries engaged in the fishery (Ziegler et al., 2016), but also over time and degree of selectivity in the fishery (Ziegler & Hornborg, 2014). Based on a theoretical model using kW and effort, fuel use in this fishery has been estimated to be 5.7 l/kg LW shrimp in Sweden and Norway (for year 2012); in Denmark it was estimated to be 4.5 l/kg LW shrimp respectively (Ziegler et al., 2016). Based on Swedish EU-MAP data (EU data collection legislation) on fuel use provided by SwAM, thus not fully comparable, fuel use was estimated to be around 3.1 l/kg LW in the Swedish fishery in 2017 (Hornborg & Mann, 2019). The estimated range in GHG emission for this fishery (including emissions from production and combustion of fuel, in total 2.94 kg CO_2e/l) and a generic value for non-fuel related emissions based on the approach in Ziegler et al. (2021), may thus be between 9.4-17.3 kg CO_2e/kg LW shrimp at landing.

The fuel use intensity of Northern shrimp caught in Greenland has also been estimated based on the same theoretical model using engine power (kW) and effort (Mann, 2018). In 2017, the offshore fleet had an average fuel use intensity of 1.6 l/kg LW whereas the coastal fleet had 0.7 l/kg LW respectively. Using the same approach as above to estimate GHG emissions, this results in 2.1-4.9 kg CO_2e/kg LW shrimp at landing.

To this end, GHG emissions from the fishing phase may range between 1.2-17.3 kg CO_2e/kg LW shrimp at landing. Edible yield varies between 25-33 %; some products are delivered to consumers shell-on.

4.1.2 Transport

For Northern shrimp imported from fisheries around Greenland and Canada, products are transported at sea to Europe in frozen form. One important harbour receiving and re-packaging Northern shrimp from Greenland is Cuxhaven in Germany (Royal Greenland, 2020). The contribution from transports varies depending on transport mode and distance. For example, chilled transportation on trucks may emit 0.248 kg CO_2e/t*km (combined GHG emissions per km of transport for one tonne of goods[37]). This includes the entire transport life cycle. For sea transport, the equivalent emissions may be 0.018 kg CO_2e/t*km[38].

The contribution of road transport in the base case of Norwegian Northern shrimp at wholesaler in Stockholm was estimated at 0.403 kg CO_2e/kg edible (10 % of total emissions). The relative contribution from transports to total GHG emissions of Northern shrimp products for the different supply chains options present in Sweden varies both depending on i) route (ranging 16-345 kg CO_2e/tonne transported; Table); ii) product form transported (LW, peeled, in brine) and the edible yield (ranging between 30-34 % in this case); and most importantly if considering the whole value chain, which fishery the landing originates from (ranging between 1.2-17.3 kg CO_2e/kg LW).

Table 3 Different routes and GHG emissions for Northern shrimp for the Swedish market.

Mode	Transport route	Distance (km)	kg CO_2e/ tonne transported
Sea	Northwest Atlantic – Esbjerg (Denmark)	3300	59
Sea	Northwest Atlantic - Cuxhaven (Germany)	3400	61
Road	Denmark - Poland	987	244
Road	Poland – Stockholm (Sweden)	1395	345
Road	Poland – Gothenburg (Sweden)	1102	273
Road	Cuxhaven (Germany) – Stockholm (Sweden)	1181	292
Road	Cuxhaven (Germany)- Gothenburg (Sweden)	843	209
Road	Bua (Sweden) – Gothenburg (Sweden)	65	16

[37] 16-32t Euro 5 at WLFDB 3.1/EU, AGRIBALYSE 3

[38] Transport, freight, sea, container ship with reefer, freezing {GLO}| market for transport, freight, sea, container ship with reefer, freezing | Cut-off, S; Ecoinvent

4.1.3 Processing and packaging

The edible yield for Northern shrimp is around 36 %, according to FAO (1989). However, this figure is a bit high. Industry (wholesaler) reports on differences in edible yield between peeling by hand of larger sizes (~33 % of frozen, boiled shrimp) compared to 25-30 % when peeling raw shrimp by machine. However, when peeling from raw shrimp, the loss in LW from boiling is included, whereas the peeling of boiled shrimp by hand has a pre-loss of 5-10 % from LW during the boiling process.

Estimating yield and loss of LW during processing is however complicated for shrimp due to various reasons. Volumes that are peeled by machine on land are delivered raw on ice for boiling and peeling at factory on land. Landings of raw shrimp that have been stored on ice have been found to increase the weight of shrimp catches. Boiling (either directly at sea or after landing) however causes water loss. To which extent the actual yield from raw shrimp landing volumes is affected depending on when to raw shrimp is boiled is unknown. According to personal communication with a shrimp stock assessor, this potential effect is accounted for in Northern shrimp stock assessments by multiplying landings of boiled shrimp with a factor of 1.13 to get raw landing volume. An investigation is ongoing on how to better include uncertainties in catch volume when both raw on ice and boiled shrimp are landed. From a yield and GHG emission perspective, the potential net effect on yield from boiling at sea or land requires further investigation.

The overall contribution from processing of Northern shrimp in the Norwegian base case was 0.262 kg CO_2e/kg edible product, or ~6.6 % of total GHG emissions (Winther et al., 2020). Processing was approximated based on data for similar processes, adding a theoretical requirement of 2 litres of boiled water per kg shrimp at 418 kJ/kg water. This equals to 0.2 kWh/kg boiled shrimp. Boiling and processing on land uses electricity whereas when Northern shrimp is boiled at sea, diesel is used. Based on Ecoinvent data for average European grid mix (0.44 kg CO_2e/kWh) and following the Winther et al. (2020) approximation, the GHG emissions of boiling would be 0.02 kg CO_2e/kg LW shrimp on land whereas if boiled at sea, this equals to 0.06 kg CO_2e/kg LW shrimp (includes emissions from combustion and production; energy content of diesel 9 800 kWh/m^3 according to https://drivkraftsverige.se/). From a GHG emission perspective, boiling at sea is thus less efficient, although marginal, and more dependent on use of fossil fuel. When actual data are collected from shrimp fisheries, the energy use for boiling is included in the fuel use intensity of the fishery. However, in theoretical estimates using kW of fishing vessel and fishing effort, this additional component is not accounted for and is unknown.

When peeling Northern shrimp by machine on land in Sweden, between 49-65 m^3 water per tonne of final peeled shrimp is used (Forghani et al., 2021; data from processing industry). All water is not boiled, some is needed for e.g. the peeling steps and the transportation between these steps. According to Swedish processing industry, the energy consumption is around 855 kWh per tonne, or 376 CO_2e (European grid mix).

Offshore fisheries delivering shrimp for Royal Greenland are dedicated for shrimp fishing only and most of the catches are processed onboard (sorted, cooked and quick-frozen) immediately after landing (Royal Greenland, 2022). When Northern shrimp is caught in coastal fisheries around Greenland, the catch is stored on ice for a maximum of four days depending on when the on-board storage facilities are filled (Royal Greenland, 2022). The catch is then landed, and size and appearance are rated prior to processing on land. At the land-based factories, catches are quality-assessed and size-graded, before entering the production line where they are cooked, peeled and quick frozen.

Peeling of Northern shrimp generates waste in the form of shells, either during consumption or processing by industry. These residues are currently turned into biogas production if peeled by machine in Sweden (Bua shellfish, 2022); some are also used as feed (Orkla, 2022a) or broth (Feldts, 2022). Incineration of 1 kg of shrimp waste with energy recovery equals to a potential reduction of the generated electricity and heat (electricity: 0.00997 kg CO_2e and heat 0.00445 kg CO_2e) from the potential environmental impact of the final product. This thus offers a minor reduction potential to overall emissions.

Peeled shrimp may be put fresh in brine in plastic containers or frozen in plastic bags before distribution to market. The contribution to overall GHG emissions of packaging is most likely marginal; as an example, transport packaging material (i.e. material used for transport of product but not on the product in e.g. retail) was in Winther et al. (2020) estimated to be 0.04 kg CO_2e/kg edible product at wholesaler.

4.1.4 Storage and distribution

Peeled shrimp are either shipped directly to markets, or to other factories for further processing and re-packaging, such as put in brine (Royal Greenland, 2022). Chilled storage is either included in the energy use of the processing facility or in the transport.

4.1.5 Overall GHG emissions

The total GHG emissions of Norwegian production of Northern shrimp (boiled and frozen peeled) – the ‘base case’ – is estimated to be 4 kg CO_2e/kg edible at wholesaler in Stockholm, with fuel use during fishing being the main driver (81 % of total GHG emissions). Given the variability seen in the magnitude of GHG emission from the fishery (1.2-17.3 kg CO2e/kg LW shrimp at landing), there is a high variability in total GHG emissions depending on which fishery the raw material is sourced from. Furthermore, from a PH perspective, yield also varies between processing by hand or machine, and so does the structure of the value chain for different products; these factors combined contribute to different overall GHG emissions, and the relative importance of different value chain steps.

4.2 Alternative distribution systems

The processing of shrimp to peeled products generates considerable volumes of shells and process water that are today a cost to the industry to get rid of. Waste reduction is a focus area for one wholesaler in Sweden handling shrimp to cut costs and GHG emissions. In Sweden, shells are mainly destined for biogas production today, with marginal reduction potential for GHG emissions (see chapter 4.1.3). Production of food ingredients such as broth or other industrial applications such as chitin/chitosan, astaxanthin or even blood pressure lowering medicines out of this biomass offers value-adding (e.g., Muñoz et al. 2018; Marealis, 2022; Feldts, 2022). Shrimp industry (both wholesaler and processor) see great value in increased utilization of these side streams to add value to shrimp production, and thus cut costs for shrimps, and are active in facilitation of finding markets. Potential uses of process water generated during boiling and peeling of shrimp has also been investigated. It contains on average 14.8 g/L protein and 2.2 g/L total fatty acids, including components such as eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and astaxanthin (Forghani et al., 2021). All attempts to utilize more of the side streams generated have the potential to reduce GHG emissions of the shrimp product but require further investigation on to which extent and identification of viable business models.

Peeling by hand closer to fishery and/or market would decrease emissions because a higher yield may be achieved and contribution to GHG emissions from transports would decrease. However, also peeling by machine closer to market offers GHG emission reduction potentials (see chapter 4.1.2).

4.3 Limitations for structural improvements in GHG emissions

The spawning stock biomass of Northern shrimp in the Skagerrak has been low since a dramatic drop in the late 2000s (ICES 2021). Shrimp stocks show in general variability over time in abundance and are affected by e.g. predation. Shrimp abundance affects the catch per unit effort that may be achieved and sets an important limit to improvements enabled in shrimp fisheries, since the fishing phase is the driver of GHG emissions in the full value chain of shrimp.

What happens in the continued fishery management affects structural improvements of the value chain based on Northern shrimp from the Skagerrak. A decrease in GHG emissions from the Northern shrimp fishery the Skagerrak may be achieved by enforcing the current regulation, where the discard of small shrimp is violating EU CFP legislation. The practise has however continued due to a combination of economic incentives for the fisherman (high price for larger size fraction due to current market structure and consumer demand) and fleet structures in Norway and Sweden (many small vessels and quota is limited). According to one wholesaler, the share of smaller shrimp in the catch has however decreased due to use of more selective gears that can reduce this share of the catch. Other fishery regulations may also cause trade-offs between GHG emissions and mitigation of ecological pressures, i.e. species-selective shrimp trawling. Selective fishing practices are vital to eliminate unwanted by-catch of vulnerable and/or quota-restricted species, such as Atlantic cod *Gadus morhua* and elasmobranchs. When catch efficiency is lowered of a fuel intensive fishing practice such as demersal trawling, the lower catch per unit effort equates to higher fuel use per kilo landing (Ziegler & Hornborg, 2014).

There may also be national rules or regulations affecting the value chain structure. In Greenland, it is mandatory to land minimum 25 % of the total catch for on-land processing (Royal Greenland, 2022). As seen in chapter 4.1.3, boiling on land may decrease GHG emissions, particularly if renewable energy sources are used. Fishing vessels may however use other energy sources for boiling onboard (natural gas), but it is unknown to which extent.

Cutting refrigerated road transport may decrease GHG emissions of shrimp products, but processing facilities where shrimps are peeled by hand are few. According to one wholesaler, costs and availability of work force is a limiting factor.

To this end, there are several GHG emission reduction opportunities, but arguably, fuel efficiencies enabled during the fishing phase offers the main improvement potentials given the large variability in fuel use intensity of the fishery.

5 Reducing GHG emissions by technical means

5.1 Trends in technological evolutions and industrial strategies

Peeling shrimp by machine results in lower yield than by hand but offers less risk for contamination (Dang et al., 2018). For the Northern shrimp value chain in Sweden, peeling by hand used to be more common. Döring et al. (2021) however reports that with the introduction of strict hygienic rules for the peeling of shrimp by hand, actors active in the shrimp processing industry has decreased. For the Northern shrimp value chain, the development has been towards machine peeling. For another cold-water shrimp in the EU, Common shrimp *Crangon crangon* caught in the North Sea, processing of the main volume was instead outsourced to few companies in Morocco. When covid-19 restrictions were enforced, this led to a substantial bottle neck in shrimp peeling capacity, forcing fisheries to stay in port because they could not sell their catches. Experience from the pandemic thus shows that the hand-peeling sector is not very resilient to crisis, which arguably also holds for potential effects driven directly or indirectly by climate change. As a result of the covid-19 pandemic, alternatives to peeling abroad are being explored for Common shrimp, especially mechanical peeling. In Sweden, shrimp processing industry (only mechanical peeling exists) report that availability of raw material is low; they can only process shrimp two days a week but have the capacity to process more.

Companies in the northern shrimp value chains support research and development of trawling methods with less impact on the seabed and reduced fuel consumption (see e.g. Royal Greenland, 2022). They also have sustainability policies related to GHG emissions reduction targets; for the Northern shrimp value chain they have an ambition to reduce GHG emissions with 25 % by 2030 compared to 2018. In Sweden, companies have internal environmental and quality policies which contribute to reduced environmental impacts. For example, there are objectives to decrease water and energy consumption, as well as continuously work with improvements and follow up on progress (Bua shellfish, 2022). They could also publish sustainability reports and calculate GHG emissions of their products (Orkla, 2022). According to interview with one wholesaler in Sweden, estimating GHG emissions is seen as important to keep track of the environmental performance. It is however also driven by increased consumer awareness and the fact that economy and many important drivers for GHG emissions (e.g., energy use, load factor of transports) goes hand in hand. The shrimp processer reports that their internal environmental policies are part of the required quality polices and standards; yet, the company wants to actively work with environmental improvements independently of those driven by various market actors. They report that they are continuously looking at possibilities to switch to green energy sources, such as investigating options for solar panels on roofs and charging stations for electrical cars and reduce energy consumption.

5.2 New processing and logistic techniques and their challenges

The largest gains in reducing GHG emissions for the Swedish Northern shrimp value chain is achieving fuel efficient fisheries, a common insight from literature (Winther et al., 2020) and stakeholder input (both wholesaler and processor). Demersal trawling is the main catch method, but there have also been attempts with creel-fishing for Northern shrimp in Canada. This fishery has been shown to have the potential to reduce GHG emissions from fishing even further – estimated GHG emissions during the fishing phase at 0.46 kg CO_2e/kg LW shrimp (Mann, 2018). In sourcing the most efficient fisheries, current trade agreements and tariffs for non-EU fisheries (affecting sourcing of Northern shrimp fisheries from Norway, Greenland and Canada) are seen as the main challenges from a wholesale perspective.

Postharvest reduction potentials include fuller utilisation of shrimp catches and peeling by hand instead of machine, but according to one wholesaler in Sweden, major obstacles include cost and availability of workforce. The processor reports that the machines used for peeling could possibly be exchanged for newer ones using less water and energy, but the current availability of shrimp raw material (only enough for processing two days a week) hinders opportunities and interest in investment. They are however looking at using alternative packaging material to reduce the amount of plastics used, but finding suitable alternatives is challenging, and it is vital that there are options that are re-usable due to market requirements.

6 Conclusions

- Actors in the value chain experience a lot of uncertainties indirectly or directly related to climate change, mainly related to fisheries (availability and cost of raw material) but also increasing PH costs that are expected to further increase as an indirect effect of climate change.
- The GHG emission contribution from PH value chain of northern shrimp in Sweden is small, although highly variable, compared to the contribution from fisheries.
- Sourcing raw material from the most efficient fisheries is most important action for overall GHG emissions reduction of the product but may be hindered by current trade agreements and tariffs.
- Concentration of EU processing facilities in shrimp value chains negatively affects GHGs due to increased transporting distances.
- Peeling by hand offers opportunities for higher edible yield but cost and availability of work force in the EU for processing by hand are limiting factors.
- Processing industry with machine peeling experience limitation in raw material and are subjected to high price competition with shrimp peeled by hand that are perceived to be of higher quality.
- Enforcement and control of EU CFP regulations in the Northern shrimp fisheries in divisions 3.a and 4.a east, and member state management actions related to national fleets, negatively affects GHG emissions of one of the fisheries supplying raw material.
- Having diversified markets (retail, HORECA, public kitchens) adds to resilience if there is a disruption in the supply chain (supply or demand).
- Available statistics are insufficient in allowing for detailed mapping of Northern shrimp value chains.

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CASE STUDY 17: INVERTEBRATES – NEPHROPS (*NEPHROPS NORVEGICUS*) – IRELAND

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Michael Keatinge

LIST OF ABBREVIATIONS

Term	Description
BIM	Bord Iasciagh Mhara
KFO	Killybegs Fisherman's Organisation
IFPO	Irish Fish Producers Organisation
IFPEA	Irish Fish Processors & Exporters Association
ISWFPO	Irish South & West Fish Producers Organisation
ISEFPO	Irish South & East Fish Producers Organisation

1. General Introduction

This CS analyses the Nephrops (*Nephrops norvegicus*) PH value chain within Ireland. Although Nephrops represent just 3 % by volume of Ireland's recent quotas, this species has a landed value within Ireland of EUR35 million (data from 2020) and accounts for 32 % of the country's fishery total value. Nephrops are exploited by vessels in the demersal segment of the national fleet and landed at all of Ireland's major fishing ports. Nephrops are primarily handled by the major fisheries co-ops and independent processors that, collectively, represent a major PH value chain accounting for significant local added value, employment etc.

1.1 The importance of Nephrops to Ireland's polyvalent fleet.

With a quota of 5,842 tonnes (data from 2022), valued at EUR49.7 million (first point of sale), Nephrops is the most valuable species targeted by Ireland's polyvalent fleet. This species accounts for 41.6 % of the total value (EUR) and 17.4 % of the volume (tonnes) of the Irish fishery, and are three times the value of the next most important demersal species (Table 1).

Table 1. Main stocks (quota by value) fished by Ireland, 2021.

Rank (€)	Species	Case Study	Stocks	Value	Share	Volume	Share
1	Atlantic Mackerel	Case Study 5	1	€71.5	68%	54,994	44%
6	Northern Albacore	Case Study 21	1	€9.9	9%	3,244	3%
7	Horse Mackerel	Case Study 5	2	€9.5	9%	15,963	13%
8	Blue Whiting	Case Study 2	1	€7.7	7%	28,444	23%
11	Atlantic Herring	Case Study 5	5	€3.4	3%	6,272	5%
12	Boarfish	Case Study 2	1	€3.1	3%	15,748	13%
	Total		**11**	**€105.1**	**100%**	**124,665**	**100%**

Rank (€)	Species	Case Study	Stocks	Value	Share	Volume	Share
2	Norway lobster	Case Study 17	2	€49.7	42%	5,842	17%
3	Anglerfish		2	€16.6	14%	3,416	10%
4	Megrim		2	€11.0	9%	3,455	10%
5	Haddock		4	€10.6	9%	5,157	15%
9	Hake		1	€7.3	6%	2,383	7%
10	Whiting		3	€7.0	6%	4,807	14%
13	Plaice		5	€3.1	3%	1,578	5%
14	Common Sole		5	€2.9	2%	313	1%
15	Cod		5	€2.8	2%	837	3%
16	Saithe		2	€2.8	2%	1,757	5%
	Other Demersal		19	€5.8	5%	4,102	12%

	Total		**50**	**€119.6**	**100%**	**33,647**	**100%**

1.2 History of the Ireland's prawn fishery.

The name Nephrops (termed locally as Dublin Bay prawn) likely came about because it was in Dublin that these animals were first regularly landed. Taken as a bycatch by trawlers fishing whitefish in the northern Irish sea, the crew often sold the bite-sized '*lobsters'* to street vendors to make extra cash. As part of the *unofficial* catch, prawns were often offloaded in Dublin Bay before the fishing boats went on to land their official catch at Howth, Skerries, Clogherhead or one of the other ports on Ireland's east coast.

If the unofficial Dublin Bay market gave the prawn commercial value, it was the advent of 'scampi'[39] in the 1950's that marked its arrival on seafood menus. Covered in breadcrumbs, deep fried, and served with tartare sauce and chips, for the next 30 years 'scampi' vied with prawn cocktail as the primary use of this species. Indeed, production soon became so focussed on the tail, with the rest of the animal usually discarded, that catch limitations soon became necessary. While some relief was afforded to local stocks through the use of imported substitutes for scampi production, UK food labelling laws now insist that any product called scampi is made only from '*Nephrops norvegicus'*[40].

Today Ireland's prawn quota is taken by approximately 100 – 120 vessels in the polyvalent fleet. Of these, 65 to 70 are fitted with onboard freezing facilities and must seek approval as an establishment subject to i) Regulation (EC) No 852/2004 on the hygiene of foodstuff; ii) Regulation (EC) 853/2004 laying down specific hygiene rules for food of animal origin; and iii) national statutory instrument, S.I.22 of 2020, which gives effect to the European Union (Food and Feed Hygiene) Regulations. Successful applicants are deemed to be freezer vessels and carry extra crew to undertake the additional work involved in freezing at sea. More importantly, in the context of this study, the PH value chain starts onboard these vessels, with frozen-at-sea prawns receiving between 150 % and 300 % the price paid to boats without onboard freezing facilities.

Along with their onboard freezing capabilities most Nephrops boats are also vertically integrated with one of a number of fishermen's cooperatives. These handle the catch from landing to final export and undertake, as necessary, additional washing, grading, packaging and storage. They also handle sales and organise group transport to Ireland's key export markets in the UK, Italy, France and Spain.

The most important of the fishermen's cooperatives are based at Clogherhead on Ireland's east coast and close to the Irish Sea Nephrops grounds; at Castletownbere in the south west and ideally located to handle catch from the porcupine bank, the Labadie and Jones bank in the Celtic Sea as well as the Smalls Grounds in the eastern Celtic Sea; at Ros an Mhíl on Ireland's west coast and close to the Aran grounds; and at Greencastle on the North coast where Nephrops from ICES area 6 are landed. In addition to the fishermen's cooperatives, about 10 to 20 % of the catch is processed by (20+) independent processors, strategically located at or close to all of the traditional Nephrops landing ports.

An unusual feature of the Nephrops value chain is the near lack of a home market. Currently Ireland exports the bulk of its catch to Italy, France and Spain, or, in the case of tails, to the UK for scampi. In 2021, for example, Irish vessels landed 6,400 tonnes of Nephrops valued at EUR53 million, but exported 5,100 tonnes valued at EUR60 million.

[39] The term '*scampi*' originates from Italy and means peeled prawn tail – not necessarily breaded.

[40] The Fish Labelling (England) Regulations 2010 (legislation.gov.uk)

That said, the domestic market for prawns in Ireland is considerable, and retails sales reached EUR28 million in 2021 with further sales of EUR40 million in the food services sector. These are however, predominantly imported prawns. For example, in 2021 Ireland's processors imported 5,100 tonnes of shrimp and prawn. These included large quantities of king prawn (*Litopenaeus vannamei*), whiteleg shrimp (*Penaeus vannamei*), pink shrimp (*Metapenaeus monoceros*), and Argentine red shrimp (*Pleoticus muelleri)* which are all readily available on the Irish retail market and used commonly in food services.

1.3 The Resource

Nephrops are currently fished in eight management units with an average TAC of 72,457 tonnes over the period 2014 – 2020. Prior to Brexit, the EU enjoyed sole access to these stocks. However, as the UK had quotas totalling 53.9 % of the entire EU share, Brexit has had a significant impact on both the fisheries and the PH trade with the EU. Not only will the UK continue to be allocated its traditional 53.9 % share of the total *Nephrops* TAC, under the terms of the Brexit Trade and Cooperation Agreement (TCA) the UK's share of the ICES area 7 stock (NEP/07) will increase from 32.8 % prior to Brexit, to 42 % post Brexit phased in over the period to 2025. Apart from the UK and Ireland, 8 other EU member states enjoy quotas for this species, including Denmark with 13 % (average 2014 – 2020), France (12.8 %) and Sweden (3.8 %).

Table 2: Nephrops Management units and TAC 2014 - 2020

Management Area	Average	TAC 2020	TAC 2019	TAC 2018	TAC 2017	TAC 2016	TAC 2015	TAC 2014
NEP/03A	10,465	13,733	13,733	11,738	12,715	11,001	5,318	5,019
NEP/2AC4-C	19,528	23,002	22,103	24,518	20,034	13,700	17,843	15,499
NEP/04-N	714	600	600	800	1,000	1,000	1,000	0
NEP/5BC6	15,075	15,899	15,092	12,129	16,407	16,524	14,190	15,287
NEP/07	22,429	16,815	19,784	29,091	25,356	23,348	21,619	20,989
NEP/8ABDE	3,891	3,886	3,878	3,614	4,160	3,899	3,899	3,899
NEP/08C	26	3	3	0	0	48	60	67
NEP/9/3411	328	386	401	381	336	320	254	221
Total	72,457	74,324	75,594	82,271	80,008	69,840	64,183	60,981

1.4 Irish Nephrops fisheries

Ireland has interests in two Nephrops fisheries; the ICES area 7 stock (NEP/07) and the West of Scotland stock (NEP/5BC6), and over the period 2014 – 2020 was allocated 54.9 % of the total EU_{27} share of these stocks. This was equivalent to 25.6 % of the EU_{27} share of all Nephrops stocks, Table 6, or 11.7 % of the TAC.

While boats have traditionally fished with bottom trawls using either single or twin (x2), in recent years a considerable number of larger vessels in the Nephrops fleet have replaced twin-rigs with quad-rigs (x4). The benefits of multi-rig compared to single-rig trawls include reduced drag due to smaller net size, improved catch rates of Nephrops and reduced bycatch of fish species such as cod[41].

The number of boats fishing Nephrops varies over time but currently runs to 100 – 120 vessels, of which 65 are equipped to freeze on board. Catches are predominantly (55 %) taken by medium sized vessels, 18 – 24 metres in length (overall), with a further 35 % taken by vessel 24 – 40 metres and the final 10 % by vessels under 18 metres, see Table 3 In addition, with just 69 polyvalent vessels in the 18 - 24 metres length class, and a further 63 in the 24 - 40 metres, approximately two-thirds of this fleet rely on Nephrops fishing as their primary source of income.

About 70 % of Ireland's Nephrops catch is taken by vessels under 24 metres in length (LOA) with the bulk, 57 %, taken by vessels between 18 – 24 metres in length and 30 % by vessels over 24 metres (LOA). Nephrops are landed at all of Ireland's whitefish ports with landings to Castletownbere (south-west), Howth (east and Ros an Mhil currently the largest at over one thousand tonnes each.

Table 3 Nephrops fishery undertaken within the polyvalent fleet

Polyvalent Vessels	Number of Vessels	Average length (m)	Total Capacity of segment (GT)	Average Capacity (GT)	Total Engine Power of Segment (kW)	Average Engine Power (kW)
VL0012	1,171	7	4,259	4	33,460	29
VL1218	79	14	2,884	37	11,154	141
VL1824	69	22	9,709	141	26,367	382
VL2440	63	27	14,576	231	34,059	541

2. Value Chain

Based on the data provided by BIM (Business of Seafood[42]), approximately 90 % of Nephrops landings are handled by the principal fisherman's co-ops, located at Clogherhead, Castletownbere, Ros an Mhíl, and Greencastle, with the balance going to the processing sector. Retail sales of Nephrops amounted to EUR28 million of which Nephrops contributed 820 tonnes (landings minus exports minus storage) valued at EUR10 million, while exports of Nephrops amounted to 1,400 tonnes (EUR19 million, data in 2021). Given retail sales of Nephrops of EUR18 million and assuming a constant profit margin, then the volume of Nephrops at retail was approximately 1,326 tonnes. The balance of 2,374 tonnes, valued at EUR32 million represents the food service component.

3. Employment

The Irish Nephrops fishery is unusual insofar as onboard freezing has become a standard approach to adding value for some 60 – 65 vessels in the polyvalent fleet. It means that the PH value chain begins on the vessel at sea in much the same way it does on a factory boat. Based on discussions with vessel owners it is reasonable to assume an additional 2 jobs per vessel, over and above the normal crew. These direct jobs are in addition to the

[41] BIM: Catch comparison of Quad and Twin-rig trawls in the Celtic Sea Nephrops fishery. 3285 BIM Quad V Twin rig trial report.indd

[42] BIM-Seafood-Business-2021.pdf

employees of the Fisherman's Co-ops located at Clogherhead, Castletownbere, Ros an Mhíl, and Greencastle to give a total of 195 direct full time equivalent jobs.

An alternative approach to estimating the number of direct FTEs uses the total direct employment in processing estimated by BIM and Oxford Economics for the entire country, scaled to the known value of the pelagic fisheries within Ireland, minus the jobs associated with all pelagic landings.

Indirect jobs in this value chain comprise those employed onboard whose employment is directly related to sales of Nephrops. These are estimated, as above, by scaling the values in the BIM-Oxford Economics, and the same is then done of induced employment.

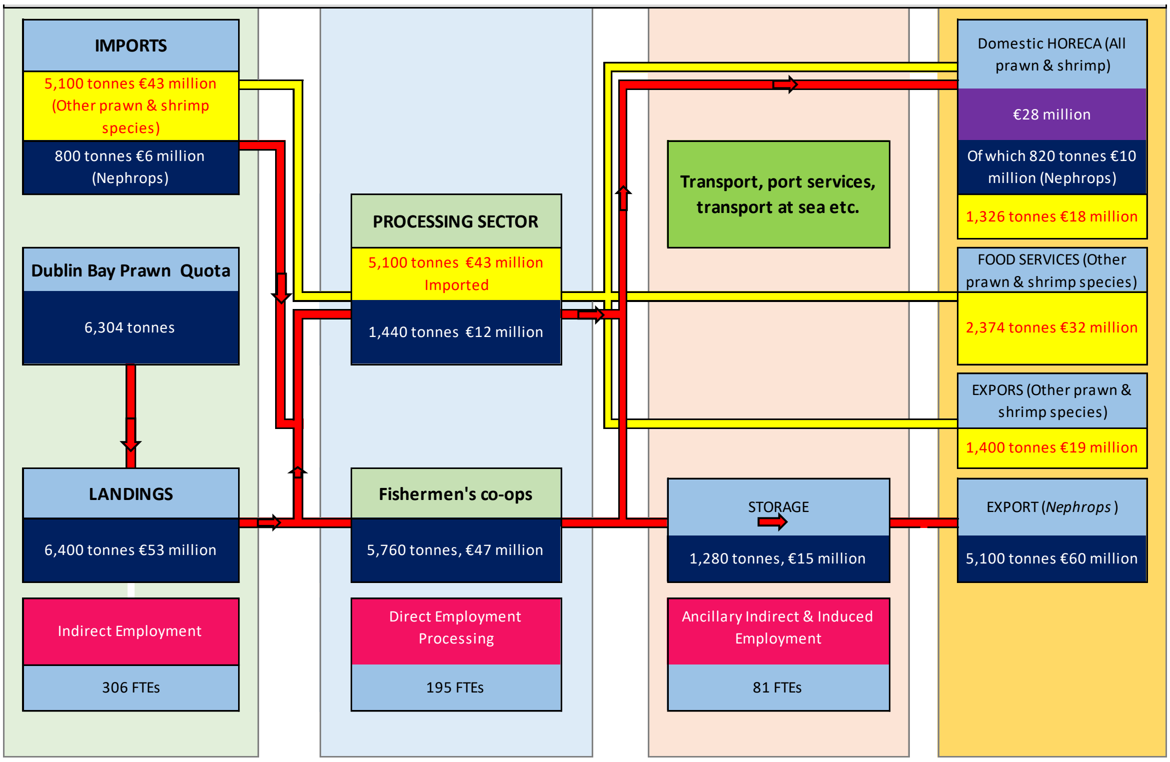

Figure 3 Prawn postharvest value chain, Ireland.

4. Quantifying the business structure of the processing sector.

Polyvalent vessels operating within the fisherman's co-op PH value chain (approximately 90 % of sales) typically pay the co-op approximately 6 % of the sale price to cover all expenses except transport. These charges are summarised below, with labour costs (65 %) representing the single biggest expense category (Table 4).

Table 4. Typical postharvest value chain cost structure

2021	Cost
Labour costs	65.0 %
Energy	7.5 %
Water & other charges	7.5 %
Packaging	4.5 %
Labelling & Traceability	4.5 %
Repairs & Maintenance	2.5 %
Banking	3.0 %
Insurance	3.0 %
Subscriptions	2.5 %

5. Conclusions

The model developed in this CS links Irish quotas, the national polyvalent fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the employment, GVA, wage bill etc of the PH value chain. It highlights, in particular, how the fleet has adapted to the changing demands of a market by developing an extensive fleet equipped to undertake onboard freezing at sea. This innovation, and the additional (onboard, at sea, PH) employment opportunities it presents, demonstrate how the polyvalent fleet has adapted to increasing water temperature, created greater onboard added value, maintained the links with shore-based fishermen's cooperatives and increased its resilience to changes in the supply of this important species.

CASE STUDY 18: INVERTEBRATES - IMPORTED SHRIMPS (PENAEUS SPP.)

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Alexander Wever, AWF Consulting

LIST OF ABBREVIATIONS

Term	Description
BT	Black Tiger Shrimp
EU 27	The 27 countries of the European Union
GHG	Green House Gas
PS	Penaeus shrimps
RAS	Recirculated Aquaculture System
VS	Vannamei Shrimp

1 Background

This CS focuses on imported frozen shrimps of the species Whiteleg shrimp (*Litopenaeus vannamei*) and Black (Giant) Tiger prawns (*Penaeus monodon*), together the most important species in the shrimp genus Penaeus, which are caught and farmed and often first processed in Asian and Latin American countries.

The outcomes are based on about 10 interviews with companies/stakeholders in the PH sector for Penaeus shrimps and on expert judgement. The interview partners include Penaeus shrimp importers and traders, seafood wholesalers, shrimp salad producers, shrimp suppliers to retail, retail chains, fishmongers and seafood journalists with operations in Germany, The Netherlands, Denmark and France.

“Tropical” middle and large sized shrimps, most of them farmed, are a globally traded seafood commodity and have – very often – been transported very long distances as frozen products between the farming or catching area and their final point of use, sometimes even just for processing in Asia after being caught in the Southwest Atlantic. As Europe has only very small volumes of large sized shrimps in the Mediterranean Sea, most of these products, in total almost 400.000 tons per year, are imported from overseas.

1.1 Species description

Vannamei Shrimp (*Litopenaeus vannamei*) aka White Leg shrimp, White Tiger Shrimp

The white leg shrimp is the most important crustacean in aquaculture. It is a tropical marine shrimp and is mainly produced in Asia and Latin America. All shrimps (also called prawns) belong to the very species-rich group of decapods (Decapoda). This group can in turn be divided into the cold-water shrimp (400 species) and the warm-water shrimp (1600 species). Only the warm-water species are relevant for aquaculture, as they grow much faster than their cold-water counterparts.

Black Tiger Shrimp (Penaeus monodon) aka Giant Tiger prawn

(Source: FAO Fisheries:) The Black Tiger Prawn inhabits the coasts of Australia, South East Asia, South Asia and East Africa. Dependant on substratum, feed and water turbidity, body colours vary from green, brown, red, grey, blue and transverse band colours on abdomen and carapace are alternated between blue or black and yellow. Adults may reach 33 cm in length and females are commonly larger than males.

1.2 Penaeus Shrimp Aquaculture

Currently, shrimp are produced in many countries worldwide. Almost all the main producers are in the Asian region, including China, Indonesia, Vietnam, India and Thailand (FAO 2021). These five countries alone produced over 75 % of the world's white-leg shrimp in 2019. Another important producing country is Ecuador, with about 12,5 % of total production.

Whereas in 1991 about 1 million tonnes of shrimp from aquaculture were marketed worldwide, in 2019 this figure had already risen to more than 6 million tonnes - and the trend is still rising (FAO, 2021). While in the 1990s mostly P. monodon was produced in aquaculture, this has now shifted in favour of L. vannamei (5,446,216 t in 2019), as disease-resistant lines are currently available for these species through selective breeding and in addition they can be obtained from aquaculture throughout the year.

Shrimp farming of BT has been practiced for more than a century for food and the livelihood of coastal people in some Asian countries, such as Indonesia, the Philippines, Taiwan Province of China, Thailand and Vietnam. Penaeus monodon was originally harvested together with other shrimp species from traditional trapping-growing ponds or as a significant by-product of extensive milkfish ponds. Later, the culture of this species spread throughout southeast and south Asia, as it can grow-up to a large size (40-60 g) with high value and demand in the international market. The introduction or importation of wild broodstock is commonly practiced among the major producing countries because local supplies are insufficient and domestication technology has not yet been commercially developed.

Over 770,000 t (FAO, 2021) of black tiger prawns are produced annually. This shrimp species is one of the most important crustaceans in aquaculture.

Shrimp aquaculture is almost exclusively carried out in extensive, semi-intensive or intensive pond systems. The production of shrimp in intensive recirculation systems is currently still a niche market, even though there are more and more such enterprises in Europe. The different types of management are defined, among other things, by stocking densities, feeding management and daily water exchange rates.

1.3 Importance of Penaeus shrimps for EU postharvest sector

Between 2015–2020, the EU 27 countries (EU27) imported on average nearly 254.000 tonnes of Penaeus shrimps (PS) products per year[43] from outside EU (EU Extra imports) with a value of more than 1,8 billion Euros on import price level. The most important countries of origin are in Southeast Asia (for example India, Bangladesh, Vietnam, Indonesia, Thailand) or Latin America (for example Ecuador, Peru, Venezuela). When these imported shrimps reach the consumer plates after a long journey through the Indian Ocean or the Atlantic Ocean and several trade steps, they represent a value of far more than 5 billion Euros.

Frozen PS are directly imported (EU Extra Imports) by all EU 27 countries, most of them also importing PS from other EU countries. The leaders in import from outside EU are France, Spain, the Netherlands and Belgium, the four together representing almost 75 % of the import value. Almost all EU 27 countries also import and export PS inside EU, which makes frozen PS probably one of the most traded seafood products in the EU. A value adding of PS products in the form of processing (cooking, brining, putting in salads) takes place in many EU countries, even though by far the most processing is already done in the countries of origin where labour costs are much lower than in the EU.[44]

Larger sized imported tropical shrimps such as PS (but also others) are found in almost all PH sectors in almost all EU countries what makes them a very important seafood category.

Before analysing the PH sector, some uncomfortable truths need to be shared:

- Most of the EU shrimp consumers (95 % or more) do not have any deeper knowledge about the product that they are buying and eating. People do not know the difference between a Vannamei shrimp, a Black Tiger shrimp, an Argentinian Red shrimp or a Rosenberg shrimp. They buy what the retailer or HORECA is offering, do not read any information on the packaging but believe in the brand or retail private labels, both often with a sustainability certification. Therefore, the shrimp's origin does not matter

[43] Eurostat-No. 0306 1792

[44] The processing (cooking) of shrimps to "Crevettes roses" that uses beside other shrimps also VS and BT is regarded in case study number 19.

for the consumer – as long as there are no negative campaigns by NGOs against certain origins.

- The knowledge level of many responsible purchase managers in retail chain head offices is not much better. Also, for them it is a matter of value-for-money, secure margins and avoiding risks to be blamed by unfriendly NGOs which do not like shrimp farming in general. Therefore, the shrimp's species or origin does not matter for the retail buyer – as long as there are no negative campaigns by NGOs against certain origins.
- When it comes to the wholesale that supplies the foodservice, the choice of bigger sized shrimps is very often just a matter of price. Restaurant chefs focus on kg prices and often do not compare glazing levels, count issues or added ingredients into the shrimps. Over the last years this has become a little bit better but still a very low price is very attractive to restaurants.
- Usually, both retailers and wholesalers do not source in the shrimp origin but buy from specialized importers in their country or the neighbouring countries. It is those specialized importers who make the origin decision which is usually driven by arguments as price, value for money, save margin and convenience ("Why changing something that works quite well…?") and climate-change-related issues such as GHG emissions was not in their focus until now.

By regarding the trade flows (Table 1-4), it becomes obvious that the role of PS for an EU country can be very different in the PH sector. There are powerful trading countries such as Belgium and the Netherlands, where over 75 % of the imports are later exported; there are pure import countries mainly in eastern Europe that have almost no exports; and there are many countries that import most of their domestic demands but also have some exports, also related to supply cruising ships. France and Spain are by far the biggest markets for PS in Europe.

Table 1: Average Import (EU Extra Imports) Value of different shrimps in the Eurostat System 0306 1791 – 1799. Source Eurostat. In yellow, the frozen Penaeus shrimps.

- EU Extra Imports: EU country importing from a country outside EU
- EU Intra Import: EU country importing from a country inside EU
- EU Extra Export: EU country exporting to a country outside EU
- EU Intra Export: EU country exporting to another EU country

Source Eurostat	0306 1791	0306 1792	0306 1793	0306 1794	0306 1799
VALUE	Frozen deepwater rose shrimps "Parapenaeus longirostris	Frozen Penaeus Shrimps / Tiger Shrimps	Pandalidae shrimps exc. Pandalus / Deep Sea Shrimp	Crangon shrimps, exc. Crangon crangon	Other frozen shrimps/prawns exc. 0306 -1791, 1792,193, 1794
Country	Average in € 2015-2020	Average in € 2015-2020	Average in € 2015-2020	Average in € 2015-2020	Average in € 2015-2020
EU 27	**72.046.639 €**	**1.808.215.567 €**	**3.329.830 €**	**418.485 €**	**810.754.790 €**
Belgium	21.395 €	218.270.117 €	75.717 €	2.233 €	43.353.459 €
Bulgaria	0 €	159.347 €	0 €	0 €	17.343 €
Czechia	0 €	3.944.050 €	0 €	0 €	522.901 €
Denmark	1.681 €	27.286.614 €	566.012 €	0 €	2.425.177 €
Germany	4.969 €	143.091.260 €	75.571 €	0 €	15.268.025 €
Estonia	0 €	129.910 €	0 €	0 €	0 €
Ireland	96.464 €	7.418.199 €	2.249.733 €	251.191 €	2.607.351 €
Spain	61.613.795 €	396.232.781 €	103.012 €	13.991 €	437.720.476 €
France	1.814.220 €	475.092.865 €	46.476 €	0 €	42.301.852 €
Croatia	41.890 €	30.873 €	0 €	0 €	1.178.603 €
Italy	5.725.925 €	174.801.176 €	25.460 €	0 €	157.022.558 €
Cyprus	0 €	5.842.342 €	0 €	0 €	287.209 €
Latvia	7.055 €	346.184 €	0 €	0 €	138 €
Lithuania	299 €	556.949 €	0 €	0 €	92.571 €
Luxembourg	1.115 €	14.953 €	9.993 €	22.823 €	258.028 €
Hungary	0 €	270.001 €	0 €	0 €	81.642 €
Malta	0 €	177.492 €	0 €	0 €	326.827 €
Netherlands	521.759 €	264.334.181 €	153.352 €	120.769 €	52.009.875 €
Austria	2.804 €	953.754 €	12.557 €	0 €	1.139.352 €
Poland	0 €	12.841.754 €	5.448 €	0 €	2.355.742 €
Portugal	2.124.261 €	51.870.637 €	0 €	85 €	35.623.310 €
Romania	0 €	980.990 €	0 €	0 €	36.634 €
Slovenia	0 €	30.616 €	0 €	0 €	567.875 €
Slovakia	0 €	10.554 €	0 €	0 €	75.097 €
Finland	0 €	104.120 €	0 €	0 €	1 €
Sweden	3.919 €	7.423.991 €	6.500 €	7.393 €	515.688 €
Greece	65.088 €	15.999.857 €	0 €	0 €	14.967.058 €

Table 2: Average Import (EU Extra Imports) Volume of different shrimps in the Eurostat System: 0306 1791 – 1799. Source Eurostat. In yellow, the frozen Penaeus shrimps.

Source Eurostat	0306 1791	0306 1792	0306 1793	0306 1794	0306 1799
VOLUME	Frozen deepwater rose shrimps "Parapenaeus longirostris	Frozen Penaeus Shrimps / Tiger Shrimps	Pandalidae shrimps exc. Pandalus / Deep Sea Shrimp	Crangon shrimps, exc. Crangon crangon	Other frozen shrimps/prawns exc. 0306-1791, 1792,193, 1794
Country	Average in tons 2015-2020	Average in tons 2015-2020	Average in tons 2015-2020	Average in tons 2015-2020	Average in tons 2015-2020
EU 27	**8.543**	**253.873**	**449**	**45**	**131.027**
Belgium	4	23.412	10	0	7.448
Bulgaria	0	41	0	0	13
Czechia	0	888	0	0	81
Denmark	0	3.329	115	0	309
Germany	1	15.611	6	0	1.683
Estonia	0	16	0	0	0
Ireland	11	888	268	28	309
Spain	6.983	67.274	12	1	69.738
France	204	69.291	5	0	6.638
Croatia	6	5	0	0	316
Italy	831	27.540	3	0	24.890
Cyprus	0	749	0	0	51
Latvia	1	45	0	0	0
Lithuania	0	79	0	0	15
Luxembourg	0	1	1	2	25
Hungary	0	36	0	0	11
Malta	0	36	0	0	57
Netherlands	145	31.566	25	12	10.015
Austria	0	124	2	0	159
Poland	0	1.809	1	0	384
Portugal	340	7.529	0	0	5.960
Romania	0	171	0	0	7
Slovenia	0	4	0	0	120
Slovakia	0	4	0	0	23
Finland	0	12	0	0	0
Sweden	0	816	0	1	61
Greece	15	2.599	0	0	2.713

Table 3: Average Trade Flows for Penaeus shrimps (EU-No. 0306 1792) per EU country, Value in Euros. Source Eurostat.

	EU Extra Imports	EU Intra Imports	EU Extra Exports	EU Intra Exports		
	0306 1792	0306 1792	0306 1792	0306 1792	0306 1792	0306 1792
VALUE	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps
Country	Average in € 2015-2020	Average in € 2015-2020	Average in € 2015-2020	Average in € 2015-2020	Average annual **Trade Value** on Import/Export Level in Euro	Average annual "Shrimp Balance" per country: Imports - Exports in Euro
EU 27	**1.808.215.567 €**	**440.362.724 €**	**42.680.708 €**	**653.618.770 €**	**2.944.877.767 €**	
Belgium	218.270.117 €	28.446.539 €	5.709.768 €	163.752.675 €	416.179.099 €	77.254.214 €
Bulgaria	159.347 €	1.198.110 €	0 €	37.485 €	1.394.942 €	1.319.972 €
Czechia	3.944.050 €	2.893.868 €	0 €	2.657.033 €	9.494.951 €	4.180.885 €
Denmark	27.286.614 €	7.174.581 €	3.283.939 €	33.888.072 €	71.633.205 €	-2.710.816 €
Germany	143.091.260 €	104.255.799 €	6.640.158 €	64.655.812 €	318.643.029 €	176.051.089 €
Estonia	129.910 €	1.433.920 €	416.031 €	316.449 €	2.296.310 €	831.350 €
Ireland	7.418.199 €	1.558.914 €	243.117 €	263.321 €	9.483.550 €	8.470.675 €
Spain	396.232.781 €	37.413.565 €	7.020.254 €	118.328.215 €	558.994.815 €	308.297.878 €
France	475.092.865 €	107.602.658 €	9.210.081 €	59.047.103 €	650.952.707 €	514.438.339 €
Croatia	30.873 €	644.485 €	37.327 €	95.797 €	808.482 €	542.234 €
Italy	174.801.176 €	21.837.804 €	655.079 €	7.496.603 €	204.790.662 €	188.487.299 €
Cyprus	5.842.342 €	1.231.328 €	0 €	26.907 €	7.100.577 €	7.046.764 €
Latvia	346.184 €	2.474.169 €	0 €	1.040.766 €	3.861.118 €	1.779.587 €
Lithuania	556.949 €	2.531.523 €	13.486 €	343.725 €	3.445.684 €	2.731.261 €
Luxembourg	14.953 €	3.471.090 €	4.062 €	182.251 €	3.672.356 €	3.299.729 €
Hungary	270.001 €	1.514.272 €	1.975 €	94.394 €	1.880.642 €	1.687.904 €
Malta	177.492 €	316.810 €	0 €	0 €	494.301 €	494.301 €
Netherlands	264.334.181 €	34.999.160 €	8.082.887 €	181.611.006 €	489.027.234 €	109.639.447 €
Austria	953.754 €	16.783.910 €	13.513 €	1.449.867 €	19.201.044 €	16.274.284 €
Poland	12.841.754 €	9.307.152 €	34.628 €	685.436 €	22.868.970 €	21.428.843 €
Portugal	51.870.637 €	32.717.934 €	987.696 €	14.474.697 €	100.050.964 €	69.126.177 €
Romania	980.990 €	5.059.640 €	143.010 €	682.357 €	6.865.996 €	5.215.263 €
Slovenia	30.616 €	694.101 €	47.824 €	346.255 €	1.118.797 €	330.638 €
Slovakia	10.554 €	277.388 €	0 €	104.812 €	392.754 €	183.131 €
Finland	104.120 €	3.365.785 €	67 €	12.151 €	3.482.123 €	3.457.687 €
Sweden	7.423.991 €	7.252.130 €	49.423 €	776.903 €	15.502.447 €	13.849.796 €
Greece	15.999.857 €	3.906.091 €	86.385 €	1.248.680 €	21.241.012 €	18.570.883 €

Table 4: Average Trade Flows for Penaeus shrimps (EU-No. 0306 1792) per EU country, Volume in tons. Source Eurostat.

	EU Extra Imports	EU Intra Imports	EU Extra Exports	EU Intra Exports		
	0306 1792	0306 1792	0306 1792	0306 1792	0306 1792	0306 1792
VOLUME	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps	Frozen Penaeus Shrimps / Tiger Shrimps
Country	Average in tons 2015-2020	Average in tons 2015-2020	Average in tons 2015-2020	Average in tons 2015-2020	Average annual **Trade Volumee** on Import/Export Level in tons	Average annual "Shrimp Balance" per country: Imports - Exports in tons
EU 27	**253.873**	**50.222**	**4.554**	**75.485**	**384.134**	
Belgium	23.412	2.925	621	18.397	45.355	7.319
Bulgaria	41	128	0	4	174	165
Czechia	888	344	0	310	1.542	922
Denmark	3.329	769	317	3.652	8.067	130
Germany	15.611	12.065	731	6.508	34.914	20.438
Estonia	16	169	125	62	372	-1
Ireland	888	193	21	24	1.125	1.036
Spain	67.274	4.359	848	15.815	88.296	54.970
France	69.291	12.535	788	7.002	89.616	74.036
Croatia	5	79	5	11	100	69
Italy	27.540	2.655	67	770	31.032	29.358
Cyprus	749	162	0	4	914	907
Latvia	45	307	0	119	471	233
Lithuania	79	344	2	40	465	381
Luxembourg	1	331	0	11	344	321
Hungary	36	167	0	12	215	191
Malta	36	38	0	0	74	74
Netherlands	31.566	3.750	848	20.463	56.627	14.005
Austria	124	1.523	1	168	1.816	1.478
Poland	1.809	990	4	79	2.881	2.717
Portugal	7.529	4.055	121	1.637	13.342	9.826
Romania	171	670	22	107	970	713
Slovenia	4	65	5	25	99	39
Slovakia	4	52	0	22	79	34
Finland	12	322	0	1	334	333
Sweden	816	814	7	77	1.714	1.545
Greece	2.599	409	22	169	3.198	2.818

2 Value Chain

2.1 Value chain description

The PH value chain for imported Penaeus shrimp is characterised by a multitude of trade stages and by a long sea freight transport of the frozen shrimp between the shrimp's origin in Southeast Asia and Latin America and its use in Europe.

Between landing in a European port and use in the food industry, gastronomy or a private household, there are several transports in trucks and several storage periods as a frozen product. The time periods here can vary from a few weeks (frozen product is thawed and processed into a chilled product with a shelf life of less than 30 days) to two years (product remains frozen and is stored).

For the vast majority of users, the exact species of shrimp used is of secondary importance; size of shrimp and price are the main selling points.

In principle, however, shrimp can only be substituted by other seafood products to a very limited extent; a permanent supply of product to the various trade levels is therefore indispensable for the functioning of the PH sector.

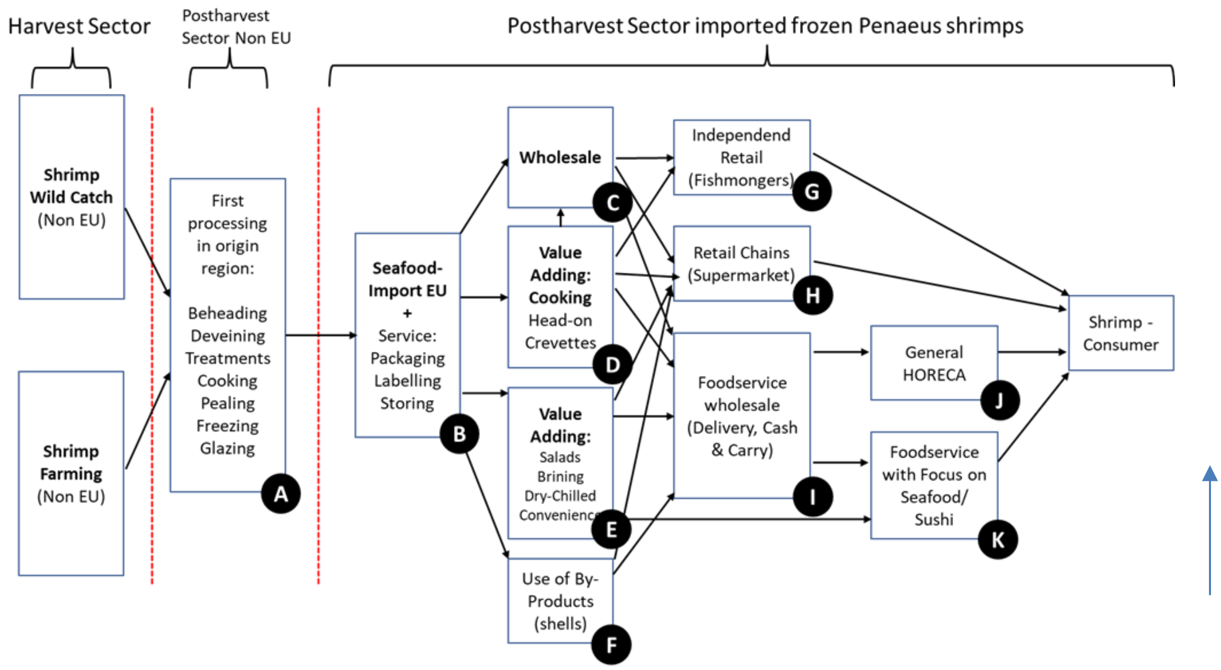

Figure 1. Postharvest value chain of imported Penaeus Shrimps (Source AWF Consulting)

<u>From Farm to Table</u>

In this section, all steps in the PH sector are described, from harvest to consumption (Figure 1).

Shrimp farm: Slaughtering, packing (Harvest sector)

Many shrimp farms are very small-scale family-run operations. There is usually only the slaughtering of the shrimps by using ice to kill the shrimps with a temperature shock. After the slaughtering, the shrimps with some crash ice to cool are brought to processing centers in the farm area where the shrimps are sorted in a first step before further processing.

A. First Processing in origin region

For PS most of the total processing takes places in highly specialized shrimp processing facilities in the farms area in Southeast Asia and Latin America. The shrimps are processed to frozen, internationally agreed, "shrimp commodity products", such as:

- Whole raw shrimp – usually in 1 kg blocks
- Raw shrimp tails – usually IQF (individually quick frozen)

But also, to more tailor-made convenience products by combining several processing steps:

- Heading
- Deveining (i.e. taking the gut out of the shrimp)
- Peeling
- Cutting the shell as "Easy peel" cut
- Blanching or cooking
- Putting on skewers
- "Enriching" the shrimps by adding water with phosphates (E 450 – 452)
- Breading

- Coating
- Glazing after freezing to prevent freezer burn
- Packing in Bulk (10–20 kg) or consumer packs following clients' specifications

B. Seafood Import EU

On the level of seafood import in the EU, there are usually specialists that globally source frozen seafood. PS are an important part of their business that includes also whitefish, Pacific Salmon, Scallops, etc.

They do the import from overseas that includes veterinary controls, customs clearing and correct labelling. Some of them work with service providers that can do also re-packing following special demands from clients.

Those importers work with frozen PS usually in two different ways. One way is to purchase standard PS products and selling them under their own brand or no-name labels to other wholesalers or fishmongers, typical sales volumes are mixed seafood pallets. Another way is to collect and process orders from retailers, industry brands or wholesalers for PS products with very detailed specifications that are sold as private labels. Those orders usually are at least a 40 ft Container containing 20 tonnes of PS; very often they work together with agents in the origin checking if specifications are met before shipping. The typical shelf life for frozen PS is 2 years.

These importers are usually based in seafood hubs that are connected to container ports as Rotterdam or Hamburg; most of them run their own frozen cold stores.

For picking up the containers and the transport to their wholesale and retail clients, the frozen PS products are moved in frozen trucks of different sizes.

C. Wholesale

Wholesale companies are more sales-orientated than the seafood import companies (B in Figure 1), but the transition between B and C is smooth. The import skills are less developed and usually their frozen storing capacities are smaller compared to B. They are located all over the country.

D. Value adding: cooking of the shrimps and selling as chilled product

This value adding sector is important in the PS (and other shrimps) PH sector in Southern European countries like France or Spain, where the product is sold loose as "Crevettes roses". The cooking of the raw whole shrimps takes place somewhere in the country of sale. This sector is discussed in the other "Imported shrimps" CS (CS21) and is mentioned here only very briefly.

E. Value adding: Salads, Brining, Dry-chilled convenience

PS shrimps are an important ingredient in many delicatessen products that are sold chilled (2–7°C) in retail and wholesale and that are produced by the food industry. This food industry purchases frozen products with very detailed specifications, thaws them and converts them to shrimp salads, Frutti-di-Mare, brines shrimps or "cocktail" shrimps. The industry usually uses already cooked and peeled shrimps what makes it different to the value adding in step D. The industry products are usually sold in small or medium transparent plastic jars in self-service shelves with a shelf life of 14–30 days. To give the clients a maximal shelf life, this industry produces after having received the order with small buffers.

F. Use of by-products: Shells

Shrimp shells are used as an ingredient for seafood or crustacean broads, crab butter or crab chips. In most cases there is a processing from the shells into a concentrate that takes place in the origin to avoid expensive shipping of low weights.

G. Independent Fishmongers

All over Europe there are still independent fishmongers, some of them in fish shops and others on weekly markets. Even though it is impossible to count the number of fish shops in the EU, it can be assumed that there are more than 30.000 units.

All fishmongers sell fresh PS as thawed raw whole shrimps or tails, but also cooked shrimps or seafood salads with shrimps, some of them self-made. The product in the counter is usually cooled with ice, often combined with an integrated active cooling of the counter. PS are not playing the dominating role at the fishmonger's assortment but are sold regularly and usually with a good margin.

Fishmongers buy their PS products together with their other seafood purchases from specialized seafood wholesalers, most of them located in seafood hubs. Depending on the distance of the fishmonger to the next seafood hub the decision is made whether to get the seafood delivered by the supplier or to pick it up at the seafood hub.

H. Retail chains

All retailers, no matter if supermarket or hard discount (e.g. storers like Aldi and Lidl) sell different PS products, some of them chilled and ready to eat, others frozen that need to be cooked before consumption. In addition, many of them also sell thawed PS, whole and tails, by individual weight over the service wet counter. In the seafood category of the retail chain, shrimps and in particular PS are quite important, mainly in value. Because of the not so easy comparability, prices of PS products in retail are usually "generously" calculated, even though some core articles do not bring high margins because they are regularly on promotion. When it comes to selling PS to end consumers, the retail chains are the biggest supplier to the consumer, followed by foodservice and fishmongers.

In general, retailers have an ambivalent relationship to PS shrimps, most of them purchase VS from farms in Latin America or Southeast Asia with sustainability certifications such as ASC. On one hand, the retailers like good availability and the choice between several origins, giving them opportunities for sharp negotiations. On the other hand, there is always a certain fear to get involved in a food scandal because of unsustainable farming practices or use of antibiotics or other unwanted medications.

If PS are sold fresh, the temperature requirements by law are between 0–7°C and for frozen PS between -18- -21°C.

Foodservice wholesale

Foodservice wholesale is the typical supplier of all types of foodservices, from restaurants, canteens, hotels to catering (HORECA). There are two general business models, in one the HORECA visits the wholesaler (Cash & Carry), in the other the wholesaler brings the goods to the HORECA (Delivery wholesale). Usually, the transport of chilled or frozen seafood takes place in small to middle-sized trucks or vans that have active cooling to ensure compliance with the required temperatures.

Almost all food suppliers to the HORECA sector offer a wide range of frozen PS products and chilled cooked PS, often in salads or brine. Because many HORECA ask for bigger shrimps to impress their guests, the share of (the larger) BT is bigger than the share of (the smaller) VS compared to the retail sales channel.

For the general wholesalers who offer a wide assortment of food and nonfood, the seafood category is somehow important to build up a quality reputation but far less important when it comes to total turnover and profit. Within the seafood category PS are one of the most important products, but not a cash cow, and often used for promotion activities because of its multi-channel possible applications.

For seafood wholesalers focusing mainly on seafood, PS are a key-product because it is purchased regularly by nearly all clients in rather high volumes. Low PS purchasing prices are essential to survive in a very competitive environment. The competition with retailers and general wholesalers who both use PS for price promotion has damaged the popularity of PS amongst seafood wholesalers over the last years.

In this context it should be mentioned that because of the high price pressure from some parts of the ethnic HORECA sector, wholesalers are widely demanding and selling PS products like raw peeled tails that have been "enriched" with added water and phosphates (E450-452) in a level up to 30 %.

I. General HORECA

If a HORECA format is not specialized in vegan/vegetarian food, it will offer shrimps with very high probability and a huge share will be frozen PS. From the food preparation point of view, frozen PS have many advantages compared to other seafood, such as: long shelf life, a long service life on buffets, still a premium food image and a high popularity for the guests. Frozen PS products are easy to store in cold stores or freezers and normally are purchased at least once a week.

For many HORECA the size-price-relation decides the product choice, leading to developments as described in H, a lot of fraud in declarations and a refusal to engage with environmental considerations. A typical example for these practices is to include the water glazing into the shrimps count on the package and to make a cheaper 30/40 (pieces per kg) raw shrimp to a more expensive 20/30 shrimp. Also, very often it becomes obvious after thawing the glazed shrimps that the water glazing was higher than declared on the packaging.

J. Foodservice with focus on seafood/Sushi

Seafood restaurants usually also offer shrimp dishes on their menus, but for them shrimps are only one of many choices and not particularly suitable for differentiation to normal restaurants. The importance of that foodservice channel therefore is rather low.

It is different in the "Sushi sector", especially in the low- and middle-priced range where shrimps (called "Ebi" on the sushi menu) are an important seafood ingredient. Very often these small VS are prepared already in the processing plants in the Asian origin (A) as a topping (small VS, cooked, peeled, almost halved, frozen) and just get laid on the rice Nigiri after thawing. Shrimps have a high recognition, a long shelf life, are easy to use and compared to other raw seafood are not too expensive. In the mid-price sector, the cooks usually use larger VS or BT tails fried as Tempura for Sushi Maki and Rolls.

3 Resilience

3.1 Physical and financial resilience

Direct climate change impacts

All stakeholders interviewed were aware of problems that may arise from climate change. At the same time, they could not name any event that would have directly disadvantaged their own company; e.g. rising sea levels, a strong flood, a long drought or so. Nor did they anticipate any events soon that would directly affect their own company.

Indirect climate change impact

However, what was mentioned by all stakeholders interviewed, were direct effects in the country of origin, indirectly affecting the stakeholders, some of them resulting from changes in the temperature of the water in the ponds, some of them as a result from extreme weather events and some of them as results of the shifting of the seasons. These changes lead to necessary measures in the country of origin, which result in cost increases for the product that are passed through the value chains and make the product more expensive for PH sector up to the end consumer. The farming conditions got far less predictable over the last 20 years and almost all stakeholders related this to climate change.

Because the climate change in the production countries is part of the harvest sector (and not the PH sector) there will be no deeper analysing of these effects. Nevertheless, it makes sense to describe them shortly and to explain how climate-change-driven developments in the harvest sector influence the PH sector, especially in its early stages that are close to the harvest sector.

An important climate effect is the so-called monsoon shift, which can have a massive impact on conditions within shrimp farms when heavy rainfall lowers the salinity within the ponds. Species such as the Black Tiger Prawn, which require a relatively fixed salinity, can be severely affected by this. The monsoon shift is a major, but not the exclusive, reason why the trend in shrimp aquaculture is towards the less sensitive Vannamei shrimp.

Heavy rains and tropical storms, especially unexpected ones, also have a drastic impact on shrimp farms located in river deltas (such as Bangladesh):

- Shrimp are flushed out of the ponds during heavy rains and are lost to the farmer.
- Predators such as reptiles or predatory fish are washed into the ponds during floods and cause high losses and dangers for the farmers.
- Sediments get into the water of the ponds, which clouds it and leads to additional heating of the water when it is exposed to sunlight.
- Furthermore, higher outdoor temperatures lead to higher water temperatures and a poorer oxygen supply to the water. Especially in Asia, the water is then often circulated with so-called "paddle wheels", which are often operated by diesel generators, for a better oxygen supply, which leads to additional energy consumption and GHG emissions.

Such "spontaneous and singular" events have occurred increasingly in recent years and have led to major challenges especially in Southeast Asia, where shrimp aquaculture is practiced in many places by small and poor farmers (about 150,000 small-scale producers).

In addition, there are problems due to the slowly rising sea level, which forces some farms to "relocate" every few years, as these farms are located in the immediate vicinity of the sea for water supply and water exchange.

3.2 Major financial constraints and reliability

In addition to the direct and indirect effects on the resilience of the PH value chain, cost increases for companies resulting from political measures to reduce climate change and temperature increases were mentioned in the interviews: keywords were energy taxes and politically forced measures to reduce GHG emissions.

Beside raw product costs, labour costs and rental costs, the costs for energies such as electricity, water/wastewater and fuel are the fourth most important cost in the Shrimps PH sector. In this respect, it is not surprising that all stakeholders stated that they try to minimise energy use in many areas. However, the main motive behind this was almost always the associated cost reduction in order to remain competitive.

In the discussion with the stakeholders, most of all the independent companies (B-E) that import shrimps (B) or buy big volumes (C-E) and sell afterwards, another point was mentioned that could cause problems and worries for the future and stresses the financial resilience of those companies more and more: increased stocks of frozen shrimps in the EU.

Because of the climate change-related issues in the harvest sector and global sea freight transport issues due to COVID and Ukraine war, the just-in-time supply (with low domestic stocks) does not work at the moment and no one knows when it will work again. Therefore, frozen shrimp stocks in the EU have been built up by the importers to secure the ability to supply important customers. This leads to more product in the product chain, more transport and longer stay of the product in the chain – and more tied-up capital that has to be pre-financed.

Usually those companies, many of them making over 20 % or more of their business with Shrimps, buy the shrimp product in a mix of fixed contracts and spot market purchases to stay competitive. Often the payment terms to the supplier are shorter than the payment terms especially to their retail customers, many of them always postponing price increases on the supplier side by several weeks.

Companies in the shrimp processing sector, especially shrimp cookers and shrimp salad producers, are very dependent on a regular and predictable supply of raw material. To exaggerate: if no shrimps arrive (because there are not-working container-harbours in East Asia (COVID), or blocked seaways (Suez), for example), the factory risks to stand still. There are theoretically alternatives to the product VS and BT, but only in limited numbers and usually not for the same price.

Companies that trade in seafood or other food products are much less dependent on shrimps than the shrimp importers and processors described above. If there is no shrimp available (very unlikely), other seafood products or even meat, vegetables and other foodstuffs can still be bought and sold.

As a rule, the further a stakeholder in the value chain is from the origin of shrimps, the lower its dependence on that specific product and usually the higher its resilience.

3.3 Stakeholders' perceptions

All stakeholders were sure that there will be enough shrimp for Europe also in the future but that prices will rise continuously because of increasing production costs and higher costs in the origin to prevent climate-change-related risks. Their estimate was that the global farmed shrimp production will continue to grow while the wild shrimp catches will be stable for long-term perspective with "some better and some worse years".

Several stakeholders discussed a hypothetical danger for the distant future, resulting from a fundamental change in breeding conditions in the farming areas close to the shores of Southeast Asia and Latin America, for example if warming of the water in the ponds overstrains the natural resistance of the shrimps or a serious increase of sea levels.

Others also mentioned a potential future of shrimp farming in Europe: currently there are dozens of mostly small-sized (5–500 tonnes per year) indoor RAS farms in the EU, which almost all produce Vannamei shrimp in high quality but at high production costs and very high sales prices, making them unattractive to most users. With gains in experience, higher production volumes and beginning supply of juveniles from within Europe those production costs per ton seem to lower but will be – for a long future – remain far above the costs of overseas outdoor farms.

4 Greenhouse Gas Emissions

4.1 GHG emissions in the value chain

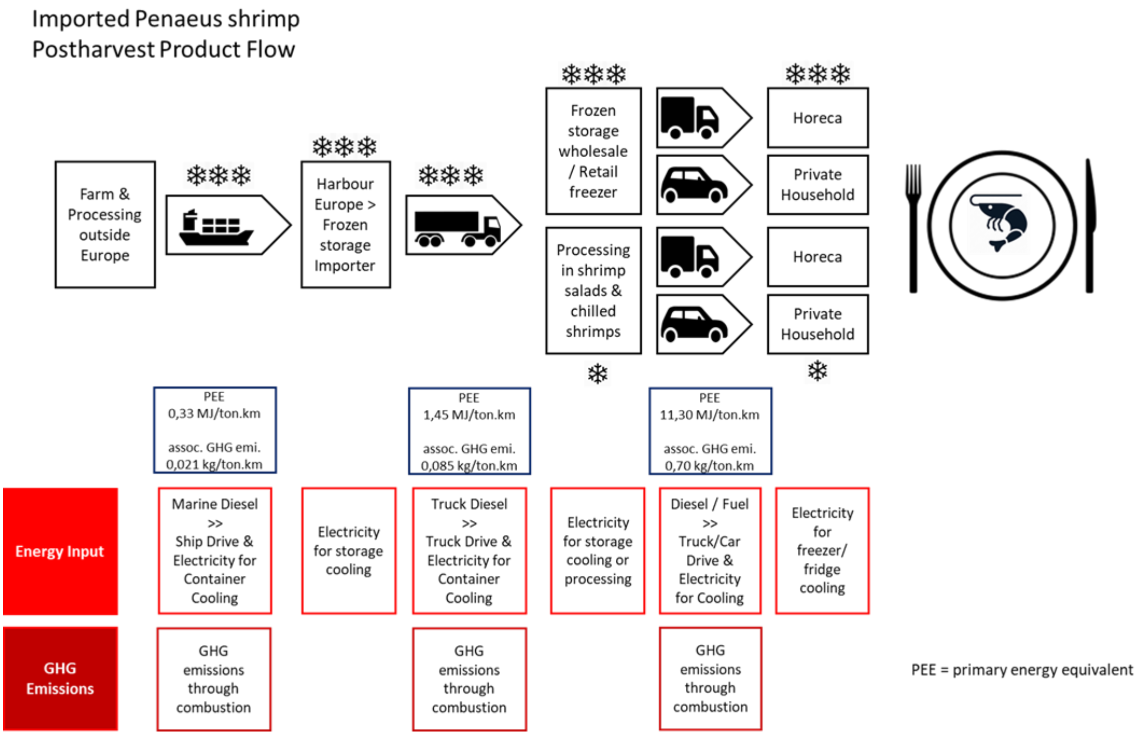

Figure 2. Production Flow for Imported Penaeus Shrimp

During interviews, when the question was asked where there would be the main energy consumptions and GHG emissions for Penaeus shrimps in the PH sector, all stake-holders mentioned the same two areas: Shrimp transport from overseas and keeping shrimps in a frozen state.

The PH PS sector is characterized by ultra-long distance container sea transports and a product storage of usually 1–24 months – both with a permanent frozen cooling between farm and preparation for the consumer.

In the first 1–2 months after first processing in the origin, the PS get transported frozen in 40ft containers by ship to an EU harbour. Those containers usually have a content of about 20 tonnes; the shrimps are packed in 10 kg bulk boxes or boxes with consumer packs of 200–1.000g.

The cooling temperature in the containers is usually about –20° C and comes from cooling units in each of the well-insulated containers. The cooling units are powered by electricity from auxiliary power units on the ship, generating electricity from diesel. The average electricity consumption of a refrigerated or frozen container is 3.5-4.5 kWh per operating hour for 20 feet and about 7-9 kWh per operating hour for 40 feet containers, typical trip duration is between 20 and 30 days.

40 ft container: 20 days x 24 h x 9 = 4.320 kWh /30 days x 24h x 9 = 6.480 kWh

What was mentioned by all interviewed stakeholders, were climate change-related developments in the countries of origin of the PS, resulting from changes in the temperature of the water and changes in the salinity of the water. These changes lead to necessary measures in the country of origin, resulting in product cost increases: more energy input for cooling and oxygen supply, insurance against natural hazards. These are passed through the value chains and make the product more expensive for the end consumer. In addition, cost increases for companies resulting from measures to reduce climate change and temperature increases were mentioned: keyword energy taxes.

Some PS importers mentioned that the PS farmers and processors in overseas areas are well aware of the climate change and the resulting challenges for them, but that the need or will to reduce GHG emission in the origin is not very strong. A probable cause for this is the poor financial base for many of the farms and that energy costs - compared to shrimp juveniles, shrimp feed, labour costs and lease – is a rather small factor for them.

In this respect, it is not surprising that all stakeholders stated that they try to minimise energy use in many areas. However, the main motive behind this was almost always the associated cost reduction in order to remain competitive. Obviously for almost all stakeholders carbon footprint is still not part of "sustainability" (as opposed to for example avoidance of environmental damage, minimisation of animal components in shrimp feed, no use of antibiotics and fair payment of farm workers), but sustainability is an issue that usually impacts many other fields of their business.

The stakeholders interviewed were not in a position to measure or calculate their own exact energy use per ton of product and an associated emission of greenhouse gases in their own company as well as in the upstream and downstream stages of the value chain. There seems to be less of a lack of will than of ability to do so.

So far, stakeholders have not felt any explicit pressure from their customers to submit a "supplier carbon footprint" for certain products. If there was an initiative to take action to improve the carbon footprint, it has almost always come from the stakeholders themselves, mainly from retail chains and usually not related to shrimps/seafood.

But all stakeholders mentioned that they (and their upstream and downstream) PH chain partners introduced measures to become more energy efficient what usually also results in a decline of GHG emissions.

Those measures came from the following fields:

- Own on-site power generation by solar energy or wind power to reduce the share and cost factor of purchased energy. Typical examples are solar panels on factory roofs. In some cases, state subsidy programs have also been used for this purpose.
- Use of intelligent heat exchange systems that simultaneously provide waste heat for heating, for example, when generating cold, or produce cold for cooling buildings when generating heat. Those systems were found in the processing industry, larger wholesalers and larger retailers.
- Significantly better building insulation, especially for cold rooms and freezers.
- More environmental-friendly refrigeration (CFC-free) through the use of new refrigerants such as CO_2 or sole glycol.
- Use of refrigeration units closed with doors (for plus and minus cooling) instead of the open refrigeration units used in the past, which entailed high cooling losses.
- Significant reduction in fuel consumption and exhaust emissions through renewal of the vehicle fleets.
- Significant reduction in fuel consumption and exhaust emissions at sea transport because of new container-ship generations (bigger ships = more containers, less fuel consumption, new propulsion concepts).
- Optimization of plastic consumption for consumer packaging through better, mostly thinner materials that require less fossil raw materials or use recycled raw materials. However, less packaging does not usually lead to lower costs.

<u>Calculation examples</u>

There are hundreds of different ways how PS move from the farm to the consumers plate and how it is processed to very different products with different yields, also stored in different cooled environments for different durations. Table 5 shows some sections of this journey with the energy consumption and GHG emissions attributable to them.

Table 5. Calculation examples of energy consumption and GHG emissions in various sections of the journey from farm to table.

		Factor:	0,33 MJ/ton-km		0,0210 kg/ton-km	full container load	
Transport Peneus Shrimps from overseas origin to EU (Rotterdam/Hamburg)			x 1,2 cooled transport			40ft = 20 tons	
Start	End	Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Guayaquil/Ecuador	Rotterdam/Netherlands	10.620	20	84.110	5.352	4205,5	267,6
Guayaquil/Ecuador	Hamburg /Germany	11.070	20	87.674	5.579	4383,7	279,0
Callao/Peru	Rotterdam/Netherlands	11.680	20	92.506	5.887	4625,3	294,3
Callao/Peru	Hamburg /Germany	12.130	20	96.070	6.114	4803,5	305,7
P. Cabello/Venezoela	Rotterdam/Netherlands	8.080	20	63.994	4.072	3199,7	203,6
P. Cabello/Venezoela	Hamburg /Germany	8.530	20	67.558	4.299	3377,9	215,0
Panaji/India (West)	Rotterdam/Netherlands	11.680	20	92.506	5.887	4625,3	294,3
Panaji/India (West)	Hamburg /Germany	12.130	20	96.070	6.114	4803,5	305,7
Haldia/India (East)	Rotterdam/Netherlands	14.150	20	112.068	7.132	5603,4	356,6
Haldia/India (East)	Hamburg /Germany	14.600	20	115.632	7.358	5781,6	367,9
Chittagong/Bangladesh	Rotterdam/Netherlands	14.350	20	113.652	7.232	5682,6	361,6
Chittagong/Bangladesh	Hamburg /Germany	14.800	20	117.216	7.459	5860,8	373,0
Danang/Vietnam	Rotterdam/Netherlands	17.100	20	135.432	8.618	6771,6	430,9
Danang/Vietnam	Hamburg /Germany	17.550	20	138.996	8.845	6949,8	442,3
Jacarta/Indonesia	Rotterdam/Netherlands	15.700	20	124.344	7.913	6217,2	395,6
Jacarta/Indonesia	Hamburg /Germany	16.150	20	127.908	8.140	6395,4	407,0
Bangkok/Thailand	Rotterdam/Netherlands	16.720	20	132.422	8.427	6621,1	421,3
Bangkok/Thailand	Hamburg /Germany	17.550	20	138.996	8.845	6949,8	442,3
		Factor:		2,79 MJ/ton-km	0,1699 kg/ton-km	full load large truck	
Transport PS from EU Harbour storehouse to seafood hubs in neighbouring countries		Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Rotterdam/Netherlands	Ijmuiden/Netherlands	80	12	3.214	196	267,8	16,3
Rotterdam/Netherlands	Urk/Netherlands	147	12	5.906	360	492,2	30,0
Rotterdam/Netherlands	Oostende/Belgium	220	12	8.839	538	736,6	44,9
Rotterdam/Netherlands	Paris-Rungis/France	460	12	18.481	1.125	1540,1	93,8
Hamburg /Germany	Bremerhaven/Germany	180	12	7.232	440	602,6	36,7
Hamburg /Germany	Copenhagen/Denmark	335	12	13.459	820	1121,6	68,3
Hamburg /Germany	Vienna /Austria	970	12	38.971	2.373	3247,6	197,8
Hamburg /Germany	Zurich/Switzerland	870	12	34.953	2.129	2912,8	177,4
		Factor:		2,79 MJ/ton-km	0,1699 kg/ton-km	full load large truck	
Transport PS from seafood hubs storehouse to wholesaler in same country		Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
Bremerhaven/Germany	Bremen/Germany	65	12	2.611	265	217,6	22,1
Bremerhaven/Germany	Dortmund/Germany	300	12	12.053	509	1004,4	42,4
Paris-Rungis/France	Dijon/France	308	12	12.374	522	1031,2	43,5
Paris-Rungis/France	Lyon/France	460	12	18.481	780	1540,1	65,0
		Factor:		3,57 MJ/ton-km	0,2199 kg/ton-km	mixed load medium truck	
Transport PS from wholesale to Horeca		Distance in km	Load in tons	total PEE per load per trip in MJ	associated GHG emissions in kg per load per trip	PEE per ton per trip in MJ	GHG per ton per trip in kg
wholesale	very near	20	8	685	42	85,7	5,3
wholesale	near	50	8	1.714	106	214,2	13,2
wholesale	medium	100	8	3.427	211	428,4	26,4
wholesale	far	200	8	6.854	422	856,8	52,8

Example 1: Whole Black Tiger Prawn, farmed in Bangladesh, packed in 1 kg semi-block with 20 % glazing (=800 g net weight), shipped in 40 ft. container (20 tons) to Rotterdam,

trans-ported by large truck to Paris-Rungis, transported by large truck to Lyon/France, transported by medium truck to HORECA 50 km away.

BT block frozen with 20% water glazing					per ton		**per weight final product**	
From	to	type	Distance km	weight kg	PEE in MJ	GHG in kg	**PEE in MJ**	**GHG in kg**
Vietnam	Rotterdam	40 ft. Cont.	17100	1000	6.772	430,92	**6.771,60**	**430,92**
Rotterdam	Paris-Rungis	32 tons+	460	1000	1.540	93,78	**1.540,08**	**93,78**
Paris-Rungis	Lyon	large truck	460	1000	1.540	65,01	**1.540,08**	**65,01**
Lyon	Horeca	mid truck	50	1000	214	13,19	**214,20**	**13,19**
						total:	**10.065,96**	**602,91**
						per 1 kg	**10,07**	**0,60**
					net weight	per 0,8 kg	**12,58**	**0,75**

Example 2: Cooked and peeled Vannamei shrimp tails, farmed in Ecuador, packed IQF in 10 kg boxes with 10 % glazing (= 9kg g net weight), shipped in 40 ft. container (20 tons) to Hamburg, transported by large truck to Bremerhaven, thawed an packed there to re-tail packs with chilled "Cocktail shrimp", transported back to Hamburg by large truck to retail central storehouse, transported by medium truck to retail outlet 100 km away.

VS IQF 10% water glazing, thawed and packed in Bremerhaven					per ton		**per weight final product**	
From	to	type	Distance km	weight kg	PEE in MJ	GHG in kg	**PEE in MJ**	**GHG in kg**
Ecuador	Hamburg	40 ft. Cont.	11070	1000	4.384	278,96	**4.383,72**	**278,96**
Hamburg	Bremerhaven	32 tons+	180	1000	603	36,70	**602,64**	**36,70**
Bremerhaven	Hamburg	large truck	180	900	603	36,70	**542,38**	**33,03**
Hamburg	Retail outlet	mid truck	100	900	428	26,39	**385,56**	**23,75**
						total:	**5.914,30**	**372,44**
						per 1 kg	**6,57**	**0,41**

Discussion of the container content:

Regarding those figures it becomes clear that the main use of energy (Diesel) and the main part of the GHG emissions is related to the long-distance sea transport in cooled 40ft containers. An analysis of the container's content shows that (beside packaging) there are 4 different types of content in those containers:

1. Necessary water protection glazing: experts believe that a water glazing of 10 % is more than sufficient to prevent freezer burn.
2. Additional glazing: in most cases when the PS product is packed to consumer packs there is an additional glazing of another 10 % water that lowers the shrimp net content to about 80 % and makes the pack/bag a little bit cheaper in the eyes of the customer.
3. Enrichment with water and additives: in many PS products – mainly for the food service – another technique is used to lower the production price (and the later sales price): the shrimp product, mostly peeled raw tails gets enriched with drinking water and additives (E450 – 452) by tumbling the product in a brine before freezing. The enrichment that are declared on the packaging rank between 10 and 30 %. The interviewed expert estimated that about 80 % of the raw PS tails (where this technique is applicable) that are sold in the food service this enrichment takes place and that only 20 % are enrichment-free.
4. Pure shrimp weight: this is the weight of the PS before glazing and enriching.

Table 6. Calculation examples of 40 foot-containers content after using different "techniques" in the processing stream

	Content in kg	necessary water glazing 10%	unnecessary extra water glazing 10%	enrichment water + additives in product in %	enrichment water + additives in product in kg	shrimp product weight in kg	shrimp content at container weight in %	water + additives content at container weight in %
A	20.000	2.000	0	0%	0	18.000	90,00%	10,00%
B	20.000	2.000	2.000	10%	1.600	14.400	72,00%	28,00%
C	20.000	2.000	2.000	20%	3.200	12.800	64,00%	36,00%
D	20.000	2.000	2.000	30%	4.800	11.200	56,00%	44,00%

In the following visualization (Figure 3) it can be seen how the net shrimp content in a 40 ft = 20 tons container is shrinking when the different techniques to make shrimps cheaper are used.

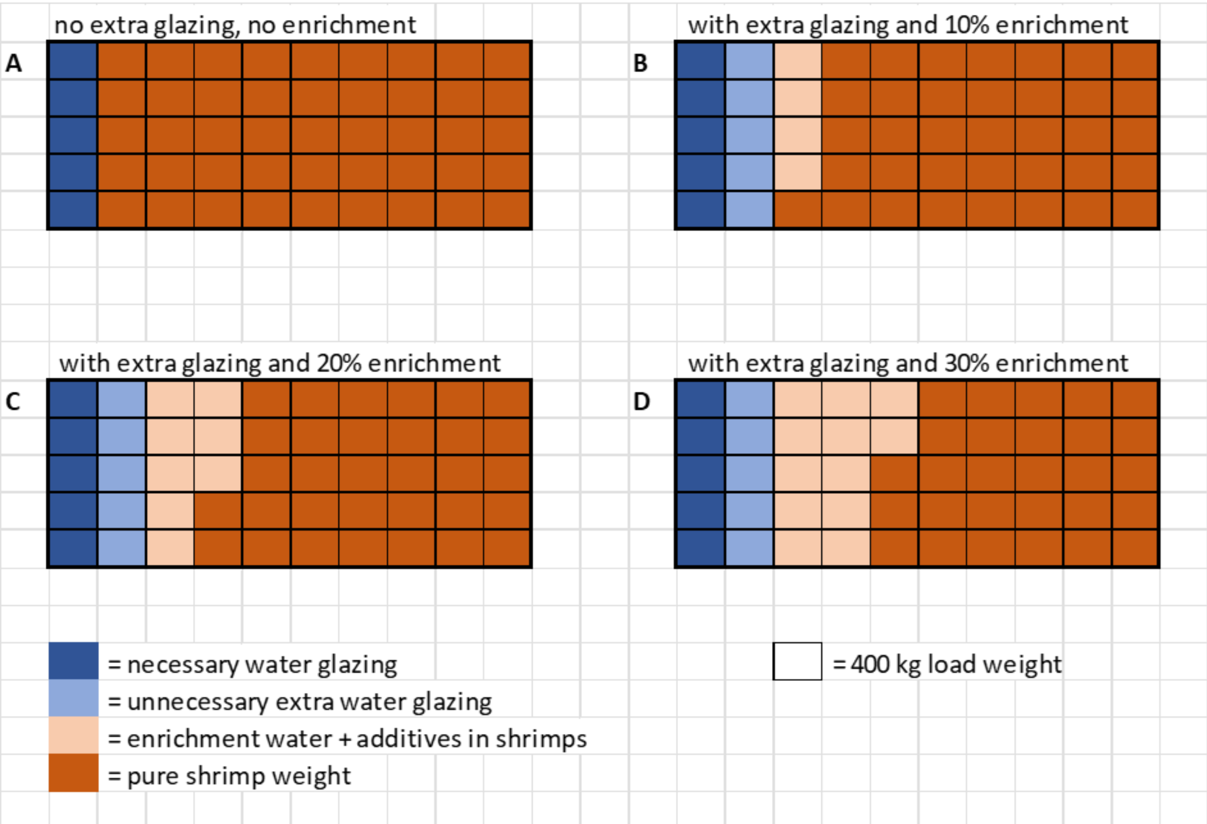

Figure 3. visualization of how the net shrimp content in a 40 ft container is shrinking due to the different techniques to make shrimps cheaper

From a climate-protection point of view, it makes no sense to ship containers that are loaded up to more than 40 % with water from overseas to Europe. There is for sure a potential to lower the GHG emissions by 25 % by stopping all or some of these techniques described above or doing those steps much closer to the consumer in Europe.

5 Conclusions

- The PH value chain for imported Penaeus shrimp is characterised by a multitude of trade stages and by a long sea freight transport of the frozen shrimp between the origin of the shrimp in Southeast Asia and Latin America and the use in Europe. Between landing in a European port and use in the food industry, gastronomy or a private household, there are several transports in cooled trucks and several storage periods as a frozen product. The time periods here can vary from a few weeks (frozen product is thawed and processed into a chilled product with a shelf life of less than 30 days) to two years (product remains frozen and is stored).
- Even though the mostly automated processing of shrimp and their frozen storage in the factories and trade stages requires electrical energy, it is mainly the long transports at sea and in medium and large trucks powered by combustion engines that account for most of the fossil energy consumption, which also leads to greenhouse gas emissions.
- In order to reduce the energy demand and the associated GHG emissions, the distance (=transport time) between shrimp farm, processing and final consumption would - theoretically - ideally have to be reduced. This is, of course, a hypothetical discussion to begin with, as neither the locations of the shrimp farms, nor the highly specialised processing platforms currently in place, nor the consumers spread across Europe can be moved spatially.
- Whether and when land-based RAS shrimp aquacultures can minimise these transport effects remains to be seen, once these facilities have overcome their teething problems and achieve regular output at competitive prices. This is not expected to happen in the next 10-15 years.
- Nevertheless, there is reason to expect that, despite the developments mentioned above, the energy demand and GHG emissions of the PH sector for Penaeus shrimp will tend to reduce. There are a number of "small" measures and developments for this:
    - Container ships will be more energy efficient in the future; on the one hand, the ships will become larger and will be able to carry more containers; on the other hand, the efficiency and consumption of the ship engines will improve while reducing GHG emissions.
    - Truck fleets are also being gradually modernised, leading to lower fuel consumption and GHG emissions.
    - Small and less energy-efficient processing units can no longer compete economically and are being replaced by larger and more efficient units.
    - More climate-friendly technologies are used for refrigeration, both during transport and storage before processing and sale (CO_2, sole glycol instead of CFCs).
    - The electricity mix used for stationary refrigeration is gradually decarbonised.
    - Modern stationary refrigeration, whether freezers or frozen food shelves in supermarkets, require less energy because they are better insulated.
    - Plastic packaging materials (films, trays) contain more and more recycled content or are lighter than in the past.
- The greatest potential for saving energy and emissions during transport would certainly be if more shrimp and less water were transported. If we consider that many containers, pallets and packages contain more than 30 % water, it would probably be possible to avoid thousands of container loads and lorry transports by avoiding excessive glazing and enrichment of shrimp with potable water and additives. Or to put it more simply: every fourth container and every fourth pallet would not have to be transported.

Gaps in knowledge and information

There is a multitude of unknowns and uncertainties when it comes to the description of the PH sector for Penaeus shrimps and to calculation of GHG emissions in it:

- The origin of the shrimps "gets lost" in the EU statistics once the shrimp has entered EU. It is not possible to find out on the level of sales to the consumer where the PS originally came from.
- There is only one Eurostat number (0306 1792) for PS and it is absolutely unprecise because it does not allow any differentiation between:
  - Vannamei shrimp and Black Tiger prawn and other Penaeus shrimps
  - Raw or cooked shrimps
  - Whole shrimps or shrimp tails with shell or peeled shrimps
- It is also unclear whether the net content is shown (without protection glazing) in the Eurostat figures or the bags content including 10–20 % water glazing. But it is known that there is usually no double-checking of the figures; that is why there are probably many sources of error and dark figures.
- It is unclear where exactly which processing steps take place, e.g. heading, peeling, enriching, glazing, freezing.
- The volume of Shrimps that goes into ready meals and shrimp salads cannot be calculated.
- It is unknown how much energy is needed to cool shrimps in storehouses and where this energy comes from (nuclear power vs. hard coal-fired power generation vs. wind energy). Also unknown is the length of stay of the products in the different transport vehicles and store houses. This can be anything between a day and two years.
- The location of the shrimp farm that supplies the shrimp processing plant is unknown. But it is certain that there is another energy absorbing and GHG emissions causing transport within the country of origin.
- The energy use and GHG emission of the container ship can be very different, depending on the type, age and size of the ship.

6 References

CBI: The European market potential for pacific white shrimp, 2021. https://www.cbi.eu/market-information/fish-seafood/pacific-white-shrimp/market-potential

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EUMOFA: Cooked shrimps in France, 2017

EUMOFA: Case study "Tropical shrimp in the EU" in "Monthly Highlights 4-2020"

EUMOFA: Species analysis

CASE STUDY 19: INVERTEBRATES – IMPORTED TROPICAL SHRIMP (*PENAEUS VANNAMEI* AND *PENAEUS MONODON*) - FRANCE

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Sébastien Metz, Marie-Pierre Mommens

LIST OF ABBREVIATIONS

Term	Description
GHG	Green House Gas
HOSO	Head-on Shell-on
IQF	Individually Quick Frozen

1. Background

Shrimp and prawns are one of the most important internationally traded fishery products. As various shrimp species are traded, the market is often divided into cold water and warm water or tropical shrimp. Warm water shrimp species are caught predominantly in areas close to the equator, though the vast majority of this biomass and are farmed in Asian and South American countries. The two main tropical shrimp species farmed are the white leg shrimp (*Penaeus vannamei*) and the giant tiger prawn (*Penaeus monodon*).

The global farmed shrimp market continues to grow faster than other aquaculture species. Over the past 25 years, shrimp aquaculture has strongly increased, with *P. vannamei* production progressively deployed in Asian countries. For many years, those two species farmed production has significantly exceeded wild-caught production.

Penaeus vannamei has become the main farmed shrimp species globally (82 % of world production of farmed Penaeus species in 2017), facilitated by low production costs. Production reached 4.5 million tons in 2017. In 2017, world farmed production of *P. vannamei* was driven by China, which provided 38 % of the global total, followed by India (13 %, which also provides wild catches), Indonesia (11 %), Vietnam (10 %, which also provides wild catches). Ecuador (10 %) recently overtook Thailand (7 %) to become the world's fifth-largest shrimp producer of *P. vannamei*. (EUMOFA).

Production of *P. monodon* was globally stable from 2000 to 2017, rising only by 17 % across this time period, reaching a total of 739 thousand tons (EUMOFA). In 2017, world farmed production of *P. monodon* was driven by Vietnam (36 %, which had experienced a substantial decline of 19 % between 2000 and 2017), followed by Indonesia (19 %). Other important producers were China (10 %), Bangladesh (9 %), India (10 %, though had experienced a decline in production of 19 % between 2000 to 2017), Myanmar (7 %), and the Philippines (6 %). Production in Indonesia and the Philippines have stable between 2000 and 2017 (+2 %) (EUMOFA). As the global demand shifted towards low-price shrimp, many farmers shifted to black tiger aquaculture in Thailand, Vietnam, Indonesia and Malaysia, encouraged by its relatively stable and high prices compared with *P. vannamei* (FAO 2019).

In 2019, European Union (EU) imports of crustaceans reached 633 thousand tons with a value of EUR4.74 billion. Shrimp represented close to 90 % of the total value and 94 % of total volume of such imports, with warmwater shrimp representing 45 % in total volume.

The EU imports between 80 to 90 % of its shrimp (with EU regional production only totalling 11 % from 2008 to 2017 following a downward trend), which is the highest valued product imported into the EU. EU landings of shrimp in 2018 totalled 81.1 thousand tons and were valued at EUR572 million, which was the highest in both volume and value for the last 10 years. In 2019, both volume and value dropped, to 57.6 thousand tons and EUR433 million.

The main commercially imported product consists of frozen shrimps of the genus Penaeus. In 2019, EU imports of Penaeus shrimp reached 284 thousand tons for a total value of EUR1.99 billion. The main importing countries in terms of value were France (23 %), Spain (19 %), the UK (14 %) and the Netherlands (13 %). The main origin countries in terms of value were Ecuador (31 %), Vietnam (17 %), India (15 %) and Bangladesh (10 %). Extra-EU exports remained limited, with 3.5 thousand tonnes of frozen Penaeus shrimp exported in 2019 for a value of 21 million EUR, the main partners being Iceland (18 %) and Switzerland (17 %), in terms of value.

Shrimp from India and Vietnam are imported in the EU at a higher price as they also include higher-valued giant tiger shrimp (*Penaeus monodon*). Most of the shrimps exported from Ecuador into the EU are head on-shell on (HOSO), while most shrimps exported from India into the EU are peeled.

1.1 Processing

After harvest, shrimp are sorted, washed, weighed, and killed immediately in iced water at 0 – 4°C. Shrimp are often treated with sulfiting agents (sodium metabisulphite is added to the chilled water) to prevent melanosis (black spot formation) and red-head. The shrimp are then kept on ice in insulated containers and delivered within 48 hours after harvest, either to processing plants or domestic shrimp markets.

There are two processed versions of shrimp that are provided to the market, frozen and cooked shrimp:

- Frozen shrimp: In processing plants, refrigerated shrimp are immediately frozen at -10 °C. After freezing, the finished product is weighed, packed, labelled and then stored at -20 °C for export, primarily by ship or air cargo. Frozen shrimp generally comes in two forms, blocks (shrimp frozen en masse) and Individually Quick-Frozen (IQF) packs. Both shrimp blocks and IQF shrimp are glazed with a protective ice coating to prevent dehydration (usually 10 %, but the ice coating may be higher in some cases see CS).
- Cooked shrimp: Graded shell-on IQF shrimp to be cooked before being presented to the market pass through a continuous steam cooker. As cooked shrimp exit the cooker, they are cooled by spraying cold water on the product. Shrimp are then sorted and defective products are removed.

Tropical shrimps are mostly imported whole and frozen to be cooked and sold as chilled products next to the consumption areas (whether head-on or head-off and sometimes peeled). Only a minor share of the import is sold through the frozen product's market, either raw and frozen or cooked and frozen. Cooked and frozen products are usually cooked on-site for better sensory quality.

Bulk remains the main marketed presentation for cooked and chilled *P. vannamei*, in the fresh fish counters of large-scale retailers and, to a lesser extent, in fishmongers' shops. But new consumption habits and demand for easy-to-cook and convenience food products have emerged. Prepacked, processed and prepared products (headed and peeled cooked and chilled shrimp, as well as marinated shrimp products), as well as certified products (Global G.A.P. and Aquaculture Stewardship Council (ASC), Label Rouge, organic shrimp), have experienced significant increases in demand within France. According to Kantar World panel for FranceAgrimer, in 2015 out of 32,000 tons of cooked shrimp purchased by households in France, 25 thousand tons (78 %) were purchased in fish counters, and 7 thousand tons packed (22 %). The French market for cooked shrimp amounts to 70 000 tons (2015) and is based at 90 % on *P. vannamei*.

Depending on the production method and desired end product, shrimp processing waste can constitute 40 to 70 per cent of the original shrimp weight: heads, meat portions, shells, legs and shrimp processing wastewater. It primarily comprises protein, chitin, and carotenoid pigments, especially astaxanthin (Figure). Nirmal et al. (2020) list several applications for these compounds in medicine, animal feed, biosourced plastics or waterremediation.

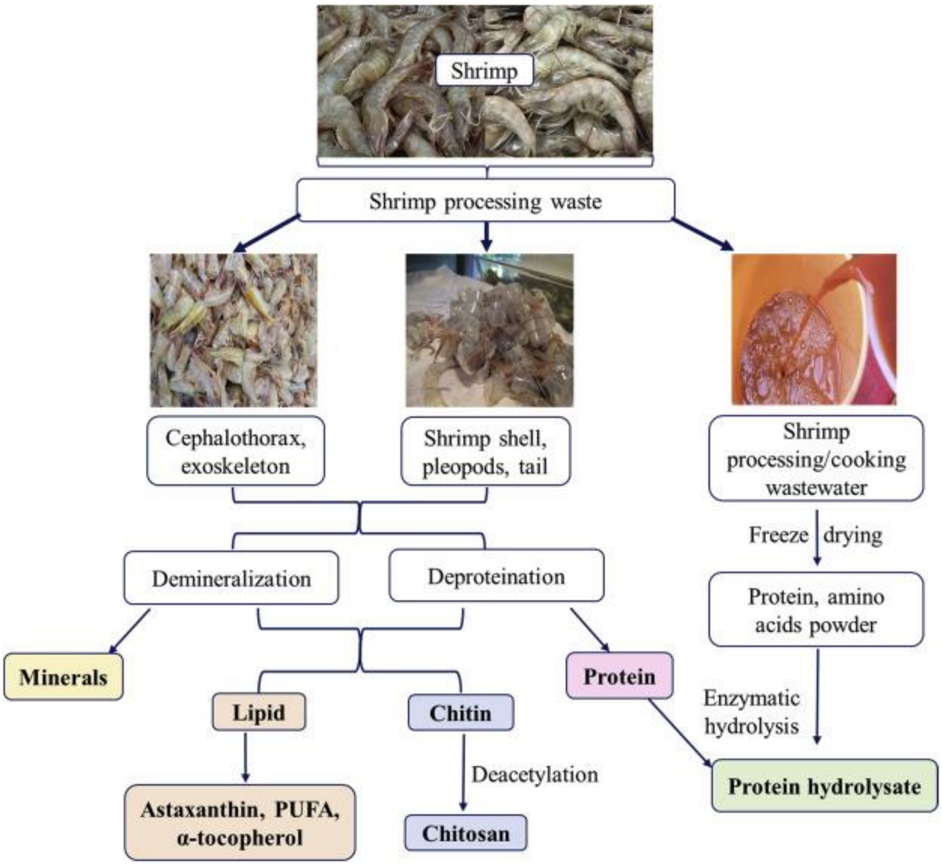


Figure 1: Bioactive compounds recovery from shrimp processing waste. From Nirmal et al. (2020)

2. Value chain description

This CS focuses on imported tropical shrimp that is sold in fish counters in France. The general flow diagram integrates all tropical imported shrimp routes. For this CS, we focus on one particular route, consisting of the import of whole shrimps (HOSO: head-on shell-on) to be sold in fish counters.

Most imported shrimp sold on the French market is farmed in tropical countries (South America, Southeast Asia, Madagascar). The supply chain can be described as follows:

- The first steps of PH operations occur in the production country: washing, sorting, chill killing, and icing occur close to the farms to maintain the freshness of the shrimp. Depending on the specifications required by final clients, shrimps may be peeled and/or cooked in the production country before freezing, but this rarely happens for products sold on fish counters or by fishmongers in France.
- Shrimps are imported frozen by sea freight. The shrimps are stored in cold storage before and after the transport.
- For the shrimps sold whole over the counter, most of the products are cooked in the EU, where several steps are performed: shrimps are cooked, cooled, sorted then packaged to be shipped to retailers (large distribution chains and fishmongers). Specialised processors are selling directly to large retailers, but there may be an aditional wholesale step before the shrimp reaches fishmongers.

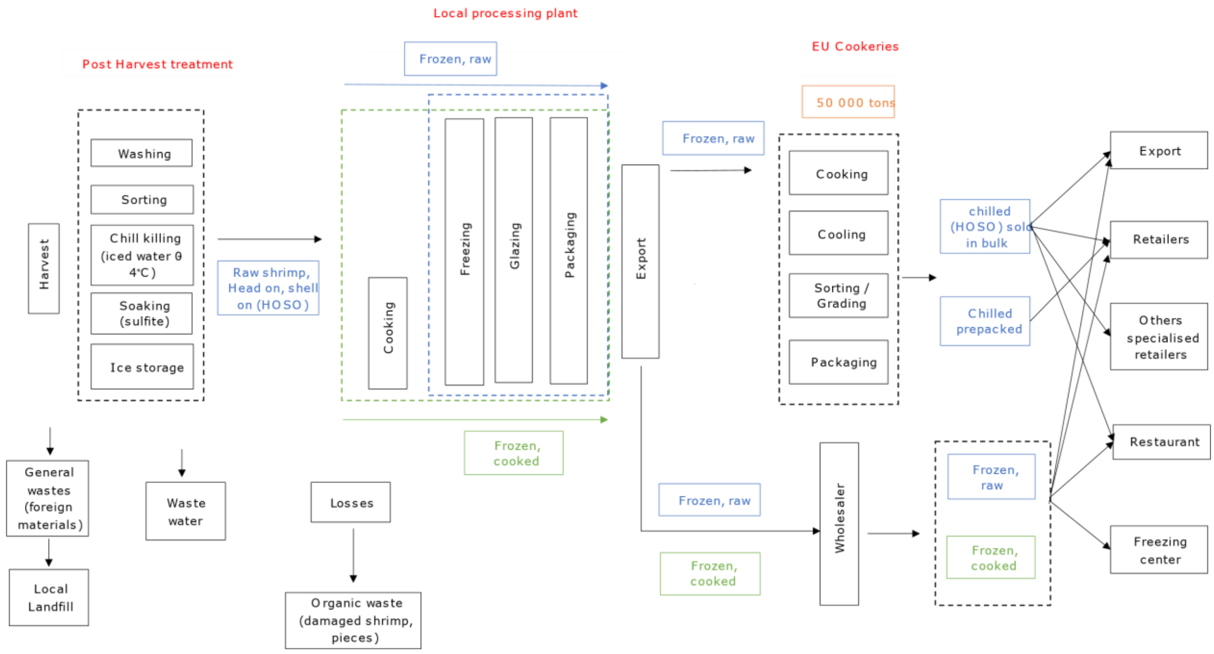


Figure 2. Postharvest value chain of Imported Shrimp.

Resilience

4.1 Physical and financial resilience

The French sector comprises importers and secondary processors cooking and packing shrimps for the French supermarkets and fishmongers. Their location is not related to any marine activity and is solely based on the history of the various groups and their connections to specific seafood hubs: major cooking plants are notably located in Boulogne-sur-Mer, Lorient, Nantes and near Toulouse. Discussing with stakeholders led to the conclusion that European-based operations are not the ones that are at risk of physical disturbance (floods, sea level rise), as they could relocate to places with lower risks. This would require substantial investments to be achieved but would allow the persistence of the supply chain even in dire conditions.

The resilience of the whole supply chain is more linked to operations taking place outside the EU, in production countries, either in South-East Asia or in South and Central America. Stakeholders mentioned the risks of floods, and sea-level rise affecting production and primary processing situated in coastal areas, and increased risk of epizootic episodes. These various risks are expected to increase the fluctuation in production levels, leading to higher volatility in shrimp prices. Overall, shrimp may always be available, but the price dimension is the large unknown part of the profitability equation of the supply chain in the future.

4.2 Major financial constraints and reliability

The concentration level in the shrimp cooking sector is not perceived as a deterrent for stakeholders to invest in new processing units when needed. The major constraint lies in the availability of raw materials, which must be provided regularly for the cooking units to remain profitable. Variations in supply are seen as a significant risk for the cooking processors, notably in terms of cash flow.

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	***Strengths*** • Well established companies with a robust business model • Processing units may be relocated in less vulnerable areas (no flood, no sea-rise issues)	***Weaknesses*** • Current processing units are not well insulated which may cause issues if heatwaves are becoming more frequent
External origin (attributes of the environment)	***Opportunities*** • Development of RAS shrimp production in Europe, disconnecting the production from environmental fluctuations	***Threats*** • Higher variability in supply due to environmental instability (heat waves, floods, epizootic episodes)

4.3 Role of management – lessons learned of adopted strategies

The French national climate change adaptation plan doesn't explicitly cite the PH sector as a key sector that would be affected by climate change.

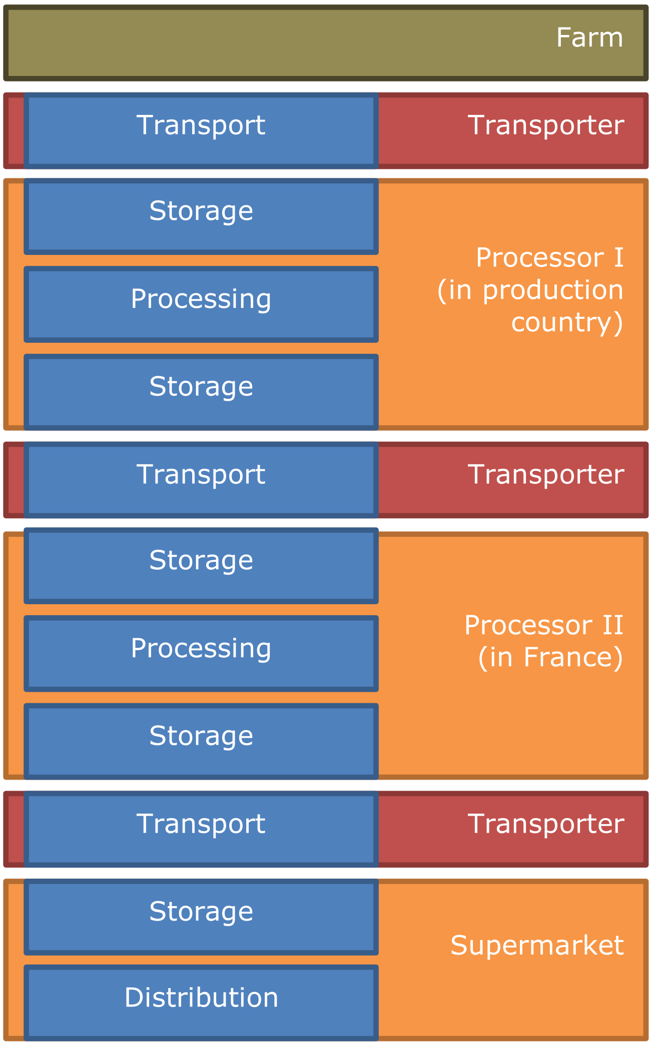
Incitations have been integrated into the design of the national EMFF and EAMFF programmes. Processors must highlight the potential energy reduction and GHG loss reduction when requesting sectoral support for new investments.

3. Greenhouse Gas Emissions

3.1 GHG emissions in the value chain

The cooked shrimp supply chain is relatively long compared to other case studies, involving only several steps in the production country and in France:

1. Transport from the farm to the primary processing unit (in the production country)
2. Primary processor (in the production country): washing, preparation (additives, glazing) and freezing
3. International transport from the production country to France, and then to the secondary processor, which may also
4. Secondary processing in France
5. Storage and distribution in supermarkets.



<u>Transport from the farm to the primary processing unit</u>

Stakeholders mentioned that this step should consist of a maximum of a few dozen of kilometres between the farms and the primary processing unit to minimise the time between catching and processing. Nonetheless, they were not able to describe further how the operations were conducted at the sectoral level (size of lorries, load of the truck, distance), hindering the ability to

<u>Primary processing</u>

Primary processing is happening in the same region to maximise the quality of the frozen product. Stakeholders based in the EU have currently little information on the GHG emissions associated with the different phases (washing, sorting, freezing, coating) happening during primary processing. Discussions with contact in Chile and Peru led to the conclusion that operations in these countries are highly variable and that the usual factors used in GHG emission analysis may be underestimating the extent of the emissions for this step.

Transport from primary processor to secondary processor

This transport step is composed of several subparts:

- Lorry transporting a container of frozen shrimp in the production country
- Container ship transporting the container from the production country to the EU. The container may be unloaded in one of the ports on major routes (Rotterdam, Rouen, Nantes) or transborded to reach a regional port. The initial phase of the maritime voyage may also happen from a small port to a larger regional hub (Jakarta, Santiago…).
- Lorry transporting the container from the port to the secondary processor.

Stakeholders indicated that the maritime routes taken by containers are usually not in a direct line from the country of origin to the EU and may have several intermediate stops. Nonetheless they indicated that they were not recording precise information on the distance travelled by containers either at sea or on land.

Secondary processor

Secondary processing consists in cooking shrimp and packing them in 1 or 2 kg plastic containers to be sent to supermarkets. Stakeholders indicated that emissions associated with each step are not monitored: companies know their total energy consumption, but they are not detailing the different steps (cooking, chilling, cold storage)

Transport from secondary processor to supermarkets

Shrimps are usually transported by the same companies transporting fresh seafood in France. These transport companies usually report GHG emissions ratios combining all their activities at an annual level, which doesn't help understand the exact contribution of transportation to the shrimp GHG emissions.

As for the fresh seafood and the mussel supply chains, there is a difference between the long hauls and the last kilometres that are not operated by the same trucks. Long hauls tend to be operated with 18-tonne refrigerated trucks, while the last kilometres are more and more handled by smaller low-emission vans due to increasing restrictions on emissions and noise in urban and suburban areas, where most supermarkets and fishmongers are located.

There is no systematic record of the distance travelled nor the load factor of the trucks used, which would allow the evaluation of the GHG emissions associated with this transport.

Supermarkets and fishmongers

Freshly cooked shrimps are usually sold in 2 to 3 days in supermarkets. Fishmongers tend to have smaller stocks and sell most of their supply in 1 day. Shrimps are presented on fish counters refrigerated with ice flakes and stored in cold chambers at night.

3.2 Alternate distribution systems

Shrimps are currently distributed through supermarkets and fishmongers. According to stakeholders, there is very little space for the development of specific channels in e-commerce for shrimp products that cannot be associated with localism (which is one of the trends in e-commerce in France).

The current distribution of cooked shrimp in France lies with supermarkets and fishmongers (higher quality, either organic certified or covered by a Label Rouge certification mark[45]). Shrimp cooking companies have very little power to foster modifications in the logistic organisation implemented by the supermarket and wholesale chains (described in CS 8).

3.3 Limitations for structural improvements in GHG emissions

Stakeholders felt that most of the GHG emission gains to be obtained were outside the scope of their operations: gains may be obtained in production countries, either on the production itself (notably adaptation of the feed) or on the primary processing processes and the transport steps. Stakeholders estimate that the cooking operations are constantly being economically optimised, with energy as one of the main inputs. Rising energy costs will push companies to adopt the most energy-efficient technologies in the medium to long term. But these technologies will be adopted for cost-saving reasons, not to improve the GHG profile of shrimp cooking production.

4. Reducing GHG emissions by technical means

Stakeholders mentioned that the current business model of shrimp cooking was well established and well optimised economically. New cooking technologies may be developed but each technique is altering to the product's taste, which is an essential part of the final product characteristics for consumers. Some stakeholders mentioned that their units might not be using the latest technologies, but the taste obtained corresponded to their market target. Investments in new technologies would potentially be linked with a period of adaptation to obtain a similar taste, which is considered a too high risk in the current situation when profit margins are shrinking following the price rises experienced since the beginning of the Ukrainian war after two-year of Covid pandemic.

5. Conclusions

For the imported tropical shrimp PH chain, impacts of climate change are mainly about supply chain disruptions and the sector's ability to source aquaculture products that may suffer from production areas that are facing important challenges (warmer temperatures, sea rise, floods).

Stakeholders considered that existing business models were close to being optimised and that there would be a need for innovations to replace current cooking technologies for the sector to modify its practices.

6. References

Nirmal, N. P., Santivarangkna, C., Rajput, M. S., and Benjakul, S. (2020) Trends in shrimp processing waste utilization: An industrial prospective, Trends in Food Science & Technology, Volume 103, Pages 20-35, https://doi.org/10.1016/j.tifs.2020.07.001

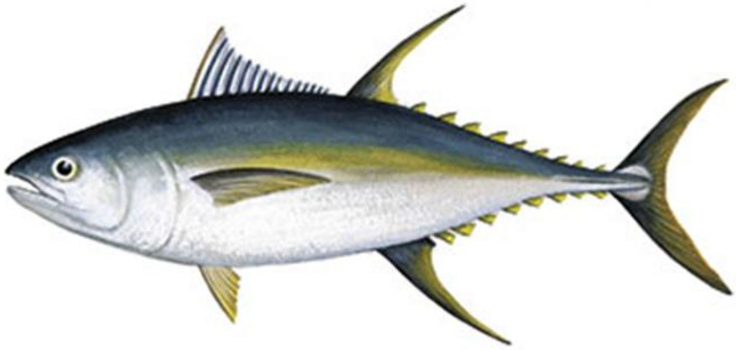
[45] French public quality system.

CASE STUDY 20: TUNAS - BAY OF BISCAY AND IMPORTED ALBACORE *(THUNNUS ALALUNGA)* AND YELLOWFIN TUNA *(THUNNUS ALBACARES)* - SPAIN

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Thunnus alalunga
Source: Official website of the European Union (https://ec.europa.eu)



Thunnus albacares
Source: Official site of Azti (https://www.azti.es)

Monica Gutierrez, Ane Ugena, Nerea Goienetxea, David Villanueva and Saioa Ramos

LIST OF ABBREVIATIONS

Term	Description
CAGR	Compound Annual Growth Rate
CSR	Certificate Signing Request
EEC	European Economic Community
EU	European Union
GHG	Green House Gas
HPP	High-Pressure Processing
ORI	Oceanographic Research Institute
QR	Quick Response code
RFMOs	Regional Fisheries Management Organisations
TAC	Total Allowable Catch
US	United States

1 Background

The albacore (*Thunnus alalunga*), also known as the longfin tuna, white tuna, or bonito, is highly migratory and widely distributed in the three major oceans, from 50ºN to 40ºS, except for 25ºN in the Indian Ocean (Collette, 2011). Within western European waters, albacore live during the winter in waters near the Azores, moving to the Cantabrian Sea at the end of spring (May to June). It is during these migrations that tuna campaigns begin (called the 'coastal season'), which generally ends in September. Vessels from Galicia, Asturias, Cantabria, the Basque Country, and France participate in this fishing season. The fishery was first certified in 2016, and the certification subsequently extended to additional fleets in 2019.

Albacore represents 7 % of the world's tuna catch, which is predominantly caught using tuna pole and commercial line-fishery techniques. This technique, pole and line gear captures tuna in a perfect condition, one fish at a time with little or no fight time, minimising bruising, skin abrasions and thus allows a higher quality meat and reduce the bycatches of marine animals. (ISSF report, 2019).

Yellowfin tuna (*Thunnus albacares*) is found worldwide in open water in tropical and subtropical seas. They are commonly found in water of 22°C and in the top 100m of the sea surface. In the Atlantic, yellowfin tuna is predominantly found in the southwest Cape region from spring to summer. By June they move south due to the increased northwest wind in the winter months, reflected in catches and seasonality of the tuna pole fishery. Generally, yellowfin tuna is more abundant in the Agulhas Current than albacore.

Modern commercial fisheries catch yellowfin tuna with encircling nets (purse seines), and industrial longlines. Formerly, much of the commercial catch was made by pole-and-line fishing, using live bait such as anchovy to attract schools of tuna close to the fishing vessel, however, purse seines account for more of the commercial catch than any other method nowadays.

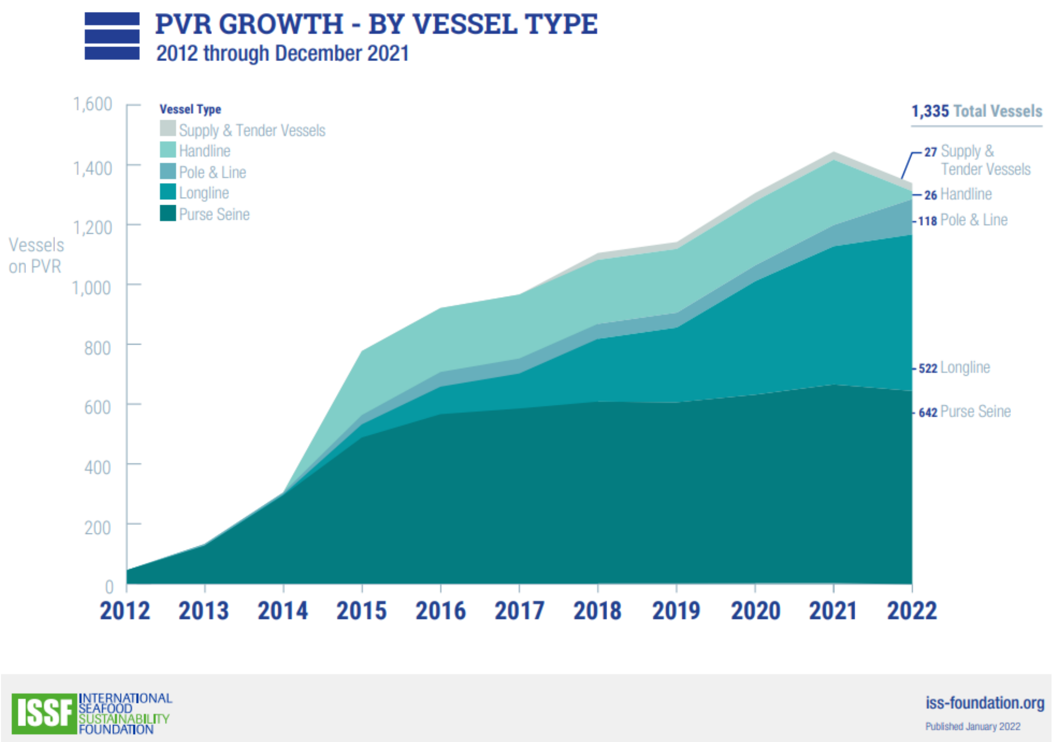


Figure 1: Distribution data for the different methods in tuna fishing. Source: ISS Foundation January 2022 (https://www.iss-foundation.org/).

Yellowfin tuna are ideal for canning, due to its dryer texture, but is also sold as fresh steak or in jars with olive oil.

The fishing sector acts not only as an important renewable resource, but also as a generator of employment and promoter of economic growth. Therefore, the effects derived from climate change and GHG are a potential challenge that society must face promptly to avoid impacts in the coming decades. Morphodynamical and chemical sea changes, ocean warming, and species migration involve multiple agents, but the fishing and fish processing sector, among others, are ones of the most affected by their consequences.

Thunnus alalunga and *T. albacares* comprise 21 % of global marine catches (FAO, 2016). However, both fisheries are 'fully utilized', and therefore are referred to as the most economically important tuna species or "principal market tunas" (Collette et al., 2011). Consequently, the intensified exploitation has caused a decline between 1954 and 2006 of 49 % of the total adult biomass (Colette et al., 2011).

These two species, as highly migratory species and due to their influence on the ecosystem structure, play an important ecological role in many regions, but the effects derived from climate change mentioned above have contributed to its damage.

Two studies regarding changes in sea temperature (Koutsikopoulos et al. (1998) and Borja et al. (2000) conclude that the south-eastern part of the Bay of Biscay showed the strongest warming trend and that air temperature, solar irradiance, vapour pressure and relative humidity explain most of that seasonal and interannual variability. Valencia et al. (2004), in another study, postulated that the morphological concavity of the south-eastern part of the Bay of Biscay results in a strong continental influence over this particularly stagnant region, and that, consequently, shelf waters are warmer in summer and fresher and colder in winter.

Tuna is characterized by dynamic distribution patterns that respond to climate variability and long-term change. For example, studies on Pacific Ocean skipjack (Dueri et al., 2016) predict significant changes in their abundance and spatial distribution in the future. It has also been predicted that the distribution of tuna will be affected by changes linked to physiological characteristics. For example, a decrease in oxygen concentration will compress the vertical habitat of tuna in the water column (Mislan et al., 2017).

2 Value Chain

2.1 Value chain description

The PH value chain of tuna from the Bay of Biscay (Figure 2) has two origins:

- Albacore tuna PH value chain starts at several Cantabrian fish auctions, where first sales take place after fresh landing by the tuna fleet. Approximately 40 % of the tuna landed is sent to canning production, the rest is destined for sale to consumers in fish shops, restaurants, and supermarkets. Primary production exists entirely from wild capture fresh (processed immediately), or they are frozen for later production during the winter months.
- Yellowfin tuna is frozen as it is caught in the Pacific, Atlantic and Indian Oceans and the logistic companies (freezer plants and distribution companies) store and distribute the frozen tuna to the canneries for their processing. In this case, 100 % of imported yellowfin tuna is destined to be canned.

The final market determines the quality of the product: type of canned tuna. Galicia has large canneries that supply supermarkets with small cans for home consumption. In comparison, the Basque Country and Cantabria are specialized in providing higher quality products such as restaurants and gourmet sector, which are distributed mainly in Spain and to European markets (such as UE, US, and Morocco).

In 2018, the volume of tuna and tuna-like species landed in the EU registered a 13 % increase from 2017 and totalled 385.511 tonnes. Nevertheless, the value decreased by 22 %, from EUR 975 million to EUR 761 million. This was due to a remarkable price drop in Spain, where the price of yellowfin tuna plummeted 53 % from 2017 to 2018, dropping from 4,19 EUR/kg to 1,94 EUR/kg. Spain, by far the EU Member State landing the most tuna, accounted for 88 % of its total volume and 77 % of its total value. In the country, landings reached 337.493 tonnes, 12 % higher than 2017, while value dropped 27 %, to EUR 571 million. On the other hand, imports of processed tuna as fillets (almost all skipjack tuna from Ecuador) continued an upward trend that saw annual increases of 10 % on average from 2016 to 2019 (EUMOFA 2020).

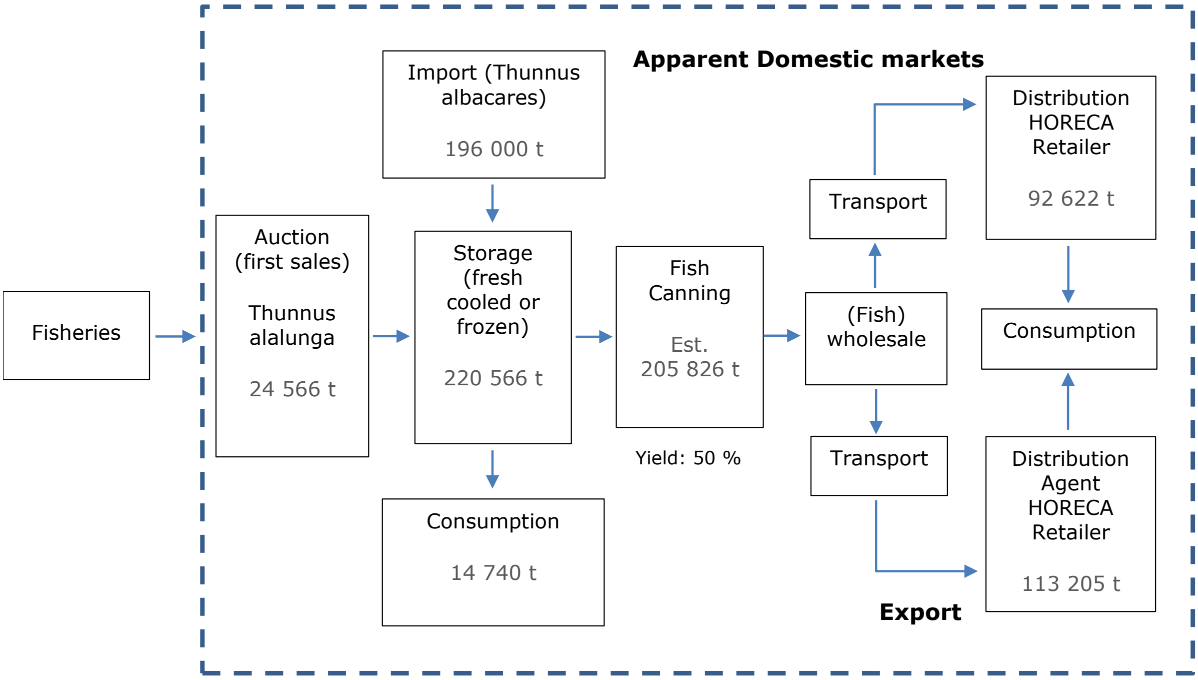


Figure 2. Postharvest value chain of Yellowfin and Albacore (2019-2020). Source: EUMOFA, European Commission (EUMOFA 2020)

Thunus alalunga is the tuna with more tradition in Bay of Biscay because of their distribution in the area. 60 % of the total captures are destined for direct consumption, and only the 40 % reach the canning industry to produce high value artisanal product.

Table 1. Postharvest value chain of *Thunnus alalunga* (2019). Sources: EUMOFA, European Commission (EUMOFA 2020)

Top 5 EU countries (landing volume)	Value first sales (annual) EUR'000	TAC in 2021 (tonnes)[46]	Main first sales locations	Product	Top importing EU countries (fillets)	Main sales
Spain 55 %; France 26 %; Ireland 11 %; Italy, Cyprus, Greece	94,775	Spain 30 %; France 14 %; Ireland 5 %; Portugal 5 %; UK 1 % TAC Atlantic Ocean: 57,600	Spain France	Canned	Spain 80 %; Portugal 12 %; France 7 %	Retail (supermarkets)

Spain, followed by France, is the country with the highest volume of fish landed, processed, and sold. The destination of this tuna is fresh sale to individuals and canned conservation for sale in the retail sector, HORECA channel and sale of high-value products.

Table 2 Postharvest value chain of *Thunnus albacares* in 2019. Sources: EUMOFA, European Commission (EUMOFA 2020)

Top 5 EU countries (landing volume)	Value first sales (annual) tonnes	Value first sales (annual) M EUR	Main first sales locations	Product presentation	Top importing EU countries (fillets)	Main sales
Spain 57 %; France 40 %; Italy 3 %	112,000	298,480	Spain; France; Italy	Frozen 52 %; Prepared or preserved 24 %; Loins 23 %	Spain 51 %; France 30 %; Italy 15 %	Retail (supermarkets)

On the contrary, the Thunnus albacares is a tuna that is fished in more distant seas and that reaches Europe in two ways: 50 % is frozen at the point of fishing and landed mainly in Spain and France. On the other hand, there is a percentage that is increasing year after year in which the tuna fished goes to the countries of South America (Ecuador and Peru mainly) where the first steps of the conservation process are carried out. The intermediate product, precooked loins, is imported by Spain and France, followed by Italy. The final product, sometimes of lower quality than the previous one, is processed in small cans for sale in supermarkets.

3 Resilience

3.1 Physical and financial resilience

Manufacturing of canned and frozen tuna products experienced a significant expansion with the economic integration of Spain into the European Union (EU) (Carmona X., 2022). However, the success of this expansion is the result of policies and practices influenced by the national extractive and processing sectors.

At the start of the Spanish integration into the EU, the fish canning industry was already a mature activity with a long tradition. However, in the decade before Spain entered the

[46] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1239 Weblink for EC with TACs 2021

EU, this industry had been largely obsolete, with a very small size and low international presence. Despite this, groups of processing companies were able to take advantage of several national changes to drive economic gains from manufacturing of canned and frozen tuna: (i) devaluations of the peseta (i.e., the currency of Spain between 1868 and 2002) at the beginning of the 1990s; (ii) the import taxes reduction that was dismantled in 1993; and (iii) European financial support from 1994 to 2006 to modernize factories and equipment and improve Spanish global competitiveness.

Such changes in the economic costs of catching and manufacturing tuna, allowed a range of Spanish companies to achieve a strong position in the seafood markets of Europe, increase the scale of their production and, in some cases, establish plants in Latin America. Such development of the Spanish tuna industry, the canning industry gained momentum and managed to overtake several of the former leaders and place itself in second place only behind Thailand.

3.2 Major financial constraints and reliability

The evolution of the Spanish fish canning industry is associated wholly with changes in the financial sustainability of the fishing industry. Below we provide details of what changes has occurred within this industry.

Tuna origin

The tuna processing industry developed worldwide since the beginning of the 20th century first as a complement and later as a substitute to the sardine canning industry. Indeed, the fish canning industry had developed during the 19th century in Europe using sardines and salmon, and later albacore (Thunnus alalunga) and bluefin tuna became the first tuna species to support intensive fisheries for the needs of fish canneries (Mongruel et al, 2010).

The development of the canning industry and the expansion of the tuna fleet in the second part of 20th century was, fundamentally, the consumption of the Spanish market. Since the end of the seventies, a new increase of tuna canned consumption was experimented thanks to successful marketing campaigns deployed by the main canning brands. To supply this growing market, tuna canners were forced to introduce new species specially frozen tropical tuna species. During the period 1989-1998, the supply of raw material to produce canned tuna was exceeded by a very stable demand throughout the period, which led to an increase in imports of raw material for the industry. As a result, some of the Spanish fishing companies made the decision to diversity their product range in the last half of the 20th century. A feasible way to achieve this was to introduce new species, such as tropical tuna. This resulted in the fishing fleet developing into a modern fleet of freezer purse seiners, fishing in Cantabrian coast and landing in Spanish ports, especially in Galicia (Ferarios Lázaro, 2013).

This development of the fishing industry into utilising tropical tuna resources, resulted in some canneries integrating vertically into the tropical tuna fishery to secure their supply and escape the volatile price fluctuations of tuna captures. Others decided to get involved in specialized companies to obtain a similar effect of risk reduction. In the end, most of the cannery companies established collective provisioning formulas through sectoral organizations or by simply focusing on the acquisition of tuna on the free market.

Business concentration process

Rapid growth after Spanish integration into the single market accelerated the concentration process, on the one hand by prompting new failures, and, on the other hand, through mergers as well as important entries into the sector. The first of the important mergers was that of two Basque canneries (Campos and Astorquiza) that, together with one of the main freezer purse seiner companies (Albacora), formed Sálica in 1990. The second was that of the Galicians Jesus Alonso and Escurís, which took place in 2001. The most important of the new entries was that of Frinsa, an important cold storage company that until then had been dedicated to the importing and marketing of tuna loins, who joined the group of tight canned producers in 1997. These five companies (Calvo, Garavilla, Jealsa, Frinsa and Sálica) accounted for 69 % of the sector's turnover in 2016 (Alimarket, 2018). The tuna canning industry within Spain had become an industry in which tuna accounted for the major share of their final product (where before they had been canning X and X species). This industry was also integrated into global value chains backwards and forwards, importing and intervening in fishing in several oceans and exporting almost half of its production to its European partners.

In early 2000s, the recent investments of European countries in several countries of Central and South America encouraged increases in production in those countries, causing changes in the location of the canning production plants.

Cost of sustainability

With changes in market preference away from meat (i.e., beef, lamb), manufactured fish products, such as canned tuna may play a substantial role in meeting rising global demand for sustainable animal protein. For example, in 2013 fish accounted for approximately 17 % of animal protein consumed by the global population. The fish protein market was valued at 2.95 million EUR in 2018 and is estimated to reach 4.02 million EUR by 2026, registering a CAGR of 4.0 % from 2019 to 2026.

A shift towards a more pescetarian diet has the potential to reduce GHG emissions.

Guaranteeing a sustainable product lies not only in the origin of the raw material (fish vs. meat vs. plant-based product), but also ensuring that the production of the material has a low greenhouse gas (GHG) footprint. For example, upgrading equipment, changes in insulation materials or updating the transport fleet can pose a major challenge to companies due to the increasing of investment and operational costs but also due to the need in the training of personnel in new technologies, in a artisanal sector, with aging personnel reluctant to change. Those additional costs associated with environmental improvements accumulated along the production chain are often reflected in an increase in the final price of the product. For this reason, even though the tuna sector has resisted for years in including environmental claims with their products, many producers are increasing the added value of their products through environmental labelling (Table 3) or CSR (Certificate Signing Request).

However, these types of labels are not focused on GHG emissions of the entire supply chain, but more the environmental sustainability of the product and the reduction in impacts to the wider ecosystem. In this regard, Czarnezki et al. (2014) reveal a variety of flaws and inadequacies associated with the current seafood eco-labels and suggests that private labels may not be the most appropriate means to convey neutral environmental information about seafood.

Table 3. Most common environmental labels for canned tuna.

MOST COMMON ENVIRONMENATL LABELS FOR CANNED TUNA		
	MSC – Marine Stewardship Council	MSC is widely used in tuna industry, almost 30 % is from a fishery that is already MSC certified and a fifth (20 %) is currently being tested to the MSC Standard. Another fifth of the global tuna catch is from fisheries working on improvements required to seek certification (19.5 % in a fisheries improvement project). This certification scheme checks tuna stocks are healthy and are being managed well, and that the fishery has minimised its impact on the ecosystem. That includes measures to minimise interactions with other marine species, such as dolphins, turtles, and seabirds.
	Dolphin Safe	Dolphin-safe labels are used to denote compliance with laws or policies designed to minimize dolphin fatalities during fishing for tuna destined for canning.
	Friend of the Sea	Friend of the Sea is a project of the World Sustainability Organization for the certification and promotion of seafood from sustainable fisheries and sustainable aquaculture. Essential criteria for fisheries are: i) the product should not originate from overexploited (nor depleted, data deficient or recovering) stocks, ii) the fishing method should not impact the seabed; iii) the fishing method should be selective (below the world average for discards, which in 2005 was about 8 %); and that iv) the fishery should respect all legal requirements.
	APR – Atún de Pesca Responsable	This Spanish Standard (UNE 195006), in addition to guaranteeing that the rights of sea workers are fulfilled, includes requirements related to maritime safety, the control of fishing activity, sanitary conditions and sustainable fishing practices.

3.3 Stakeholders' perceptions of Climate change and environmental footprint mitigation

To gather the perception of the agents involved in the value chain of canned tuna, regarding climate change and the mitigation of the environmental footprint of this sector, surveys were carried out to collect said information.

The first action developed was to carry out a flow with the canned tuna value chain. Figure 3 shows the value chain for canned tuna processing from the fish market to the consumers. This value chain involves not only the main line, but also other activities related to the value chain that may be relevant in the chain and that may be indirectly affected by climate change in your business, since it depends directly on the main line of the value chain.

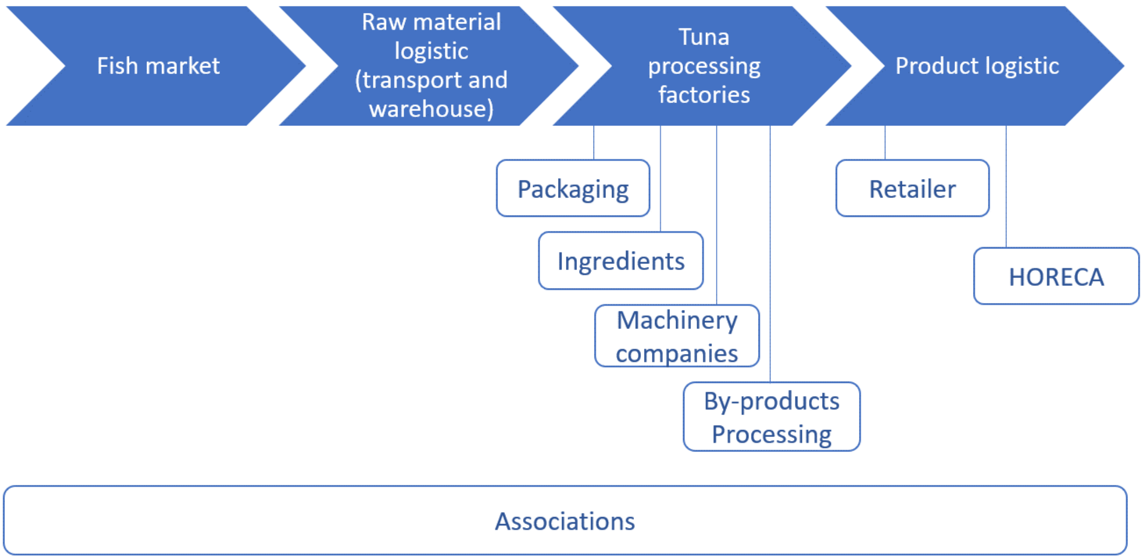


Figure 3. Stakeholders involved in tuna canning value chain

Once the different entities that were part of the value chain had been identified, a selection of one company for each of the following categories was made based on AZTI's experience and contacts to ensure their response:

- Fish auction
- By-product company (fishmeal)
- Retailer
- Logistics
- Canning lines manufacturers
- NGO
- Processor/trader

The second step was the sending of letters explaining the purpose of the project related to knowing the degree of adaptation to climate change and the mitigation of the environmental footprint of the companies that are part of the canned tuna value chain. Annex 1 contains the typical example used to send to the selected companies in Spanish and Basque languages.

Some of the contacted stakeholders answering the letter to find out more details. In the rest of the cases, a call was made to arrange a face-to-face appointment to facilitate the collection of information. This was decided due to the length of the questionnaire and the limited availability of time.

On the other hand, a translation and an adaptation of the recommended questionnaires was carried out to adapt them to each type of stakeholder and to save time and not confuse them with too many questions/information. Annex 2 shows an example of the reference questionnaire with some parts in pale ink to avoid in the interview.

Below is a summary of the main conclusions on the perception of the different consulted stakeholders on the changes that have occurred in the last 25 years and their impact on the value chain. A special focus has been made on the impact that climate change has had on its business and also the ability of the sector to adapt to these changes has been analysed. Finally, some of the stakeholders consulted have dared to foresee how there may be changes in the future to adapt to the changes to come.

All the interviews, except the by-product company, were made in presential mode. Stakeholders were asked whether climate change has had any effect on their respective industry. Although the impacts of climate change on tuna stocks have been well reported in the literature (Cortes 2021, Dueri 2016, Mongruel 2010, Ruiz-Salmón 2021 and Tan 2009), consulted stakeholders perceived that climate change has not special impact on tuna catches and on the rest of the tuna canning chain. Despite this, in the last 25 years stakeholders have detected that sometimes populations of albacore are closer to the coast than before, reducing the use of fuel by the commercial fleet, while also enhancing the opportunities for smaller boats to also utilise such resources. They stated that this is likely due to increased food resources for albacore (i.e., higher abundances of anchovy closer to shore). In 2005, the population of anchovies (albacore's main food) fell to extremely low levels, for which a biological strike was established (fishing was prohibited). The bans on the anchovy fishery helped to maintain the resource at sufficient levels of biomass to allow its recovery as soon as favorable environmental conditions allowed the survival of the juveniles. Thus, the abundance of this resource was restored to levels prior to the closure of the fishery.

Overall, **fish processors** have not perceived a substantial change in the size and weight of albacore. Some years they have a lower fat content, but this is likely due to changes in the availability of their food source (anchovy).

Production for all fish processors is highly dependent on water availability and energy consumption. Tuna canneries use large quantities of water for cleaning purposes and for cooking and sterilisation processes. Likewise, energy is needed in huge amounts for cold storage, sterilisation, cooking and can processes throughout the entire value chain. However, the costs of such resources have risen dramatically in recent years. (27 euros per MWh in March 2020, 45 euros per MWh in March 2021 and 345 euros per MWh in March 2022") Within the industry, reductions in water and energy consumption have been undertaken continuously across the last decade, but stakeholders stated that is likely not enough to ensure the sustainability of their businesses. Companies propose financial aid to modernize their technology to achieve more efficient equipment with less water and energy consumption

The logistics aspect also has changed accordingly within the value chain. Twenty years ago, the companies dedicated to the fish trade had their own fleets of fishing vessels, fish markets, refrigeration systems and logistics on land. But today, the prevailing economic systems mean that this has changed towards more economically viable models, that include outsourcing services for certain tasks. The integration of Spain into the European Common Market and the compliance with the Common Fisheries Policy treaties, meant a significant reduction in the fleet that fishes in European fishing grounds. This led to a business reorganization and separation of activities in search of more economically viable models. The business separation of fishing from fish canning activities caused that the raw material prices and availability to be more fluctuating.

There has been a change in the origin of **raw materials** for tuna canning industry. For example, 20-25 years ago, raw matter was landed and processed in Spain, from the start (tuna capture) to finish (tuna can). However, part of the production is now outsourced to Latin America (Ecuador and Peru, mainly), because the cheaper labour, less restrictive environmental legislation. There the raw tuna is processed into precooked loins, that are then frozen and sent to Spain where companies undertake a canning process.

Regarding the **auxiliary materials** used throughout the fish chain (can material, packaging), they have been adapted to cover hygiene regulations, including penalizing of single-use materials, as well as using less heavy and more easily storable materials.

Lastly, in recent years there has been greater **consumer** interest in the environmental performance of the products they buy. So, food industry, in general, has been motivated to make changes in the use of sustainable materials (more sustainable packaging) or products with more sustainable fishing practices leading to increased use of eco-labels products.

Table 4. SWOT tuna canning industry from Bay of Biscay. Based on interviews

	Helpful (to achieving the objective)	Harmful (to achieving the objective)
Internal origin (attributes of the organizations)	Strengths • Healthy source of protein • Canned tuna is a commodity with a wide use by consumers • High level of financial fundings for the investment in green technologies • Growing demand for high-value marine products, which can give rise to lower-value fractions for sale as raw material.	Weaknesses • High intensity in energy consumption in processes related with the storage (cold/freeze) or product transformation • Transport in trucks of the raw material and products, high dependency on fossil fuels • High intensity in water consumption in the processing sectors • Traditional sectors with old machines (energy/water inefficient)
External origin (attributes of the environment)	Opportunities • Circular economy principles contribute to ensure the fish value chain becomes more sustainable • High demand for marine products • The consumer is increasingly concerned about the environmental aspects of the products they consume	Threats • The changing price of energy due to environmental and geopolitical situations, which could make the industry unsustainable • Increasingly stringent European emissions regulations • Increasingly globalized transport, which makes it a more fragile link in the chain, in case of the increasing prizes in the fuel

4 Greenhouse Gas Emissions

4.1 GHG emissions in the value chain

The carbon footprint of canned tuna is estimated based on each kg of tuna as raw material, and includes downstream emissions from auction, tuna canning factories, storage, and distribution to retailer. Although there is an extensive literature regarding the effects of GHG on tuna fishing, there is limited data detailing the GHG emissions on the tuna manufacturing processes (Ruiz-Salmón et al., 2021).

Considering that only 365 kg out of 1000 kg are canned and that 90 g of tuna and 30 g of additive are put into each can, the carbon footprint of a can of tuna was quantified as 0.98 kg CO2 eq in the baseline scenario (considering the economic allocation of all co-products), while in the non-circular scenario it reached 1.01 kg CO2 eq per can.

In this sense, the low results for Ecuadorian canned tuna (Avadí et al., 2015) can be explained by lower fuel use in the Ecuadorian and Peruvian fisheries, mainly due to a better catch per unit effort in relation to a higher abundance of the resource (Fréon et al., 2014).

Cortés et al. (2021) published one of the most recent and complete studies on multi-product strategy to enhance the environmental profile of the canning industry towards circular economy in Spain. Regarding inventory data, Cortés et al. found that to process one tonne of raw tuna, 180.8 kWh of electricity, 2.6 MWh of natural gas and 120.6 L of water are consumed by the Spanish caning industry. The study concludes that canned tuna from Galicia (Spain) has an average impact of 8.2 kg CO_2 per kg of product. As the total product annually from Spain is 223000 tonnes (2015 values), the estimated GHG emissions from this industry are 1,828,870.600 tons CO_2 per year.

Comparing the complete value chain, Carlos *et al* was concluded that both the fishing stage and the production of primary packaging (tinplate or aluminium) are the main drivers of environmental impacts, and all improvement actions should focus on them.

It has been shown that the fishing and primary processing stages are the most relevant sub-systems within the environmental profile of the canned tuna value chain. The inventory of the fishing stage showed, as previous studies on different fishing fleets, that the impacts of the **fishing stage** come mainly from the *production and consumption of diesel and antifouling*. *Primary packaging* presented the highest environmental impact in the life cycle impacts of **canned tuna**. Aluminium production, lamination and extrusion had the highest impact in almost all impact categories, as expected for canned products. By-product valorisation processes, both edible and inedible, have proven to have a low impact, improving the final environmental impact.

The results show the need to improve the application of the circular economy in the tuna canning sector, converting waste into raw materials to produce new products, minimising the consumption of material and energy resources. In this sense, the application of multiproduct strategies has been shown to improve the environmental profile of canned products through the allocation of environmental burdens among the new products, although further analysis from a sustainability point of view is required.

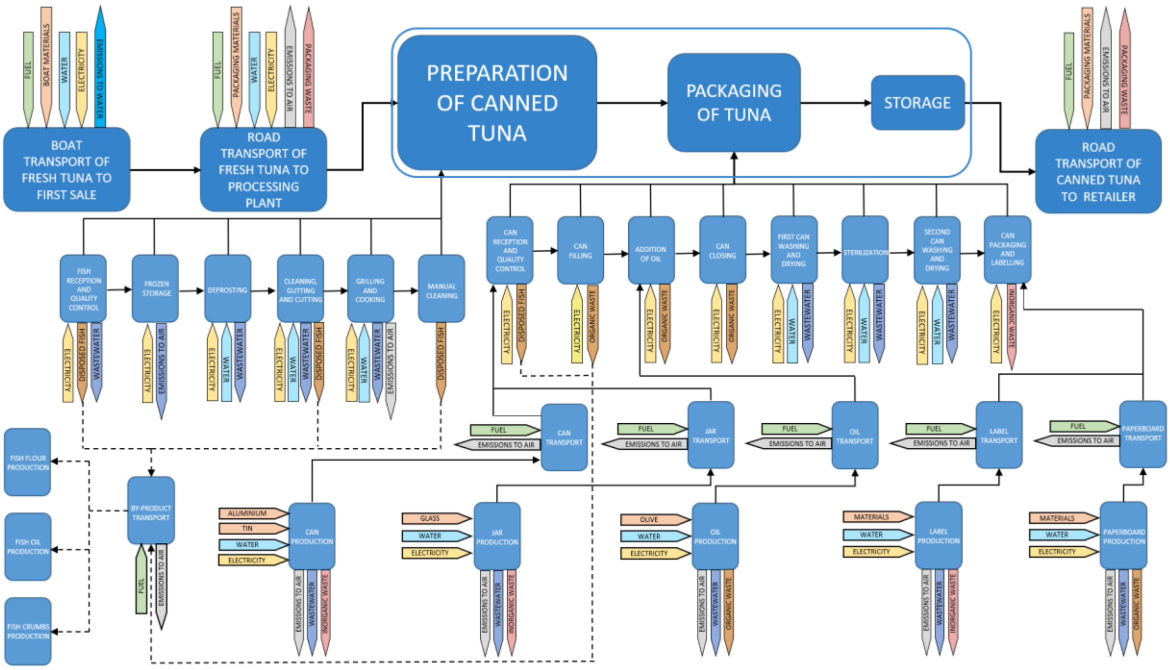


Figure 4: Detailed value chain diagram of generic canned fish

<u>Auction</u>

Once tuna is landed (in the harbour), its quality and certain chemical parameters, such as the amount of sodium or histamine, are checked to ensure that the fish is in perfect condition. After the quality check, tuna is then classified, auctioned to different companies, and then transported at a suitable temperature by refrigerated trucks to processing plants (Figure).

In the Basque Country there is a differentiation according to the species each harbour is specialized in. For example, the cod-fishing fleet has traditionally been concentrated in Pasajes, while freezer tuna vessels have been concentrated in Bermeo. Additionally, although all the harbours have tried to modernize themselves over the years, there are major differences between the infrastructure of the harbours of Galicia or Cantabria and those of the French coast. The albacore tuna is landed fresh in small boxes so that the piece does not suffer, then it is transported to the fish market/auction where it is conditioned fresh with flake ice until it is sold. This process takes a few hours, which ensures the quality of the product. For this reason, it is necessary in these ports to have ice machines nearby.

Figure 5: Main flow-chart of the processes involved in the auction

The main environmental aspects regarding the activities of the tuna value chain are energy consumption, mainly due to the cold storage and the refrigerated transport, the fuel used by vessels transporting the imported tuna and the fuel used during distribution to retailers.

Regarding fuel used by fishing fleets, there is concern among the companies involved since they fear that subsidies for fuel would be eliminated, this represent a major concern because fuel consumption depends completely on the location the fish are at.

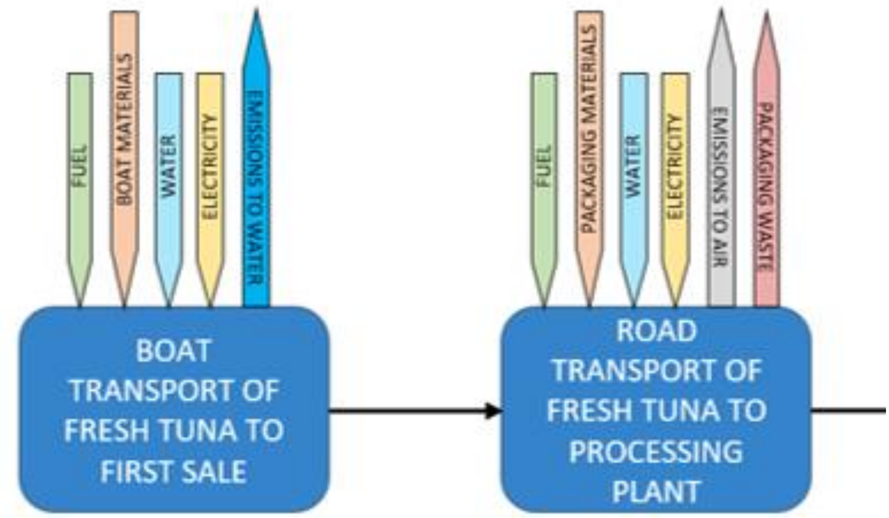


Figure 6: Main inputs and outputs in auction processes

Tuna canning factories

Once in the processing plant, salt, mercury, and other contaminants are measured and a quality control is carried out so all defective pieces can be discarded and sent as by-products for fishmeal, fish oil or animal feed production. The ones selected for processing within the factory, following the quality control, are weighed, classified, identified for traceability, and then stored at a suitable temperature until they are processed.

The amount of fish needed for the plant production is then thawed, either at room temperature or by defroster (with the consequent energy consumption in its case), and washed. Then, the head is cut with a cutting saw, the viscera are removed manually, and both are sent as by-products. A second washing is carried out to remove the remaining parts that will also be sent as by-products. Water used for the first and the second washing is recirculated in the factor and reused in the washing process.

Once pieces are washed, they are placed in stainless steel trays for cooking. After being cooked, tuna is left to cool before manual cleaning is carried out where fins, skin, tail, thorns, and dark coagulated blood are removed. Then the product is placed on a conveyor belt to be packed and the remaining scraps and smaller pieces are pressed and packaged to be sold as "fish crumbs".

Depending on the container used, the processed tuna coming from the conveyor belt is jarred or canned, then filled with cover liquid (olive oil, sunflower oil or vinaigrette) hermetically sealed (i.e., air- and watertight seal), and coded for traceability. The jars and cans are then washed with pressurized and reusable water to remove traces of oil, dried and taken into an autoclave for their sterilization. This final step eliminates microorganisms and ensures the product have a shelf life of approximately 6 years.

The product (canned or jarred) is rewashed, dried, labelled, packed, and stored at room temperature for its distribution. A quality control is carried out before, during and after all the packaging process, where the packaging material is subjected to a weight and appearance control.

The common general process line in tuna canning industry is shown in Figure 7:

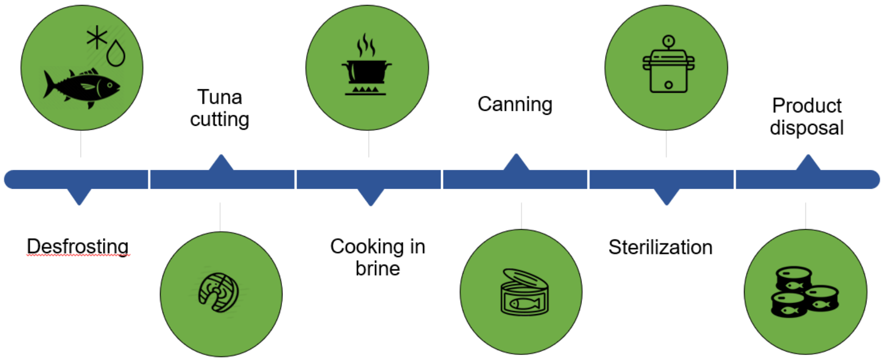


Figure 7: Main process line in tuna canning industry

Tuna canning is one of the most important food sectors in the Bay of Biscay. Specifically, companies settled in Galicia are medium or large sized companies, that market to large commercial stores. In comparison, the Basque Country is known for maintaining a traditional procedure from fishing to processing, dominated by small companies whose main objective is to obtain the best quality possible in the final product. However, the rise of raw material prices (see section 2.1 of this report), environmental regulations (Directive 91/271/EEC concerning urban wastewater discharges), and increasingly restrictive sustainability standards demanded by society (as mentioned in section 3.3), are some of the main challenges the sector is facing.

This industrial sector has an important environmental impact caused by the high water (9-17 m^3/Tn product) and energy consumption (240-530 Kwh/Tn product), and wastewater effluents with high organic load, oils and fats, nitrogen (N), phosphorus (P), solids, and salt content (10–50 times higher than urban wastewater, > 30000 μS/cm compared with urban wastewater around 500-2000 μS/cm). It also generates a high quantity of waste, since only 40 - 60 % of tuna can be used in the final canned product (Gutierrez, 2019). However, tuna discards are usually treated as by-products for the fishmeal and fish oil industry.

Many of these companies have the latest machinery on the market, understood as the most efficient technology with the lowest consumption, and claim to carry out measures to reduce their consumption of electricity and water. However, their interest lies in reducing costs in short and long term. They assure that they do not see a direct link between their activities and climate change, and even if there was so, they would not invest in it until they see that all agents in the value chain are committed to do the same.

4.2 Alternate distribution systems

The distribution system used by all the stakeholders interviewed, for both the transport of the product itself and the transport of auxiliary materials such as ice, is the groupage. This is a shipping method used for transporting goods from several customers in the same vehicle and enables higher fill rates and fewer empty running. The reason for working this way, according to the companies, is its cost-effectiveness. This method avoids having to buy trucks and hire workers, with all the expenses that this entails. In addition, by using such grouped transport, despite not being the main objective of the stakeholders, there is likely a reduction in transportation emissions and GHG associated with such transport, in comparison to individual transport by each company.

4.3 Limitations for structural improvements in GHG emissions

According to the information collected in the interviews with the stakeholders, several reasons are identified that limit the structural improvement for the mitigation of GHG emissions, affecting more than one stage of the tuna value chain in the Bay of Biscay.

One of the most important limitations is the irregularity in production, this is mainly affected by regulatory factors. This encompasses national fishing quotas, which are part of a mechanism that regulates the number of fish (per species) that can be fished by the fleet of each country. Sometimes, this quota is monopolized by a few members of the chain, which focuses the supply of tuna for the rest of the value chain, raising prices or forcing them to resort to imports.

Another regulatory factor that represents a limitation for some companies is the regulation and labelling that is handled for tuna species, e.g., Council Regulation (EEC) No 1536/92 of 9 June 1992 laying down common marketing standards for preserved tuna and bonito. This, added to the diverse requirements that each client requests according to the government that governs them, for example, tracking systems based on QR or bar codes intended to ensure food safety and preventing fraud (e.g., when a product is labelled as a bonito product, but it is made of other species of less commercial value), cause some participants in the tuna value chain to focus on other species with simpler RFMOs regulations.

For most stakeholders interviewed, undertaking structural improvements that enhance the economic situation of the company, the demand for the product and the production capacity are more important that those that reduce their GHG emissions (unless the reductions of such emissions are required by regulation). However, in recent years it has been observed that companies, mainly large ones, have begun to invest in environmental improvements with the aim of obtaining environmental certifications or labels, due to the increasing level of consumer awareness regarding the environment.

Lastly, although occurring on infrequent occasions, the lack of raw material to processors is associated with changing fish behaviour, which may or may not be present in the areas estimated for their fishing.

5 Reducing GHG emissions by technical means

5.1 Trends in technological evolutions and industrial strategies

In general, consulted stakeholders perceived those changes have occurred in the sector technologies, but that such change has been much slower than expected. Sometimes, they are the stakeholders themselves who contact their technology providers to demand equipment with lower energy consumption or that produces fewer emissions. However, price of such new equipment and the specificity of them in terms of process requirements (equipment must designed accordingly to fish species, sizes and product presentations handled by the processor) is a challenge for the industry, while the natural depreciation in value of the technology does not allow stakeholders to adequately recover any investment in such technology.

Many stakeholders work with companies that advise them on whether their processes or infrastructures are efficient or not, even so, they invest in the latest machinery on the market. This is so that the machinery lasts as long as possible and consumes as little resources as possible. All their processing machinery, including forklifts, pallet trucks, and the strapping machine located inside the fish auction, must be, by law, electric, however many companies still use combustion engine machinery.

Regarding the electricity used for chilling or freezing, the interviewees affirm that there is no great possibility of change in the market. Some of them have moved or changed the ice factory and have resized it to their current fleet. But this has been for economic reasons, not environmental. Other stakeholders anticipate a reduction in consumption since they will invest in thermal energy (currently evaluating technology options), and others have installed solar panels. However, even though in some months self-consumption reaches 50 %, other months does not exceed 5 %. Stakeholder have also carried out a study to assess the installation of electric or hybrid machinery on boats, but there is none on the market for small boats and it would not be feasible since their autonomy is of about 3 hours, which is not suitable for most journeys.

There is a discrepancy between different interviewees regarding government funds. According to some of them, there are not funds from associations to promote the implementation of technologies or strategies, or there are but they do not see that there is machinery or infrastructure that is profitable or effective. However, a few stakeholders have been subsidized by the Basque government to invest in strapping machines, scales, computers, etc., and have even provided funding, through a subsidy for businesses direct or indirectly related to fishing, to open their own retail fish shop.

Regarding associations, the interviews showed that they have not coordinated any initiative to form or inform its members about the strategies that can be implemented to reduce GHG emissions.

5.2 New processing and logistic techniques and their challenges

There are multiple current and emerging technologies in the fish processing industry, which, through decarbonization and a higher efficiency, help to reduce GHG emissions within the manufacturing process. These types of technologies are predominantly related to cold storage and freezing, control of water activity, heating, thawing, and packaging, and are described in detail below.

Control of water activity

A well-known drying technology is microwave heating. As this technique generates heat inside the product, it has great potential for decreasing processing times and increasing energy efficiency, compared to the traditional drying process, where the heat goes from the surface to the inside of the product (Duan et al., 2011; Viji et al., 2022). However, single microwave heating has several drawbacks, such as development of hotspots and overheating at the edges due to non-uniform temperature distribution (Viji et al., 2022). A combination of microwave and conventional drying or other emerging technologies has a vast potential to alleviate these drawbacks (Viji et al., 2022).

The airless drying system consists of a rotary-dryer that uses superheated water steam as drying medium. Heat is transferred from a heat exchanger to the drying medium to evaporate moisture from wet feed in the dryer. However, since airless dryers are designed according to process requirements and literature is limited, it is difficult to identify relevant improvements on airless dryers as a technology.

Another drying technique is the heat pump dryer, which is based on the use of hot and dry air of a controlled temperature and relative humidity. Integrating renewable energy sources, such as solar or geothermal, in hybrid systems to enhance the performance of conventional heat pumps are currently under research and development.

Among salting techniques, injection salting has been increasingly used to speed up salting, increase automation, homogenously distribute the salt within the seafood tissue and improve processing yields. To decrease the processing time and improve the diffusion of salt, the combined application of other food processing technologies such as pulsed electric fields, ultrasounds, or laser micro perforation, may enhance mass transfer during subsequent salting process and therefore could be utilised (Cropotova et al., 2021; Olivares et al., 2021).

Heating

An innovative cooking technology is the ohmic heating, which has been proposed for cooking and pasteurising fish. It is an interesting new technology due to its ability to heat foods quickly with minimal destruction and to provide higher energy conversion efficiencies, more uniform heating, and more reduced processing time comparing with the conventional thermal processing.

Sous-vide, meaning "under vacuum" is a technique where fish are packed in heat-stable vacuumized pouches and then cooked in water using low temperatures. It provides a very efficient and consistent transfer of heat from water to food product and increases the shelf life of products due to the absence of oxygen in the vacuum sealed pouch.

Ultrasound-assisted cooking involves the application of ultrasound during water immersion heating, accelerating the heat and mass transfer and, therefore, reducing processing time. It also reduces the loss of nutrients, development of off-flavours and deterioration of functional properties of foods that take place in thermal processing. Its application for fish cooking is an emerging technology that has been slightly studied during the last 20 years and remains at laboratory or pilot scale.

Air frying is an alternative technique of frying to dehydrate food products with hot air and oil droplets in the frying chamber; typically crust fried food with very low-fat content has been achieved (Fang et al., 2021; Yu et al., 2020). Air frying uses hot air circulation instead of hot oil, offering shorter processing time comparing to the conventional air drying, but a longer frying time than conventional frying. It not only exerts great benefits to health, but also has environmental advantages, such as lowering oil consumption and achieving the zero effluent discharge (Yu et al., 2020).

Vacuum frying is defined as the frying process that is carried out under pressures below atmospheric levels, preferably below 6.65 kPa (Andrés-Bello et al., 2010). Due to the low pressure, the boiling point of the water in the food is lowered. This reduces the processing temperature and the browning reaction during processing (Andrés-Bello et al., 2010; Fang et al., 2021). Thus, vacuum frying offers some advantages, including the reduction of the oil content in the fried product, the preservation of natural colour and flavours of the products and the reduction of adverse effects on oil quality (Andrés-Bello et al., 2010).

Regarding pasteurization, innovative technology currently on the market that could reduce energy consumption is microwave pasteurization, although it still has some bottlenecks such as lack of homogeneous heating or the impossibility to use metal packaging. Additionally, non-thermal emerging technologies with the potential to be used for pasteurization includes the use of cold plasma, high hydrostatic pressure, pulsed lights, ultrasound, or ultraviolet decontamination.

Emerging thermal and non-thermal technologies could have environmental benefits by improving the overall energy efficiency of the process (Pereira and Vicente, 2010). For instance, cold pasteurization using high-pressure processing (HPP) can potentially reduce energy use by 20 % compared to traditional thermal processing (Boziaris, 2014). However, a fair comparison of the processes is not easy since most of the measurements are done at pilot scale and thus, proper process specifications have not been given.

Thawing

Microwave assisted thawing, where microwaves penetrate the product heating both interior and surface may be an important step forward. At an industrial level, it can be applied in both batch and continuous conditions. Microwave assisted thawing requires shorter thawing time (minutes) and smaller space for processing, also reducing drip loss and chemical deterioration (Li & Sun, 2002). However, there is still need for further improvement in this technique, including uniformity of heating and temperature control. It cannot be used in the presence of metallic packaging.

Radiofrequency assisted thawing works similarly to microwave assisted thawing, though are different in terms of the wavelength and direction of them produced. Radiofrequency waves have a longer wavelength, and they move from one electrode to another, while microwaves have a shorter wavelength and move in a random way. These characteristics make radiofrequency better at heating regular shaped thick objects than microwaves, which are better at heating irregular shaped objects. Both technologies require short thawing times (minutes) and are energy efficient, they both also have common issues like the lack of uniform heating (James et al., 2017) and proper temperature control (Li et al., 2020).

6 Conclusions

- The consulted stakeholders were very interested in sharing their experiences in the sector throughout their professional career, however, they refused to share more precise data when asked about financing or environmental projects.
- Few of the stakeholders knew their environmental footprint, and when asked for production data, or other aspects related to their environmental development, they were reluctant to share it.
- The vast majority of GHG emissions within the canned tuna PH value chain come from primary packaging and energy (electricity and natural gas) consumed for heating and sterilization processes. Thus, increasing energy efficiency and finding alternative energy sources are relevant aspects to care about when intending to minimise GHG emissions.
- Even though machinery providers constantly invest on improving equipment efficiencies there is a short room for achieving relevant breakthroughs on this field. This means that a great part of the companies' efficiency depends on operation and production strategies.

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Supplementary 1: Letter explaining the purpose of the questionnaire

A quien corresponda:

Contacto con usted en nombre de **AZTI, Centro Tecnológico** miembro de la Alianza Vasca de Investigación y Tecnología (Basque Research & Technology Alliance).

Actualmente, AZTI forma parte de un **estudio a nivel europeo**, comisionado por la Unión Europea, enfocado en la **adaptación de las actividades post-pesca de la cadena de valor pesquera frente a los efectos del cambio climático**, y a la **mitigación de su huella ambiental** mediante la reducción de emisiones de gases de efecto invernadero.

El objetivo de dicho estudio es permitirle a la Comisión evaluar si la actual Política Pesquera Común tiene en cuenta las implicaciones del cambio climático en la gestión pesquera, y cómo esta política puede contribuir a la mitigación del cambio climático.

Una parte crucial del estudio es la **recogida de información facilitada por las organizaciones y empresas referentes** dentro de la cadena de valor pesquera, como lo es [Nombre de la empresa], por lo que estaríamos muy agradecidos si nos concedieran una entrevista con el objetivo de recabar los datos necesarios para el estudio.

Su colaboración es de gran importancia para presentar un **panorama representativo sobre la cadena de valor post-pesca**, y a su vez nos permitirá **transmitir las necesidades y/o preocupaciones de su sector a la Comisión Europea** con el objetivo de que sean tomadas en cuenta en el futuro.

La información recabada durante la entrevista **no será publicada y será tratada siguiendo acuerdos de confidencialidad y no-divulgación**.

Sin más, por el momento, quedo a la espera de una respuesta y de la posibilidad de acordar una fecha y hora para la entrevista.

Gracias.

AZTI

Nori dagokion:

Zurekin harremanetan jartzen naiz **AZTI Fundazioa**ren izenean, Euskal Aliantzako kide den Ikerketa eta Teknologiako zentro teknologikoa.

Europar Batasunak eskatuta, AZTI **Europa mailako ikerketa** baten parte da, alde batetik, **arrantzaren balio-katearen ondorengo jarduerak, klima-aldaketaren ondorioetara egokitzea**ri eta bestetik, berotegi-efektuko gasen isuriak murriztuz **ingurumen-aztarna murriztea**ri zuzenduta dagoena.

Ikerlan honen helburua, Batzordeari, egungo Arrantza Politika Bateratuak arrantzaren kudeaketan klima-aldaketak kontuan hartzen dituen eta politika horrek klima-aldaketa arindu dezakeen balioztatzeko aukera ematea da.

Azterketaren zati erabakigarria arrantzaren balio-katearen barnean, [Enpresaren izena]ren moduko **erakunde eta enpresa erreferenteak emandako informazioa biltzea** da, beraz, asko eskertuko genuke azterketarako beharrezkoak diren datuak biltzeko zuekin elkarrizketa bat.

Zure parte-hartzea garrantzi handia du **arrantzaren ondorengo balio-katearen ikuspegi adierazgarri** bat aurkezteko, eta, aldi berean, zure **sektorearen beharrak edo/eta kezkak Europako Batzordeari transmititzeko**, etorkizunean kontuan izan daitezen.

Elkarrizketan bildutako informazioa **ez da argitaratuko** eta mezu elektroniko honi erantsitako **konfidentzialtasun eta ez-ezagutze akordioei jarraituz erabiliko da**.

Gehiago luzatu gabe, momentuz, erantzunaren eta elkarrizketarako data eta ordua adosteko aukeraren zain nago.

Eskerrik asko.

AZTI

Supplementary 2: Reference questionnaire used for the interviews

PARTE 1: DETALLES DEL ENTREVISTADO

Nombre del entrevistado:
Organización:
Ubicación (ciudad o municipio) y país:

Tipo de organización (selecciona una de las siguientes opciones):

- X Lonja
- ☐ Procesador (incl. packaging)
- ☐ Importador/Exportador
- ☐ Venta mayoreo (solo marisco)
- ☐ Venta mayoreo y distribución (no solo productos marinos)
- ☐ Agente comercial y distribución
- ☐ Compañía de transporte (marítimo, Terrestre o aéreo)
- ☐ Almacenamiento (frio, fresco o seco)
- ☐ Marketing
- ☐ Vendedor (Retailer)
- ☐ HORECA
- ☐ Proveedor de tecnología

Especies:
Link to website organisation:
Email:

PART 2: TASK 1 – RESILIENSIA DE LA CADENA DE VALOR

Preguntas indicadas en Amarillo son sugerencias de preguntas importantes para todos los sectores

PASADO (hasta 15-25 años atrás)

a. ¿Hubo en el pasado eventos relacionados con el clima que afectaron a su organización (p. ej., cambios en el suministro de pescado, cambios en el transporte, proliferación de algas, inundaciones, abundancia o desplazamiento de las poblaciones de peces)?
   a. En caso afirmativo, ¿qué eventos y cuál fue el efecto?

PRESENTE (ahora y hasta 5 años adelante)

b. ¿Hay algún evento actual o previsto (dentro de 5 años) impulsado por el clima que afecte a su organización? Si es así, ¿puede dar ejemplos?
   P.ej. inundaciones por lluvias intensas u olas, aumento del nivel del agua del mar, aumento de la temperatura del agua, calores de verano, períodos de invierno más fríos, cambios de estaciones, etc.

c. Complete la matriz de confrontación FODA con respecto al cambio climático que actualmente (o se espera dentro de 5 años) afecta a su organización:

		Factores externos (fuera de su círculo de influencia como organización)	
		Oportunidades	Amenazas
Factores internos (Dentro de su círculo de influencia como organización)	Fortalezas	• ..... • ..... • *Dirección interesante para invertir su esfuerzo*	• ..... • ..... • *Amenazas que no tienen tanto impacto para su organización*
	Debilidades	• ..... • ..... • *Donde otras organizaciones ganan en competencia con la suya*	• ..... • ..... • *Aquí necesita una mejor estrategia de defensa para su organización*

a. ¿Qué es lo que más le impulsa/motiva o estimula a usted como organización a tomar medidas sobre el cambio climático? Por ejemplo, ¿supervisa e informa sobre su huella (por ejemplo, CO2) impuesta por otros (su minorista, inversor/banco financiero, etiqueta ecológica, etc.) o es su propio interés/iniciativa?

b. ¿Percibe alguna ventaja o desventaja como organización debida al cambio climático?
    a. ¿Cuáles desventajas? Por ejemplo, el cambio o migración de las poblaciones de peces, mayor tasa de mortalidad entre los productos del mar para la cosecha, mayores costos de producción debido a un transporte más prolongado o escasez de materias primas y recursos, materia prima de menor calidad (debido al aumento de las temperaturas, mayor riesgo de que los productos del mar perezcan, etc.).
    b. ¿Cuáles ventajas? (por ejemplo, especies nuevas o futuras en áreas de pesca regionales, mejor posición de competencia debido al impacto climático en otros lugares del mundo, etc.)

c. ¿Existe alguna legislación o restricción (e.g. Fit for 55, impuestos de carbono, energía, uso de agua potable o impuestos por aguas residuales), vigente o esperada, relacionada con la sostenibilidad o el ambiente que afecte a su organización?

d. ¿Su organización ha hecho adaptaciones para mitigar o fortalecer su resiliencia física y financiera? *Ver table 1 para información general sobre potenciales adaptaciones contra el cambio climático*
    a. ¿Fueron exitosas? ¿Podría explicar por qué y cómo?

e. ¿En qué medida son afectados sus ingresos/facturación por eventos climáticos?
    a. Por ejemplo, ¿aumentó el costo operacional (producción)?

b. Si así fuese, ¿cuáles costos y en qué medida?
c. ¿Tiene costos de compra más altos o más bajos para los productos del mar debido a los costos relacionados con el cambio climático por parte de sus proveedores?

FUTURE (15-25 years ahead)

a. Considera que en los proximos 15 a 25 años sucederán eventos climáticos que afecten a su organización?
    a. Si es así, ¿cuáles serían estos eventos climáticos?

b. ¿Cuáles son los tres impactos/riesgos más importantes para su organización?
(La tabla 2 en el apéndice presenta una lista con ejemplos de impactos y riesgos)

c. ¿Qué podría hacer tu organización para enfrentar dichos impactos y riesgos?

d. ¿Cuáles son las principales oportunidades y barreras por afrontar con estos impactos y riesgos?
Por ejemplo: legislaciones, tamaño/fuerza de la industria, costos, administración, conocimiento.

e. ¿Qué flujos comerciales, diferentes debido al cambio climático, espera dentro de 15 a 25 años?

f. ¿Qué tipo de costos prevé que aumentarán debido al cambio climático, y en qué medida, en los próximos 15 a 25 años?

g. ¿Cuáles oportunidades ve en los eventos propiciados por el cambio climático? (nuevas especies, cambios en el consume de pescado, etc.)

GENERALES

h. ¿Cómo informa e involucra a los consumidores (B-2-C) y los canales de distribución (B-2-B) para cambiar sus patrones de compra/consumo teniendo en cuenta el cambio climático? (por ejemplo, ¿qué instrumentos de marketing aplica y cómo garantizar que se promuevan las especies menos familiares para los minoristas y los consumidores?)

i. ¿Cómo podrían sus clientes y consumidores estar informados e involucrados para adaptar su comportamiento de compra de productos del mar para que coincida con las especies nuevas/próximas y/o disponibles localmente debido al aumento de la temperatura del agua u otros eventos de cambio climático?

j. ¿Tiene alguna recomendación o solución técnica para reducir las emisiones de GEI dentro de la cadena de valor?

Tabla 1: Estrategias de mitigación y adaptación por parte de las partes interesadas de la cadena de suministro de productos del mar para gestionar los impactos del cambio climático.
Fuente: Fleming y otros (2013). Riesgos del cambio climático y opciones de adaptación en las cadenas de suministro de productos del mar de Australia: una evaluación preliminar. Gestión de riesgos climáticos 1 (2014) 39–50.)

Impactos directos del cambio climático	Impactos indirectos del cambio climático	Posibles adaptaciones al cambio climático	Adaptación potencial para otros factores impulsores y cuestiones de política
Eventos climáticos extremos	Aumento de los costos de combustible y energía	Cambiar la estructura de la industria (número de operadores, licencias)	Mejorar la concienciación y la información pública (diferenciación de especies, sostenibilidad)
Cambios en las ubicaciones del stock	Mayor incidencia de enfermedades	Mejorar el marketing (etiquetado, información, aumentar el atractivo)	Simplificar o superar regulaciones (restricciones de desarrollo, número)
Cambios en las existencias (volúmenes, temporadas, velocidad de crecimiento)	Mayor uso de energía	Mejorar la eficiencia del combustible (eficiencia de los buques, reducir los enlaces de transporte, tiempos de pesca o transporte más específicos y uso de combustible)	Apoyar la formación y acreditación y la próxima generación de trabajadores
Aumento de la temperatura		Monitorear/modelar impactos (acidificación, oxígeno disuelto, nivel del mar, lluvia, salinidad, enfermedades)	Igualar la demanda
		Programas de cría	Aumentar el enfoque en vivo
		Aumente la colaboración en toda la cadena de suministro	Reducir la dependencia de la captura salvaje (huevas/stock, alimento)
		Cambiar ubicaciones	Aclarar los objetivos de la pesca para minimizar el conflicto o la confusión.
		Cambiar horarios de temporada	Aumentar la exportación
		Mejora del producto (certificación, acreditación)	Total de veces que se discutió la actividad
		Cambiar de especie	
		Cambiar la pesca, las opciones de recolección (jaulas más grandes, bastidores de elevación, nuevas técnicas, captura incidental)	
		Cambiar las opciones de almacenamiento (cultivo en tanques, almacenamiento en el extranjero)	
		Cambio de marketing (nuevos mercados, nuevos productos)	
		Usar energías alternativas	
		Mejorar la eficiencia energética	

Mejorar la eficiencia del agua

Tabla 2: lista de impactos y riesgos a través de la cadena de valor de productos del mar causados por el cambio climático

Eslabones de la cadena de suministro	Tipología de impactos/riesgos del cambio climático
Procesado	• Daño o destrucción completa de los activos
	• Ausencia o aumentos en los volúmenes de suministro de materias primas (mariscos desembarcados o cultivados)
	• Mayores costos de compra (primeras ventas, por ejemplo, debido a viajes de pesca o transportes más largos, o escasez debido al mal tiempo, etc.)
	• Riesgos de responsabilidad
	• Interrupción de plantas y líneas de producción
	• Regulación con respecto a las emisiones de carbono
	• Cambios en la eficacia o eficiencia de los procesos de producción
	• Mayores costos de energía y actividades de mantenimiento
	• Mayor costo de las operaciones aguas arriba en la cadena y la calidad del producto
	• Estímulo de inversiones en energías renovables y eficiencia energética
	• Despliegue de prácticas operativas de menor intensidad de carbono (con menores emisiones de GEI)
Transporte	• Problemas relacionados con las defensas costeras
	• Retrasos que conducen al pago de indemnizaciones a los operadores y causan problemas a los clientes
	• Cables aéreos caídos debido a fuertes vientos
	• Deslizamiento de tierra resultante de fuertes lluvias
	• Asegurar la estabilidad de las estructuras
Almacenaje	• Vulnerabilidad de infraestructura, personal, comunicaciones, suministro, etc.
	• Posible dislocación debido a eventos climáticos extremos
	• Mayores costos de energía para congelar o enfriar los productos del mar con calores de verano
Distribución/minoristas/HORECA	• Riesgo reputacional en los sectores aguas abajo debido a una mayor necesidad de transparencia
	• Disminución o agotamiento de la venta (agotado) de productos del mar debido a contratiempos provocados por el cambio climático en la cadena de suministro

	• Nuevas regulaciones sobre el etiquetado de productos
	• Aumentos en los costos y precios de producción de bienes de consumo
Consumidores	• Necesidad de mejorar el diseño del producto con el objetivo de eliminar el material de empaque y mejorar la durabilidad, reutilización, reciclabilidad y eficiencia de los materiales del producto
	• Inflación de productos del mar debido al aumento de costos relacionado con el cambio climático
	• Agotamiento de existencias de ciertos productos del mar debido a contratiempos provocados por el cambio climático en la cadena de suministro

PART 3: TASK 2 - REDUCING GHG EMISSIONS BY STRUCTURAL MEANS

En este trabajo nuestro objetivo es estimar las emisiones de gases de efecto invernadero relacionadas con el suministro de productos del mar. Para ello, necesitamos comprender las emisiones asociadas a todas las actividades a lo largo de la cadena, desde la captura hasta el punto de venta al usuario final (consumidor). Tomamos en consideración las emisiones directas (como el uso de combustible), pero también los efectos indirectos. Por ejemplo, cuando se usa hielo, este hielo se produce en una máquina que consume electricidad. Todas las emisiones se asignan a los productos vendidos. Esto implica que cuando se producen pérdidas, las emisiones por kg de producto vendido aumentan algo.

PESCADORES

a. ¿En qué país y puerto atracan?

b. ¿Cuánto pescado pescan anualmente?

c. Uso de combustible:
   a. ¿Qué tipo de combustible usan en los barcos?
   b. ¿Cuál es el consume anual de combustible por barco? (aproximado)

d. Energía en tierra asociada con el pescado (hasta su punto de venta):
   a. ¿Qué tipos de fuentes de energía (incluyendo electricidad), relacionada al pescado, utiliza su organización?
   b. ¿Cuál es su consumo anual de estos combustibles/electricidad?
   c. Si el consumo de electricidad no está disponible:
      i. ¿Cuánto tiempo está almacenado el pescado entre su llegada hasta el transporte hacia el cliente?
      ii. ¿El almacén está refrigerado, o el pescado se mantiene frio con hielo?

e. Hielo para refrigeración y almacenaje:
   a. ¿Colocan el pescado en hielo?
   b. Si es así, ¿producen el hielo con su propia máquina? (entonces la producción de hielo será incluida en la información sobre consumo de electricidad)
   c. Si el hielo es comprado, ¿cuánto hielo se compra por tonelada de pescado?

f. ¿Ha cambiado significativamente el consumo de energía en los últimos 20 años?

g. ¿Prevén reducciones significativas de consumo de energía en los próximos 10 años?

h. ¿Intenta activamente reducir el impacto climático? Si es así, ¿cómo?

TRANSPORTE

Pescado de la pesquería al comerciante, del comerciante al cliente, del centro de distribución al minorista u otros clientes.

a. ¿Cuáles son las ubicaciones de salida y destino? (país + nombre de ciudad)
    a. Pregunta alternativa: ¿cuál es la distancia de transporte desde la salida hasta el destino?

b. ¿Con qué tipo de vehículo se transporta el pescado del pescador al comerciante? (camión grande, camión mediano, camión portacontenedores, barco portacontenedores, barco portacontenedores, avión, etc.)

c. ¿Cuánto hielo se añade por tonelada de pescado?

COMERCIANTE

a. Energía utilizada por el comerciante (hasta el punto de venta):
    a. ¿Qué tipos de fuentes de energía (incluyendo electricidad), utiliza su organización?
    b. ¿Cuál es su consumo anual de estos combustibles/electricidad?
    c. Si el consumo de electricidad no está disponible:
        i. ¿Cuánto tiempo está almacenado el pescado entre su llegada hasta el transporte hacia el cliente?
        ii. ¿El almacén está refrigerado, o el pescado se mantiene frio con hielo?

b. Hielo para refrigeración y almacenaje:
    a. ¿Colocan el pescado en hielo?
    b. Si es así, ¿producen el hielo con su propia máquina? (entonces el uso de energía para la producción de hielo se incluirá en los datos de consumo de electricidad)
    c. Si el hielo es comprado, ¿cuánto hielo se compra por tonelada de pescado?

c. ¿Qué porcentaje del pescado es descartado/perdido?

d. ¿Su organización empaca el pescado?
    a. Si es así, ¿qué tipos de materiales de empaque son utilizados? (incluyendo almohadillas absorbentes de humedad) ejemplo: plástico, metal, latas, etc.

e. ¿Cuál es el peso promedio de este material por tonelada de producto de pescado?

f. ¿Qué otros materiales son utilizados? (ayudas al proceso, aceites añadidos, nitrógeno líquido, CO_2, etc.)

g. ¿Cuánto de estos materiales se usa por tonelada de pescado? (o por tonelada de producto de pescado)

PROCESADOR

a. Ubicación (ciudad y país)

b. ¿Qué tipo de proceso(s) realizan? (fileteado, enlatado, …)

c. ¿Qué alimentos o productos para piensos (u otros productos con valor económico) obtiene del pescado?

d. ¿Cuál es el volumen de producto o productos en relación con el volumen de pescado suministrado? (en otras palabras: ¿cuál es la eficiencia de fileteado/procesamiento?)

e. ¿Cuál es la relación económica entre las corrientes de productos?

f. ¿Cuál es el destino de los residuos?

g. ¿Qué cantidad de residuos es generada por tonelada de pescado suministrado? (Puede ser por múltiples productos)

h. ¿Qué porcentaje de pescado es rechazado/perdido?

i. ¿Cuál es el destino de ese pescado?

j. ¿Cuál es el destino actual de los residuos?

k. ¿Cuánto tiempo se almacena el pescado antes de ser procesado?

l. ¿Cuál es el consumo total de electricidad de la planta por tonelada de pescado suministrado? (También puede ser expresado por tonelada de producto vendido)

m. Si el consumo total de electricidad no está disponible, se intentará estimarlo a partir de las siguientes actividades:
    a. ¿Se enfría el pescado durante el almacenamiento con el hielo que se agregó antes del suministro, o se enfría activamente con el equipo de almacenamiento de refrigeración?
    b. Si el pescado se mantiene en una sala de almacenamiento con refrigeración eléctrica, ¿cuánto tiempo se mantiene allí antes de procesarlo?
    c. ¿Cuál es el uso de electricidad en el procesamiento por tonelada de pescado (o por tonelada de producto alimenticio)?
    d. ¿Añaden hielo a los productos finales?
    e. Si es así, ¿producen hielo con su propia máquina? (entonces el uso de energía para la producción de hielo se incluirá en los datos de consumo de electricidad)
    f. Si el hielo es comprado, ¿cuánto hielo se compra por tonelada de pescado?
    g. ¿Cuánto tiempo son almacenados los productos de pescado después del procesado?
    h. ¿El producto de pescado durante el almacenamiento se enfría con el hielo que se agregó, o se enfría activamente con el equipo de almacenamiento de refrigeración?

n. ¿Qué otras fuentes de energía son utilizadas en la planta? (gas natural, aceite combustible, etc.)

o. ¿Cuánto de estas se utiliza por tonelada de pescado? (o por tonelada de producto de pescado)

p. ¿Qué tipos de materiales de empaque son utilizados? (incluyendo almohadillas absorbentes de humedad) ejemplo: plástico, metal, latas, etc.

q. ¿Cuál es el peso promedio de este material por tonelada de producto de pescado?

r. ¿Qué otros materiales son utilizados? (ayudas al proceso, aceites añadidos, nitrógeno líquido, CO_2, etc.)

s. ¿Cuánto de estos materiales se usa por tonelada de pescado? (o por tonelada de producto de pescado)

t. ¿Ha cambiado significativamente el consumo de energía en los últimos 20 años?

u. ¿Prevén reducciones significativas de consumo de energía en los próximos 10 años?

v. ¿Intenta activamente reducir el impacto climático? ¿Si es así, cómo?

w. ¿Prevén cambios en el destino de los residuos?

MINORISTA/OTROS PUNTOS DE VENTA

Los datos se proporcionan preferiblemente por producto pesquero individual.

a. Cuando corresponda: ¿cuánto tiempo en promedio se almacena el pescado entre el suministro y la colocación en el estante minorista?

b. ¿Cuál es el período promedio de mantenimiento en el estante (desde el momento del suministro y el momento de la venta)

c. ¿Añaden hielo al pescado?

d. ¿Producen el hielo, es suministrado con el pescado o es suministrado por separado?

e. ¿Cuánto hielo por kg de pescado?

f. ¿Qué porcentaje de pescado es desechado?

g. ¿Cuál es el destino del pescado desechado?

h. ¿Utilizan material de empaquetado?
    a. Si es así, ¿qué material y cuanto por kg de pescado?

PART 4: TASK 3 - REDUCING GHG EMISSIONS BY TECHNICAL MEANS

La lista exhaustiva de preguntas a continuación es relevante para cada sector dentro de la cadena de valor postcosecha. Como no todas las preguntas se pueden hacer en una entrevista con tiempo y recursos limitados además de contactos limitados, el entrevistador puede elegir preguntas relevantes para su entrevista relacionadas con la TAREA 3. Las preguntas indicadas en amarillo son sugerencias de preguntas importantes para todos los sectores. Las preguntas técnicas específicas de los diferentes sectores se pueden encontrar debajo de las preguntas generales (p. ej., productor de alimentos para peces, minoristas, distribuidores) y son especialmente importantes para las asociaciones, los proveedores de tecnología, las ONG y las administraciones públicas. Dado que los proyectos actuales tienen como objetivo recopilar datos cuantitativos tanto como sea posible, se recomienda hacer preguntas cuantitativas y buscar los números.

PREGUNTAS GENERALES

General

Estas preguntas generales están estableciendo una línea base de conocimiento del stakeholder, primero de toda la cadena de valor de postcosecha y segundo del conocimiento específico del segmento de postcosecha en el que operan los interesados.

a. Según su conocimiento, ¿cuáles son los aspectos/procesos más importantes en la cadena postcosecha general que tienen el mayor impacto en las emisiones de GEI/carbono?
b. Según su conocimiento, ¿cuáles son los aspectos/procesos más importantes dentro de su empresa que tienen el mayor impacto en las emisiones de GEI/carbono?
c. ¿Qué importancia tienen las nuevas tecnologías en la cadena postcosecha para reducir las emisiones de GEI/carbono para su empresa?

Tecnologías postcosecha

Esta sección profundizará en las tecnologías postcosecha. Nuestro objetivo aquí es revisar las tendencias en la evolución tecnológica e identificar posibles nuevas técnicas de procesamiento y logística y sus desafíos. Esta sección se subdivide en temas específicos (tecnología, inversión, implementación, ganancia y limitaciones). Estos temas también volverán para las preguntas técnicas específicas de cada sector. Muchas preguntas se basan en respuestas sí/no y, por lo tanto, excluirán algunas de las preguntas repetitivas. El entrevistador tiene la flexibilidad de combinar preguntas de un solo tema, varios temas o incluso varias secciones. Sin embargo, nuestro objetivo es recopilar la mayor cantidad de información posible de una manera preferiblemente ordenada.

Tecnología

a. ¿Su empresa ha medido/monitoreado las emisiones de GEI/carbono en los últimos 20 años, lo hace actualmente o planea hacerlo en el futuro?
   a. Si es así, ¿qué parámetros fueron, están o serán medidos?
   b. Si es así, ¿cómo fueron, son o serán medidos estos parámetros?
b. ¿Ha implementado su empresa alguna tecnología en los últimos 20 años que haya contribuido a la reducción de las emisiones de GEI/carbono?
   a. Si es así, ¿estas tecnologías se han integrado gradualmente (múltiples pero pequeños cambios) o ha sido paso a paso (pocos, pero grandes cambios) en los últimos 20 años??
c. ¿Ha realizado su empresa alguna actualización de equipo/tecnología?
   a. Si es así, ¿por qué fueron realizados estos cambios?
   b. Si es así, ¿cuándo fueron realizados dichos cambios?
   c.
d. ¿Su empresa está desarrollando o contribuyendo al desarrollo de nuevas tecnologías con respecto a la reducción de emisiones de GEI/carbono??
   a. Si es así, ¿cuáles son esas tecnologías? (ver matriz con tecnologías potenciales)

Implementation

a. ¿Ha implementado su empresa alguna tecnología en los últimos 20 años, actualmente o en el futuro, que haya contribuido o podría contribuir a la reducción de las emisiones de GEI/carbono?
   a. Si es así, ¿qué tecnologías son esas (ver matriz con tecnologías)?
   b. Si es así, ¿cómo contribuyeron a reducir las emisiones de GEI/carbono?

   c. Si es así, ¿estas tecnologías se han integrado gradualmente (múltiples pero pequeños cambios) o ha sido paso a paso (pocos, pero grandes cambios) en los últimos 20 años?
b. ¿Por qué su empresa está implementando tales tecnologías (por ejemplo, para reducir los costos a largo plazo)?
c. ¿Cuáles son las principales dificultades técnicas que ha encontrado en la implementación de estas tecnologías?
   a. ¿Existe algún desafío técnico específico?
   b. ¿Existe alguna otra limitación?

Inversiones

a. Si su empresa ha implementado alguna tecnología postcosecha en los últimos 20 años para reducir las emisiones de GEI/carbono, ¿cuál fue el costo de la inversión?
   a. ¿Qué parámetros o indicadores tiene en cuenta su empresa a la hora de seleccionar una nueva tecnología en la que invertir?
   b. ¿Cuánto está dispuesta a invertir su empresa? (por ejemplo, % de beneficio)
b. ¿Tiene su empresa planes de inversión futuros para tecnologías novedosas que podrían resultar en la reducción de emisiones de GEI/carbono?
   a. Si es así, ¿Cómo identifica su empresa nuevas opciones tecnológicas al planificar inversiones?
   b. Si es así, ¿son planes de inversión específicos?
   c. Si es así, ¿El plan de inversión tiene una parte dedicada a la Investigación y el Desarrollo (I+D) de estas nuevas tecnologías?
c. ¿Sabe si hay algún financiamiento externo específico (p. ej., subvenciones de gobiernos locales/nacionales, basados en la UE, otros) para implementar tecnologías que contribuyan a la reducción de emisiones de GEI?
   a. Si es así, ¿Han solicitado tal subvención?

Ganancias

a. Si su empresa ha implementado nuevas tecnologías que resultan en la reducción de emisiones de GEI/carbono:
   a. ¿Cuál fue la reducción prevista u observada en las emisiones de GEI/carbono debido a la implementación de nuevas tecnologías? (pasado)
   b. ¿Cuál es la reducción prevista u observada en las emisiones de GEI/carbono debido a la implementación de nuevas tecnologías? (presente)
   c. ¿Cuál será la reducción prevista u observada en las emisiones de GEI/carbono debido a la implementación de nuevas tecnologías? (futuro)
b. ¿Hay otros beneficios de implementar tecnologías de reducción de emisiones de GEI/carbono?
   a. ¿La reducción de las emisiones de GEI/carbono es la principal razón para implementar nuevas tecnologías o existen otras ventajas más importantes?
c. ¿Los proveedores de tecnología destacaron los efectos ambientales positivos o cualquier otro beneficio de las tecnologías que ha implementado?

Limitaciones

a. ¿Qué tan importante es el aspecto financiero (por ejemplo, costo, presupuesto, impuestos, etc.) como factor limitante para desarrollar, invertir o implementar nuevas tecnologías postcosecha?
   a. ¿Existe alguna limitación financiera específica?
b. ¿Qué tan importantes son los aspectos legales (como limitación) en la implementación de tecnologías innovadoras de postcosecha?
   a. ¿Existe alguna limitación legal específica?
c. ¿Existe alguna estrategia o limitaciones de gestión para la implementación de nuevas tecnologías postcosecha para reducir las emisiones de GEI/carbono?

Matriz de tecnologías:

Tecnología	Pasado	Presente	Futuro
Preparación: drenado, pesado, selección, valoración, desvicerado y descabezado			
Sistemas de drenado y pesado de pescado			
Tanques RSW (Agua de Mar Refrigerada) para preenfriamiento (fase de matanza de pescado)			

Tecnología	Pasado	Presente	Futuro	Tecnología	Pasado	Presente	Futuro
Procesado							
Calentamiento				Curado			
Cocción (pasteurización)							
Campo de pulso eléctrico (PEF)				Ahumado			
Inmersión en agua							
Rociado con agua				Sub-productos			
Vapor y aire				Enzimas			
Rotor de vapor				Empaquetado			
				MAP – Modified			
Calentamiento óhmico				Sistema de empaquetado atmosférico			
Irradiación				Empaquetado inteligente			
Descongelado				EcoFishBox			
Aire quieto combinado con campo eléctrico de alto voltaje				Cajas EPS Innovadoras			
Enlatado				Empaques BluWrap			
Bombas de calor				Empaques comestibles			
Extracción de aceite				Auxiliares			
CO_2 supercrítico como solvente				Limpieza			
Congelado				Limpieza en lugar (Clean in place)			
Enfriamiento inmediato				Sistemas de recirculación			
Procesado a alta presión				Fuentes de energía			

Hielo líquido	Sistemas de energía solar privados
Congelado rápido	Certificados verdes de energía
Congelador de chorro de aire (superchilling)	Microredes inteligentes
Congelado isocórico	Sistemas de recuperación de calor
Almacenaje en frío	Alumbrado
Deshumidificadores	LED
Controlar actividad del agua	Otros
Secado	
Microondas	
Sistema de secado solar híbrido	
Sistema de secado sin aire (harinas de pescado)	

Estrategias Industriales

Esta sección profundizará en las estrategias industriales postcosecha. Las estrategias industriales se definen como estrategias operativas "en el lugar de trabajo". Nuestro objetivo aquí es revisar las tendencias en la evolución de las estrategias industriales e identificar posibles nuevas estrategias que se están desarrollando y sus desafíos. Esta sección se subdivide en temas específicos (estrategias, desarrollo, inversión, implementación, ganancia y limitaciones). Estos temas también volverán para las preguntas técnicas específicas de cada sector. Muchas preguntas se basan en respuestas sí/no y, por lo tanto, excluirán algunas de las preguntas repetitivas. El entrevistador tiene la flexibilidad de combinar preguntas de un solo tema, varios temas o incluso varias secciones. Sin embargo, nuestro objetivo es recopilar la mayor cantidad de información posible de una manera preferiblemente ordenada.

Estrategias

a. ¿Su empresa realizó, actualmente realiza o va a realizar alguna actualización de estrategias industriales que contribuyan a la reducción de emisiones de GEI/carbono?
    a. ¿Cuándo se realizó o realizará esta mejora?
    b. ¿Por qué se cambiaron o se cambiarán algunas de las estrategias?
    c. ¿Qué cambiaron o cambiarán específicamente?
    d. ¿Cómo realizaron o realizarán esos cambios?
    e. ¿Hubo o habrá algún cambio técnico específico?

Implementación

a. ¿Ha implementado su empresa alguna nueva estrategia industrial que resulte en una reducción de las emisiones de GEI/carbono en los últimos 20 años? (pasado)
    a. Si es así, ¿Qué estrategias eran esas? (ver matriz con estrategias industriales)
    b. Si es así, ¿Cómo contribuyeron estas estrategias a la reducción de las emisiones de GEI/carbono?
    c. ¿Han medido algún parámetro?
b. ¿Su empresa está implementando actualmente alguna nueva estrategia industrial que resulte en la reducción de las emisiones de GEI/carbono? (actual)
    a. Si es así, ¿Qué estrategias son esas? (ver matriz con estrategias industriales)
    b. Si es así, ¿Cómo contribuyen estas estrategias a la reducción de las emisiones de GEI/carbono?
    c. ¿Están midiendo algún parámetro?

c. ¿Su empresa está planeando implementar en el futuro alguna nueva estrategia industrial que resulte en la reducción de las emisiones de GEI/carbono? (futuro)
    a. Si es así, ¿Qué estrategias serán esas? (ver matriz con estrategias industriales)
    b. Si es así, ¿Cómo esperan que esas estrategias contribuyan a la reducción de las emisiones de GEI/carbono?
    c. ¿Se planea medir algún parámetro?
d. Si su empresa ha implementado nuevas estrategias industriales que resultan en la reducción de emisiones de GEI/carbono:
    a. ¿Cómo ha implementado su empresa dichas estrategias? (desarrolladas por sí mismas, vistas por otros, asesoramiento de expertos, etc.) (pasado)
    b. ¿Cómo está implementado su empresa dichas estrategias? (desarrolladas por sí mismas, vistas por otros, asesoramiento de expertos, etc.) (presente)
    c. ¿Cómo implementará su empresa dichas estrategias? (desarrolladas por sí mismas, vistas por otros, asesoramiento de expertos, etc.) (futuro)
e. ¿Por qué su empresa está implementando tales estrategias industriales? (por ejemplo, para reducir costos a largo plazo)
f. ¿Cuáles son las principales dificultades técnicas que han encontrado en la implementación de estas estrategias industriales?
    a. ¿Hay algún cambio técnico específico?

Desarrollo

a. ¿Qué tan importantes son las estrategias industriales para reducir las emisiones de GEI/carbono para su empresa?
b. ¿Su empresa está desarrollando o contribuyendo al desarrollo de nuevas estrategias industriales para reducir las emisiones de GEI/carbono?
    a. ¿Qué estrategias específicas son esas? (ver matriz con estrategias industriales)
    b. ¿Este desarrollo de nuevas estrategias ocurre a través de una asociación de su sector del segmento de postcosecha o en colaboración con otras empresas?

Inversiones

    a. How much is your company willing to invest in new industrial strategies (% of profit)?
b. ¿Existe algún financiamiento específico en su empresa para implementar nuevas estrategias industriales que resulten en la reducción de emisiones de GEI/carbono?
c. ¿Sabe si hay algún financiamiento externo específico (p. ej., subvenciones de gobiernos locales/nacionales, basados en la UE, otros) para implementar estrategias industriales para reducir las emisiones de GEI/carbono?
    a. Si es así, ¿han solicitado esa subvención?

Gain

a. Si su empresa ha implementado nuevas estrategias industriales que resultan en la reducción de GHC/emisiones de carbono:
    a. ¿Cuál fue la reducción prevista u observada en las emisiones de GEI/carbono debido a la implementación de nuevas estrategias? (pasado)
    b. ¿Cuál es la reducción prevista u observada en las emisiones de GEI/carbono debido a la implementación de nuevas estrategias? (presente)
    c. ¿Cuál será la reducción prevista u observada en las emisiones de GEI/carbono debido a la implementación de nuevas estrategias? (futuro)
b. ¿Hay otros beneficios de implementar estrategias industriales de reducción de GEI/carbono?
    a. ¿Es la reducción de las emisiones de GEI/carbono la principal razón para implementar nuevas estrategias industriales o existen otras ventajas más importantes??

Limitaciones

a. ¿Qué importancia tiene el aspecto financiero (por ejemplo, costo, presupuesto, impuestos, etc.) como factor limitante para desarrollar, invertir o implementar nuevas estrategias industriales?

   a. ¿Existe alguna limitación financiera específica?
b. ¿Qué importancia tienen los aspectos legales (como limitación) en la implementación de estrategias industriales nuevas o innovadoras?
   a. ¿Existe alguna limitación legal específica?

Matriz con estrategias industriales:

Estrategia industrial	Pasado	Presente	Futuro
Procesado			
General			
Estrategias de producción más limpia			
Mejor aislamiento y refrigeración más eficiente			
Minimizar las cargas de calor con un mejor control de puertas y minimizar las cargas eléctricas			
Otros			

Preguntas específicas del proceso

Esta sección profundizará en el funcionamiento específico de la empresa postcosecha y los procesos utilizados en esa empresa. Nuestro objetivo aquí es recopilar datos técnicos comparables para diferentes segmentos de postcosecha. Estos datos no se recopilan para la interpretación, sino únicamente con fines de recopilación e informes. Esta sección se subdivide en temas específicos (productos, procesos, entradas, salidas y evoluciones). Estos temas también volverán para las preguntas técnicas específicas de cada sector. Muchas preguntas piden valores específicos. Nuestro objetivo es recopilar la mayor cantidad de información posible de una manera preferiblemente ordenada.

Productos

a. ¿Puede dar una descripción general de los tipos y cantidades de productos que su empresa produce anualmente?
b. ¿Puede dar una descripción general de los tipos y cantidades de subproductos que su empresa produce anualmente?
c. Si esto se puede encontrar en los informes de la empresa, ¿puede proporcionar un enlace al informe?

Processes

a. ¿Qué parte de los procesos que se ejecutan en su empresa tiene el mayor impacto en las emisiones de GEI/carbono?
   a. ¿Es un impacto negativo o positivo?
   b. ¿Por qué esta parte tiene un impacto tan grande?
b. ¿Qué parte de los procesos que se ejecutan en su empresa tiene el menor impacto en las emisiones de GEI/carbono?
   a. ¿Es un impacto negativo o positivo?
   b. ¿Por qué esta parte tiene un impacto tan pequeño?
c. ¿Puede facilitarnos las fichas técnicas de las máquinas utilizadas en el proceso ?
d. Si esto se puede encontrar en los informes de la empresa, ¿puede proporcionar un enlace al informe?

Entradas

a. ¿Puede dar una descripción general de los tipos, cantidades y origen de las principales materias primas?
b. Do you monitor electricity consumption overall or separated per part of the postharvest process in your company?

   a. How are these consumptions controlled or monitored (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
c. If natural gas is consumed, do you monitor the overall or separated per part natural gas of the postharvest process in your company?
   a. How are these consumptions controlled or monitored (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
d. Can you give an overview of the packaging format and material per product used?
   a. How important is the source of the packaging material for your company?
   b. Does your company monitor input of packaging materials?
e. Can you give an overview of the refrigerants (type and amount) that are consumed yearly?
   a. How important is the source of the refrigerants for your company?
   b. Does your company monitor the input of refrigerants?
f. Can you give an overview the yearly water consumption of your company?
   a. Do you monitor water consumption overall or separated per part of the postharvest process in your company?
   b. How is water consumption controlled or monitored (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?

Outputs

a. Can you give an overview of the amount of (bio)waste your company produces?
b. Can you give an overview of the type, amount and final destination of other wastes (e.g., raw materials, packaging, refrigerants, heat waste, water waste)?
c. How are waste production and processing controlled and monitored in your company (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
d. If this can be found in company reports, can you provide a link or forward to the report?

Evolution

a. Has your company's electricity consumption been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
b. Has your company's natural gas (or other fossil fuel) consumption been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
c. Has your company's water consumption been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
d. Have your company's GHG/carbon emissions been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
e. Has your company's waste been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?

Any other remarks or information that the stakeholder is willing to share?

PRODUCTORES DE PIENSOS PARA PECES

El cuestionario específico para los productores de alimentos para peces se puede compilar a partir de las preguntas generales anteriores. Los datos cuantitativos también son clave para el proyecto actual y, a veces, es necesario "cavar" en busca de datos para obtener datos cuantitativos. Por lo tanto, pregunte tanto como sea posible por valores reales y números relacionados con preguntas específicas relacionadas con la tecnología.

MINORISTAS Y DISTRIBUIDORES

El cuestionario específico para minoristas y distribuidores se puede compilar a partir de las preguntas generales anteriores. Más preguntas técnicas específicas se pueden encontrar a continuación. Los datos cuantitativos también son clave para el proyecto actual y, a veces, es necesario "cavar" en busca de datos para obtener datos cuantitativos. Por lo tanto, pregunte tanto como sea posible por valores reales y números relacionados con preguntas específicas relacionadas con la tecnología.

Tecnologías postcosecha

Inversiones

Ganancias

a. ¿Existen incentivos legales para llevar un "producto verde" al mercado?
b. ¿Existen otros incentivos (por ejemplo, técnicos) para llevar un "producto verde" al mercado?

Estrategias industriales

Ganancias

a. ¿Una "etiqueta ecológica" (eco-label) mejora las emisiones de GEI/carbono?
    a. ¿Cómo afecta la etiqueta a las emisiones?
    b. ¿En qué parte de su proceso o parte de la cadena de valor una etiqueta trae una reducción de emisiones?
    c. ¿Cuánto reduce las emisiones una "etiqueta ecológica"? (por parte de la cadena)
b. ¿Hay otras ganancias de las "etiquetas ecológicas"?

Preguntas específicas del proceso

a. ¿Se ha reducido el consumo eléctrico de su empresa en los últimos 20 años?
    a. Si es así, ¿Cuánto se ha reducido este consumo? (por producto/unidad (kg, tonelada, etc.))
    b. ¿Por qué se redujo este consumo?
    c. ¿Puede rastrear en qué parte del proceso de postcosecha en su empresa ha reducido este consumo?
b. ¿Se ha reducido el consumo de gas natural (u otro combustible fósil) de su empresa en los últimos 20 años?
    a. Si es así, ¿Cuánto se ha reducido este consumo? (por producto/unidad (kg, tonelada, etc.))
    b. ¿Por qué se redujo este consumo?
    c. ¿Puede rastrear en qué parte del proceso de postcosecha en su empresa ha reducido este consumo?
c. ¿Se ha reducido el consumo de agua de su empresa en los últimos 20 años?
    a. Si es así, ¿Cuánto se ha reducido este consumo? (por producto/unidad (kg, tonelada, etc.))
    b. ¿Por qué se redujo este consumo?
    c. ¿Puede rastrear en qué parte del proceso de postcosecha en su empresa ha reducido este consumo?
d. ¿Se han reducido las emisiones de GEI/carbono de su empresa en los últimos 20 años?
    a. Si es así, ¿Cuánto se ha reducido este consumo? (por producto/unidad (kg, tonelada, etc.))
    b. ¿Por qué se redujo este consumo?
    c. ¿Puede rastrear en qué parte del proceso de postcosecha en su empresa ha reducido este consumo?
e. ¿Se han reducido los residuos de su empresa en los últimos 20 años?
    a. Si es así, ¿Cuánto se ha reducido este consumo? (por producto/unidad (kg, tonelada, etc.))
    b. ¿Por qué se redujo este consumo?

   c. ¿Puede rastrear en qué parte del proceso de postcosecha en su empresa ha reducido este consumo?
f. ¿Cómo se registran los camiones (específicos para productos del mar u otros objetivos de transporte)?
g. ¿Qué tipo de motor utilizan para el transporte de su producto?
   a. Tipo de combustible (diésel, electricidad, hidrógeno, etc.)
   b. Nivel del motor EURO (EURO4-6)
   c. ¿Monitorean el consumo de combustible o el costo financiero relacionado con los combustibles?
   d. ¿Cuánto combustible es usado?
   e. ¿Los camiones están equipados con tecnología para reducir el consumo de combustible? (kits de carrocería, llantas, tipos de remolque, etc.)
h. ¿Qué tipos de refrigerantes se utilizan en los remolques frigoríficos?
   a. ¿Cuáles son esos refrigerantes?
   b. ¿Se controla el uso del refrigerante?
i. ¿Los remolques frigoríficos están homologados para un transporte específico?
   a. ¿Cuáles son esas certificaciones?

ASOCIACIONES

El cuestionario específico para asociaciones se puede compilar a partir de las preguntas generales anteriores. Más preguntas técnicas específicas se pueden encontrar a continuación. Este apartado de preguntas específicas se subdivide en temas específicos distintos a los anteriores (miembros, formación, financiación, consultoría/coordinación). Los datos cuantitativos también son clave para el proyecto actual y, a veces, es necesario "cavar" en busca de datos para obtener datos cuantitativos. Por lo tanto, pregunte tanto como sea posible por valores reales y números relacionados con preguntas específicas relacionadas con la tecnología.

Tecnología postcosecha

Miembros

a. ¿La reducción de las emisiones de GEI/carbono es clave para sus miembros?
b. ¿Sus miembros han implementado o ayudado a implementar alguna tecnología postcosecha en los últimos 20 años que haya contribuido a reducir sus emisiones de GEI/carbono?
   a. Si así es, ¿cuáles eran esas tecnologías? (ver matriz anterior con tecnologías) (pasado)
c. ¿Están sus miembros actualmente implementando o ayudando a implementar tecnologías postcosecha que contribuyan a reducir sus emisiones de GEI/carbono?
   a. Si es así, ¿cuáles son esas tecnologías? (ver la matriz con tecnologías) (presente)
d. ¿Están sus miembros planeando implementar o ayudar a implementar tecnologías postcosecha para los próximos 5-5+ años que contribuyan a reducir sus emisiones de GEI/carbono?
   a. En caso afirmativo, ¿cuáles serán esas tecnologías? (ver la matriz con tecnologías) (futuro)

Capacitación

a. ¿Su asociación brinda información/capacitación a sus miembros sobre tecnologías que reducen las emisiones de GEI/carbono?
   a. Si es así, ¿sobre qué tecnologías se proporciona información/capacitación?
   b. ¿Qué tipo de información/formación se proporciona?
b. ¿Están sus miembros solicitando información/capacitación sobre tecnologías que reduzcan las emisiones de GEI/carbono?
   a. Si es así, ¿qué tipo de tecnologías se solicitan?
   b. ¿Qué tipo de información/formación se solicita?
c. ¿Hay algún tercero (consultoría, proveedores de tecnología, etc.) que le brinde información/capacitación a usted como asociación o a sus miembros con respecto a tecnologías que reduzcan las emisiones de GEI/carbono?

Fondos

a. ¿Recibe su asociación fondos de administraciones nacionales/otras para promover la implementación de tecnologías que reducen las emisiones de GEI/carbono?
b. ¿Están sus miembros solicitando financiamiento o apoyo económico para implementar tecnologías que reduzcan las emisiones de GEI/carbono?

Consultoría/coordinación

a. ¿Ha coordinado en los últimos 20 años alguna iniciativa para implementar tecnologías que reduzcan las emisiones de GEI/carbono de sus miembros?
    a. Si es así, ¿cuáles fueron esas iniciativas?
b. ¿Está coordinando actualmente alguna iniciativa para implementar tecnologías que reduzcan las emisiones de GEI/carbono de sus miembros?
    a. Si es así, ¿cuáles son esas iniciativas?
c. ¿Está planeando coordinar alguna iniciativa para implementar tecnologías que reduzcan las emisiones de GEI/carbono de sus miembros? (por ejemplo, dentro de 5 años)
    a. Si es así, ¿cuáles serán esas iniciativas?
d. ¿Está desarrollando o contribuyendo a desarrollar (con otros socios) nuevas tecnologías postcosecha para reducir las emisiones de GEI/carbono de sus miembros?

Estrategias industriales

Miembros

a. ¿Sus miembros han implementado o ayudado a implementar alguna estrategia industrial en los últimos 20 años que haya contribuido a reducir sus emisiones de GEI/carbono?
    a. Si es así, ¿cuáles fueron esas estrategias? (ver matriz con estrategias) (pasado)
b. ¿Están sus miembros actualmente implementando o ayudando a implementar estrategias industriales que contribuyan a reducir sus emisiones de GEI/carbono?
    a. Si es así, ¿cuáles son esas estrategias? (ver matriz con estrategias) (presente)
c. ¿Sus miembros planean implementar o ayudar a implementar estrategias industriales para los próximos 5-5+ años que contribuyan a reducir sus emisiones de GEI/carbono?
    a. Si es así, ¿cuáles serán esas estrategias? (ver matriz con estrategias) (futuro)

Capacitación

a. ¿Su asociación brinda información/capacitación a sus miembros sobre estrategias industriales que redujeron las emisiones de GEI/carbono?
    a. Si es así, ¿sobre qué estrategias se proporciona información/capacitación?
    b. ¿Qué tipo de información/formación se proporciona?
b. ¿Están sus miembros solicitando información/capacitación sobre estrategias industriales que reduzcan las emisiones de GEI/carbono?
    a. Si es así, ¿qué tipo de estrategias se solicitan?
    b. ¿Qué tipo de información/formación se solicita?
c. ¿Hay algún tercero (consultoría, proveedores de tecnología, etc.) que le brinde información/capacitación a usted como asociación o a sus miembros con respecto a estrategias que reduzcan las emisiones de GEI/carbono?

Fondos

a. ¿Recibe su asociación fondos de administraciones nacionales/otras para promover la implementación de estrategias que reducen las emisiones de GEI/carbono?
b. ¿Están sus miembros solicitando financiamiento o apoyo económico para implementar estrategias que reduzcan las emisiones de GEI/carbono?

Consultoría/coordinación

a. ¿Ha coordinado en los últimos 20 años alguna iniciativa para implementar estrategias que reduzcan las emisiones de GEI/carbono de sus miembros?
    a. Si es así, ¿cuáles fueron esas iniciativas?
b. ¿Está coordinando actualmente alguna iniciativa para implementar estrategias que reduzcan las emisiones de GEI/carbono de sus miembros?
    a. Si es así, ¿cuáles son esas iniciativas?
c. ¿Está planeando coordinar alguna iniciativa para implementar estrategias que reduzcan las emisiones de GEI/carbono de sus miembros? (por ejemplo, dentro de 5 años)
    a. Si es así, ¿cuáles serán esas iniciativas?

d. ¿Está desarrollando o contribuyendo a desarrollar (con otros socios) nuevas estrategias postcosecha para reducir las emisiones de GEI/carbono de sus miembros?

PROVEEDORES DE TECNOLOGÍA

El cuestionario específico para proveedores de tecnología se puede compilar a partir de las preguntas generales anteriores. Más preguntas técnicas específicas se pueden encontrar a continuación. Esta sección de preguntas específicas se subdivide en temas específicos diferentes a los anteriores (tecnología, clientes, desarrollo, capacitación). Los datos cuantitativos también son clave para el proyecto actual y, a veces, es necesario "cavar" en busca de datos para obtener datos cuantitativos. Por lo tanto, pregunte tanto como sea posible por valores reales y números relacionados con preguntas específicas relacionadas con la tecnología.

Tecnología postcosecha

Tecnología

a. ¿Cuáles son los puntos más importantes de la propuesta de valor de sus productos/tecnologías? (por ejemplo, menor precio en el mercado, bajos consumos, mejorar la calidad de los alimentos, etc.)
b. ¿Cuáles son los factores clave que impulsan sus nuevos desarrollos o la actualización de su equipo actual? (por ejemplo, reducir el costo del equipo, reducir el consumo eléctrico, aumentar los kg/h, reducir el tiempo de procesamiento, etc.)
c. ¿Tuvieron que considerar las emisiones de GEI/carbono en el pasado al diseñar nuevas tecnologías?
    a. Si así fue, ¿cuándo?
    b. Si así fue, ¿cómo fueron implementados los nuevos diseños?
    c. Si así fue, ¿cuánta ganancia calculada/predicha hubo?
d. ¿Está considerando actualmente las emisiones de GEI/carbono al diseñar una nueva tecnología?
    a. Si es así, ¿cómo?
e. ¿Qué hace exactamente que su tecnología sea más eficiente en GEI/carbono? (por ejemplo, uso de energía, velocidad, etc.)
    a. ¿Cuáles son las ganancias actuales calculadas/predichas?
    b. Si no ha considerado esto antes, ¿planea reducir las emisiones de GEI/carbono de sus productos en un futuro cercano?
f. ¿Los equipos que tienen un menor impacto ambiental son más caros que los equipos "tradicionales"?
    a. Si es así, ¿dónde exactamente está el costo extra?
g. ¿Sus tecnologías siguen alguna certificación/normas?
    a. Si es así, ¿cuáles son?

Clientes

a. ¿Están sus clientes solicitando tecnologías para reducir sus emisiones de GEI?
    a. Si es así, ¿sus clientes han pedido esto específicamente en el pasado?
    b. Si es así, ¿cuándo?
    c. Si ha sido así, ¿qué pidieron específicamente los clientes?
b. ¿Hay una demanda creciente en los últimos años?
c. ¿Está dando impactos ambientales calculados/estimados de sus productos/tecnologías a sus clientes?
    a. Si es así, ¿cuáles son esos parámetros de impactos?
d. ¿Qué tan importante es el equipo certificado o el equipo construido siguiendo una determinada norma?
e. Si hay un costo adicional asociado con una tecnología más eficiente en GEI/carbono, ¿quién paga ese costo?

Desarrollo

1. ¿Qué tan importante es el costo como factor limitante para desarrollar nuevas tecnologías con emisiones reducidas de GEI/carbono?
2. ¿Qué importancia tienen los aspectos legales o los procedimientos estándar en el diseño y desarrollo de tecnologías nuevas o innovadoras?
    a. ¿Son estos ventajosos o desventajosos?
3. ¿Sabe si hay algún financiamiento externo específico (p. ej., subvenciones de gobiernos locales/nacionales) para desarrollar tecnologías para reducir las emisiones de GEI?
    a. Si así es, ¿Han solicitado tal subvención?
    b. ¿A cuánto ascienden estas subvenciones?

4. ¿Hay algún tercero (centros de investigación, universidades, otros proveedores de tecnología, etc.) que lo ayude en el desarrollo de tecnologías que reduzcan las emisiones de GEI/carbono y el consumo de insumos para construir sus productos/tecnologías?
    a. Si es así, ¿quiénes son?
    b. Si es así, ¿cuál es su contribución exacta?

Capacitación

a. ¿Están sus clientes solicitando información específica relacionada con la reducción de emisiones de GEI/carbono?
b. ¿Le estás dando esta información a tus clientes?
c. ¿Está educando a sus clientes incluso si no hay una pregunta específica para la tecnología que reduce las emisiones de GEI/carbono?

ONGs Y ADMINISTRACIONES PÚBLICAS

El cuestionario específico para ONG y administraciones públicas se puede compilar a partir de las preguntas generales anteriores. Más preguntas técnicas específicas se pueden encontrar a continuación. Los datos cuantitativos también son clave para el proyecto actual y, a veces, es necesario "cavar" en busca de datos para obtener datos cuantitativos. Por lo tanto, pregunte tanto como sea posible por valores reales y números relacionados con preguntas específicas relacionadas con la tecnología.

Conciencia

a. ¿Está realizando campañas específicas para aumentar la conciencia y el compromiso relacionados con la reducción de las emisiones de GEI/carbono en las empresas pesqueras?
    a. Si es así, ¿cuáles son esas campañas?
    b. Si es así, ¿Qué información proporcionas en estas campañas?
b. En los últimos 20 años, ¿ha desarrollado programas de financiación específicos (p. ej., subvenciones, préstamos, etc.) para reducir las emisiones de GEI/carbono de las empresas del sector de productos del mar?
    a. Si fue así, ¿cuáles fueron?
    b. Si fue así, ¿cuántos fondos estaban disponibles para las partes solicitantes?
    c. Si fue así, ¿cuáles eran las condiciones para solicitar los fondos?
c. ¿Está desarrollando actualmente programas de financiación específicos (p. ej., subvenciones, préstamos, etc.) para reducir las emisiones de GEI/carbono de las empresas del sector de productos del mar?
    a. Si es así, ¿cuáles son?
    b. Si es así, ¿cuántos fondos están disponibles para las partes solicitantes?
    c. Si es así, ¿cuáles son las condiciones para solicitar los fondos?
d. ¿Está planeando lanzar (en 5-5+ años) programas de financiación específicos (p. ej., subvenciones, préstamos, etc.) para reducir las emisiones de GEI/carbono de las empresas del sector de productos del mar?
    a. Si es así, ¿cuáles serán?
    b. Si es así, ¿cuántos fondos estarán disponibles para las partes solicitantes?
    c. Si es así, ¿cuáles serán las condiciones para solicitar los fondos?

CASE STUDY 21: TUNAS - ALBACORE TUNA *(THUNNUS ALALUNGA)* - IRELAND

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Michael Keatinge

LIST OF ABBREVIATIONS

Term	Description
BIM	Bord Iasciagh Mhara
IFPO	Irish Fish Producers Organisation
IFPEA	Irish Fish Processors & Exporters Association
ISWFPO	Irish South & West Fish Producers Organisation
ISEFPO	Irish South & East Fish Producers Organisation

1. Introduction

Albacore tuna are quota managed species caught by the Killybegs based RSW fleet, but there is no significant, local, postharvest value chain for this species. Possibly, the first fishery that Irish fishermen recognise as partly due to climate change with warmer waters bringing tuna closer to Ireland, this CS examines the role of management in implementing introductions of new species to the market.

1.1 The role of management: EU drift net ban 1998 -2002

The Irish albacore tuna fishery began in 1990 when enterprising fishermen from south and west coast ports like Dunmore East, Baltimore, Castletownbere, and Dingle began an experimental fishery with assistance from BIM, Ireland's seafood development agency. With just 40 tonnes of albacore landed in the first year, the fishery grew quickly over the next decade reaching 4,858 tonnes by 1999.

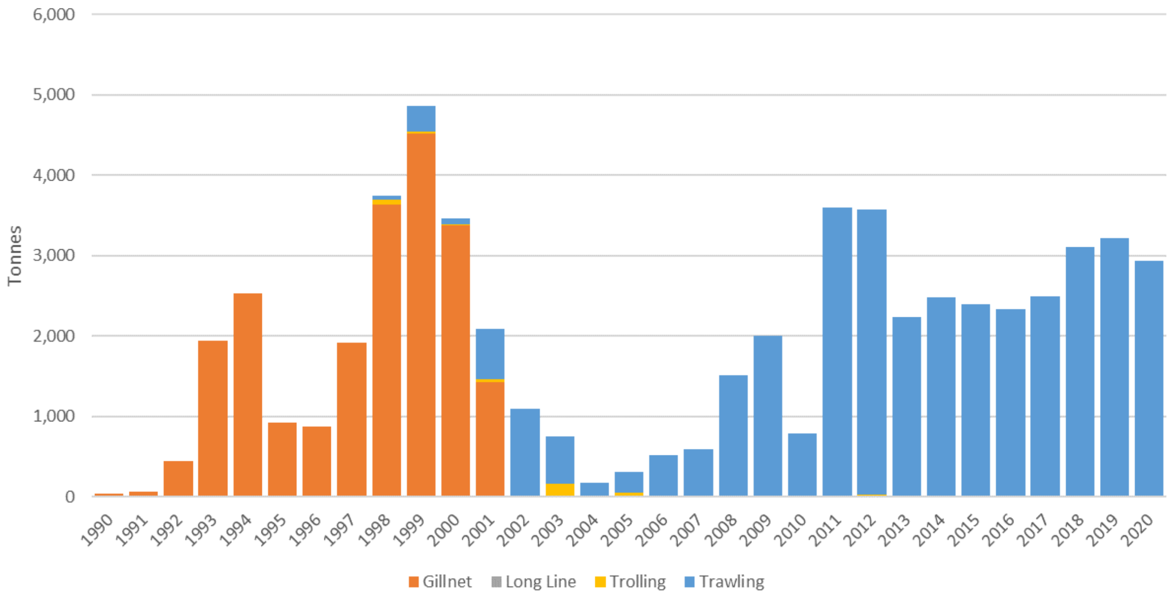


Figure 1: Irish Albacore landings, by gear, 1990 - 2020

In the early years boats travelled south, sometimes deep into the Bay of Biscay, before returning to Ireland to land their catch in Dingle and Castletownbere with the latter recording 85-90 % of the landings. This early peak in the fishery also coincided with the phasing out of surface driftnet, as such gear was responsible for incidental bycatch of dolphins and other sea mammals. The phasing out of driftnets began in 1998 and by the end of 2002 the fishery was completely banned. However, this was not before Ireland had built up a track record sufficient to earn it a share when quotas were introduced for albacore in 2001. Irelands quota that year was 3,158 tonnes, almost 11 % of the 28,712 tonnes allocated to the EU. However, the driftnet ban was catastrophic for Ireland's nascent tuna fishery and by 2004, within three years of securing a quota, catches had fallen dramatically and the fishery, essentially, collapsed (2002 - 2007).

During the period of the driftnet phase out (1998 – 2002), and with EU financial assistance, BIM worked with fishermen to replace the driftnet with alternative gears, including surface long lining, trolling and pair-pelagic trawling. Only the latter was successful, and then only gradually, with the fishery suffering an almost complete failure in 2004, before slowly returning to full uptake over the next 8 to 10 years.

2. Resource

With a TAC of 37,801 tonnes (essentially unchanged in 20 years); an EU share of 28,121 tonnes (80 % of the TAC), and a value of EUR92 million in 2021, the albacore fishery is the 12th most important species by value and 14th by volume of all EU quota managed stocks. It is the 11th most important species landed by the Irish fleet. Data collected for the STECF Annual Economic Report (AER) show that 83.5 % of Ireland's albacore catches are currently taken by vessels over 24 metres in length, with 70 % taken by polyvalent and RSW pelagic trawlers 24 – 40 metres.

The STECF (AER) data set[47] shows that catches are predominantly taken in waters to the south of Ireland with 91 % taken in ICES area 8d in the Bay of Biscay. For an RSW vessel operating out of Killybegs this is a distance of some 600- 800 nautical miles and 3 days steaming to get to the fishing grounds. And whereas BIM has reported growing evidence that, in recent years, Irish vessels are waiting until albacore migrate closer to the Irish coast before entering the fishery (a more sustainable approach as it results is less fuel being used) nonetheless there has been a major change in the fishery with the bulk of Irish caught albacore now landed abroad.

Up until 2015, most (97 – 100 %) albacore was landed into Irish ports including Castletownbere (with 80 % of the total). These fish were then brought by truck to Spain where they were utilised by local PH value chains. Since 2016 however this has changed and 90 %-93 % of the albacore caught by Irish vessels are now landed directly into ports in France and Spain. For example, in 2019, Irish vessels landed a total of 3,119 tonnes of Albacore of which of which 2,327 tonnes (80 %) were landed in Douarnenez in France and a further 568 tonnes (20 %) in Ondarroa, Spain (Table 1).

Landings of albacore to Irish ports currently (2018 -2019) average about 250 tonnes or 7-8 % of the total. Albacore is a seasonal fishery (August/September) and supply can be an issue for both seafood processors and retailers. That said, all of the pelagic species landed in Ireland are seasonal. With tuna, Irish seafood companies have developed products that are available nationwide in high street and selected gourmet food stores and restaurants throughout the year. Often these products use reimported Irish tuna processed in Spain. According to BIM's annual Business of Seafood report, tuna has the 4th highest retail sales of all the seafood sold in Ireland. Tuna generated sales of EUR21 million in 2021 (5 % of the total). These sales however relied on a considerable quantity of imported tuna in tins and other prepared formats.

[47] See website for data download: Economic and Social Analyses - European Commission (europa.eu)

Table 1: Irish caught Albacore landed in France and Spain
Source: (Annual Statistics | Sea Fisheries Protection Authority (sfpa.ie)

Destination of Irish caught Albacore	Share	Volume (tonnes)	Value (€ millions)
2019 Quota		2,854	
Total Landings		3,119	€6.97
Landed to foreign ports	93%	2,890	€6.46
Of which, Douarnenez (France)	80%	2,327	€5.22
Ondarroa (Spain)	20%	568	€1.27
Landings to Irish ports	7%	229	€0.62
2018 Quota		2,845	
Total Landings		3,102	€8.08
Landed to foreign ports	92%	2,839	€7.40
Of which, Douarnenez (France)	86%	2,445	€6.43
Ondarroa (Spain)	13%	356	€0.93
Landings to Irish ports	8%	263	€0.69

3. Value Chain

Most of Ireland's PH value chain relies on imported tuna (4,800 tonnes) for the domestic market (Figure). But as much of this is canned the added value is therefore outside the seafood sector. While there is distribution and sales network for the latter, the added value, employment etc associated with it do not derive from the Irish caught product and are no further considered here. However, the scale of current retail sales of imported tuna, EUR28 million, gives a measure of added value lost to the sector. If 2,890 tonnes of the 4,800 tonnes currently imported were replaced with Irish caught fish then, pro rata, EUR16.85 million of the retail figure would be available to a PH value chain in Ireland. This value is also used to estimate the number of direct jobs lost to processing in Ireland. The same factor is used to estimate the number of jobs lost in the service sector. In comparison, the primary value of the catch (EUR7 million) still accrues to the fishers, and this value as a percentage of the total value of all the catch of the RSW fleet gives the percentage of indirect jobs depending on the fishery. Any indirect or induced labour depending on these jobs may be included.

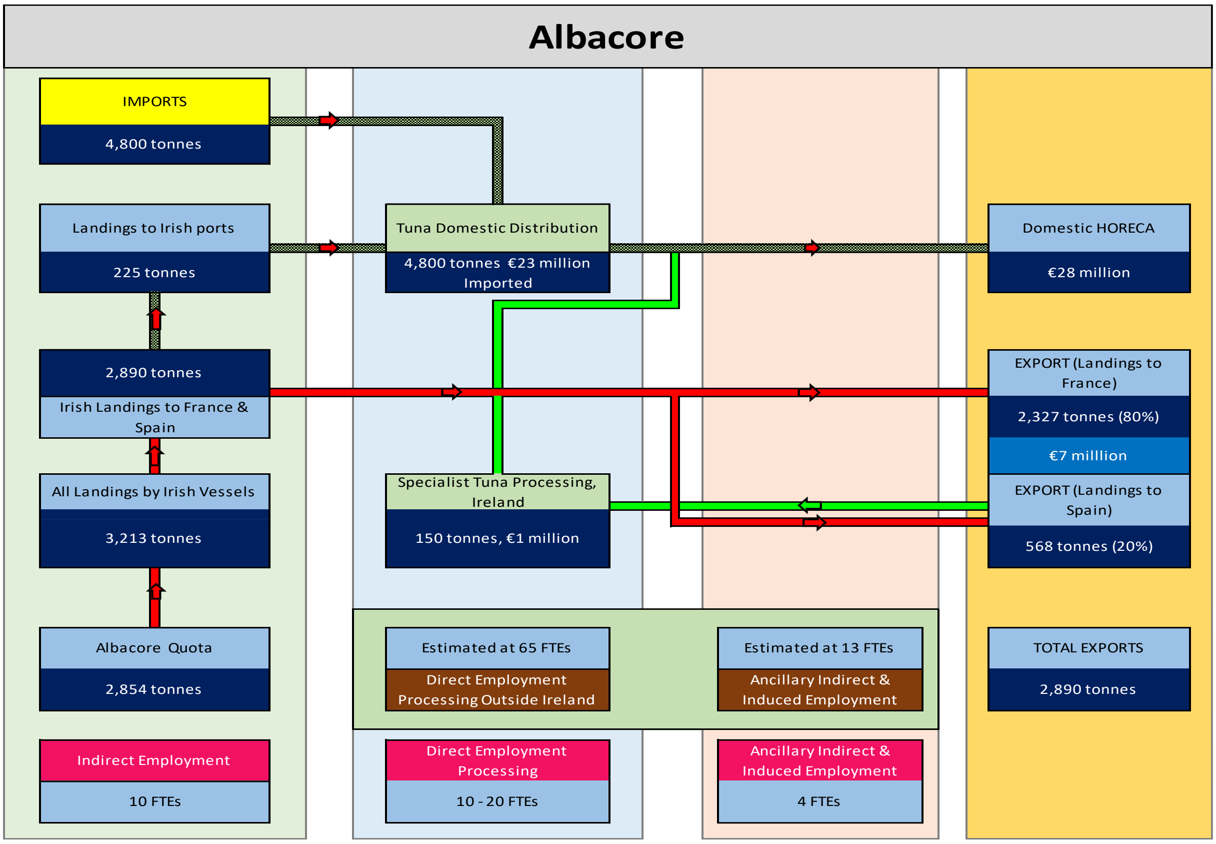


Figure 2 Albacore postharvest value chain.

4. Resilience to climate change

This CS explores a fishery where the primary (harvest) value of a fishery and the PH added value are uncoupled. Albacore tuna is, possibly, the first fishery that Irish fishermen recognise as partly due to climate change with warmer waters bringing tuna closer to Ireland. Yet, despite access to the resource for 30 years, Ireland has not developed a processing capability for Albacore and, instead exports it all directly to France and Spain.

For the skipper, the decision to land abroad is influenced by the conditions under which the fish are caught and stored and the economic cost of making the return trip to Ireland (which will become more expensive in light of the current very high fuel prices). The decision to continue in the fishery, however, will be influenced by fuel costs. It is possible that some boats will not make the journey south in years ahead. For the processor, the decision not to invest in the necessary post value chain is, in part, influenced by the conditions under which the fish are caught and stored (fish quality) but also by the uncertainty around the fishery in the period after the introduction of the drift net ban. Therefore, in terms of resilience, rising sea temperatures could bring fish closer to Ireland and this could tip the balance in favour of an indigenous PH value chain. Conversely, rising fuel costs could tip the cost-benefit balance making it unprofitable to journey south from Killybegs and spend time searching for fish etc at the current price per kg. Such uncertainty and other considerations currently tip the balance against an indigenous PH value chain.

5. Conclusions

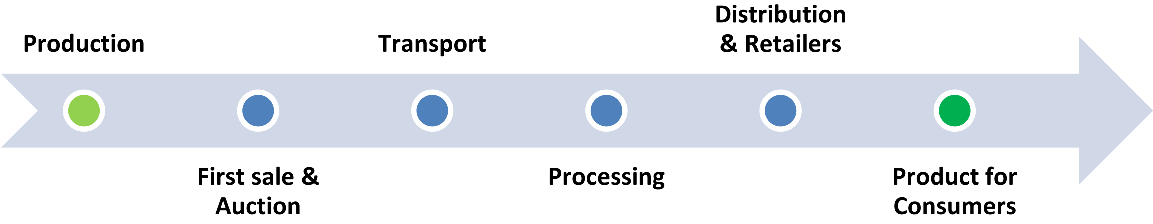
The development of a fishery for albacore tuna off Ireland's south and west coasts is for many in the sector the best example of a fishery that has come about through climate change. And yet, almost 30 years after it first started, this fishery is today landing most of its catch, not in Ireland, but directly in to France and Spain where it joins existing, local, PH value chains with little if any benefit to the Irish seafood sector.

In this CS the PH value chain for Ireland's albacore tuna fishery is successfully mapped including volumes and value. The model developed in the CS links Irish quotas, the Killybegs fleet, the results of the data collection framework and STECF annual economic report with independent reports by BIM (Ireland's Seafood Development Agency) that establish the employment, GVA, wage bill etc lost to Ireland by not having an indigenous PH value chain for this species.

CASE STUDY 22: MULTIPLE - IMPROVING INDUSTRIAL STRATEGIES AND PROCESSING TECHNOLOGIES

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions



Adelbert De Clercq, Tim Plevoets, Damian Villagra

LIST OF ABBREVIATIONS

Term	Description
ASC	Aquaculture Stewardship Council
CS	Case Study
ESG	Environmental, Social, and Corporate Governance
FCR	Feed Conversion Ratio
FSC	Forest Stewardship Council
GHG	Green House Gas
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LUC	Land Use Change
MSC	Marine Stewardship Council
PEFCR	Product Environmental Footprint Category Rules
PH	Postharvest
R&D	Research & Development
SDG	Sustainable Development Goals
UN	United Nations
R&D	Research and Development

1 Background

The PH sector includes all activities involved in the sale/auction, handling, transport, processing, distribution and marketing after the fish/seafood raw materials have been caught (fisheries) or harvested (aquaculture) to reaching the end consumer. Although the PH industry includes a wide variety of different stakeholders, they are all immersed in an industry that is very likely to feel the consequences of future socioeconomic and environmental changes caused by climate change. To survive, the sector will actively need to adapt, taking concrete actions to absorb, cope and avoid direct and indirect climate change impacts on their activities.

Within its value chain, the seafood PH industry includes extensive processing and product modification operations. These generally require lots of energy, produce a significant amount of waste, and are very sensitive to material disruption, resulting in direct and indirectly produced Greenhouse Gas Emissions (GHG) emissions. Furthermore, the energy intensity and substantial environmental impact of such PH activities can make this sector less resilient to GHG-driven climate change. Therefore, GHG emissions must be reduced for this sector to be an integral part of a low-emission agro-food system, in line with the framework set out by the European "Green Deal", and to enable the industry's long-term survival. This involves reducing GHG emissions at all levels of the value chain and making the best use of available resources through the development and/or implementation of new and more sustainable technologies (e.g., low greenhouse effect refrigerants), but also by the introducing and adapting a "different way of doing things' (industrial strategy) (e.g., "good housekeeping", change of supply chains).

Different to the rest of the case studies (CS) presented in this research report, the present CS is not restricted to a particular species/group of species (e.g., sole) and/or specific processing/transformation industry (e.g., canned, frozen seafood), but encompasses the whole PH value chain. The present CS aims to understand which technological and industrial strategy changes have been, are being and/or will be implemented in the seafood PH industry to reduce GHG emission. The present CS investigates and brings together grey literature sources (i.e., institutional sustainability reports) and information from three interviews with stakeholders involved in the PH value chain of different seafood products. Questions for the interviewee were deliberately chosen and modified specifically to the stakeholder from the 'reference questionnaire for stakeholder consultation. Although the scope of their activities may not cover the entire value chain; they are considered as relevant sources of information to help understand past, present, and future changes.

The stakeholders included a fish feed producing company, a fish product processing company and finally, a fish processing equipment manufacturing company. The feed producer processes different raw materials (of animal and vegetable origin) into fish feed (e.g., pellets), which is sold to and used by aquaculture farms to grow a large variety of species. The second company processes imported aquaculture and fisheries seafood (e.g., tropical shrimps, gastropods) into different fresh and frozen products which are sold predominantly to the retail sector. Finally, the last company, develops, produces, and sells fish and seafood processing equipment (e.g., fileting machine) and software to the fish PH processing industry.

Although the main objective of this CS is to identify which technological and industrial strategy changes have been adopted or will be adopted by the PH sector to reduce GHG emissions, the sector's physical and financial resilience to climate change, the value chain main sources of GHG emissions, and the sectors motivations and limitations for change were also investigated and are presented in the present case study. Further details on specific technological and industrial strategies are presented in the "overview technology and industrial strategy sheets".

2 Value Chain

2.1 Value chain description

The seafood PH value chain can be defined as all interlinked activities that bring a product from its conception (fisheries/aquaculture) to the final consumer. As stated previously, in this CS the seafood PH value chain is described by the activities of three independent companies: fish feed producing company (further referred to as feed producer), a fish/seafood product processing company (further referred to as a seafood processor) and finally, a fish processing equipment manufacturing company (further referred to as an equipment manufacturer). The PH value chain will be described following three main subdivisions: raw materials sourcing, its production and transport, processing (i.e., fileting, peeling) and transformation (i.e., packaging), and finally the transport and supply to the final customer.

Raw materials for fish feed production are sourced globally, come from a vast number of different origins, and are transported by land, air, or sea to the processing facilities. Nonetheless, based on literature and stakeholder interviews, the impacts of climate change (e.g., seasonal shift) and fisheries pressure (e.g., stock collapse), has led to severe sourcing challenges and encouraging the shift from mainly fishmeal (e.g., sardines, anchovies) toward alternatives (e.g., plant based, alternative protein/oil sources) for feed production. The seafood producer also sources its raw materials (e.g., tropical shrimps) internationally, but seems to be less sensitive to climate change-based impacts as it does not rely on only one or a few suppliers but has the capacity to shift its supply chain where the best cost-efficient deal can be made. Climate change may negatively affect one of its suppliers (e.g., reduced harvest volume), but favour another supplier in another region, country or even continent. Raw materials are subsequently transported in frozen bulk by sea freight. No information was obtained on the sourcing and transportation of basic building materials used by the equipment manufacturer.

Once at the processing facilities, the raw materials are processed and transformed into finalized products following a specific chain of processes. For the three stakeholders interviewed in the present CS, this section of the value chain represents the core of their company's activities. For fish feed production, it includes the storage (e.g., silo), cleaning, grounding of ingredients into fine powder, mixing and finally pelletization. Similarly, the seafood producers' processes start with frozen blocks of seafood raw materials, which are gradually thawed, cooked, or blanched, and packaged according to the customers' needs and demands, and finally stored in cold storage units. Specific details on the value chain processes for each of the companies can be found in the company sheets (see Supplementary 1: Company sheets). For both stakeholders above, specialized equipment is used for their processing activities. It is here where the equipment manufacturer comes into play, by developing and producing new and more efficient equipment for specific processes, such as fish grading, portioning, and trimming. Sophisticated software is also developed to manage the functioning of all equipment as efficient as possible. The software may be directed at directly improving the sustainability of processes or indirectly by increasing the efficiency of the plant and reducing waste production.

Finally, products are transported from the processing and storing facilities to the customer. The type of transport used will depend on the product and distance to the destination. For instance, the seafood processer relies exclusively on road transport to supply retail and food industry customers throughout Europe, while fish feed might be transport by land or sea freight depending on the destination. The feed producer does affect this part of the value chain through its own operations; however, transportation is usually delegated to specialized third party contractors, which results in increased efficiency and reduced costs for the feed producer but also reduces the feed producer's capacity to influence and take decisions in this part of the value chain. No information was obtained on the transportation methods used by the equipment manufacturer, however, logic dictates that a combination of transport of land and sea is used.

Although the three stakeholders consulted in the present CS are involved in a different part of the PH value chain, most of their activities relate to the processing of raw ingredients into finalized products, either through the processing of raw materials itself or by the development of equipment to process raw materials. Little to none of their activities are involved in the transportation of supplies and finalized products, which appears to be common practice in the industry.

3 Resilience

External changing factors can put the resilience of an industry to the test. Events such as climate change can influence global supply chains, product availabilities and economies. The resilience of an industry to external and/or internal changes depends on several characteristics, such as sensitivity to disturbances, problem perception, availability of alternatives, financial buffers, etc.

The following paragraphs will investigate the above-mentioned changing factors for the specific stakeholders. These will delve deeper into the subject by consoling interview responses, available grey and academic literature.

3.1 Physical and financial resilience

Financial and physical disturbances impact the supply chain differently and this can happen simultaneously or independently. Climate change is expected to impact the value chain of seafood products by influencing catch potential (Barange et al., 2018), the cold chain (James & James, 2014), transport (Thornes et al., 2012), etc. The direct impact on the PH stakeholders depends on their role within the supply chain, but also on the scale and duration of the disturbance.

3.1.1 Physical resilience

The impact of physical disturbances such as climate change on the PH value chain of fishery products was mentioned in both academic literature and interviews. The inputs stream of the sector is vulnerable for these direct impacts, and these have already been impacting the value chain.

Fish feed producing companies have noticed the impact of physical disturbances on the raw material supply chain. Over the years, fishing pressures and climate change have stimulated the transition towards sustainable alternatives. Fish oil and fishmeal are essential ingredients for the fish feed producing industry, because they allow for efficient and effective delivery of proteins and fatty acids. With declining fish stocks, the major source for fishmeal and oil, related to climate change impacts and overfishing, there has been an increased demand for sustainable alternatives. Producers are looking for alternatives in certified products, by-products, plant-based products, and other alternatives. Using a plethora of fish oil and fishmeal alternatives furthermore aims at increasing the resilience to external disturbing changing factors, because not all raw materials are affected and impacted at the same time.

Seafood processing companies acquire fishery and aquaculture products from multiple producers, which reduces the influence of physical disturbances due to a diversified source of products to process. In the interviews, the seafood producer briefly described their product supply chains across the globe. The seafood producer mentioned how several Indian suppliers have been undergoing climate change related consequences. Faster life cycles with product being harvested earlier in the season, and increased drought periods make it more difficult to harvest products, while increased monsoon intensities disturb the shrimp growing ponds. These shifts can physically challenge the product output for the seafood producer. However, because the seafood producer makes use of global fish product suppliers, local seasonal fluctuations of where seafood is produced have a lesser effect on the product availability at the processors end. Additionally, if the growth season and yield vary throughout the years, suppliers can similarly shift their product source so that the seafood producer can keep providing high value products while keeping costs at a minimum.

Both feed producer and seafood producer make use of globally sourced raw material and unprocessed fish products. This partial dependency can make them vulnerable for other supply chain disruptions. These supply chain disruptions be caused by climate change induced impacts (storms), geopolitics (war), changes in the global economy (recessions, global oil crisis), or other global disruptions (COVID-19, issues with ship freight). The seafood producer mentioned that disruptions of the ship freight can heavily influence their value chain and subsequent prising. Because the raw fish products used by the seafood producer are imported from all over the globe through ship freight, supply chain disruptions can heavily influence their value chain, resulting in steep increases in prices both the raw product as their final processed product. Similar disturbances were also mentioned by the feed producer, however their raw materials are sourced from a large range of sources, such as certified fisheries, by-products, soy plantations, and even internally researched and developed alternatives. This lowers their dependency on both climate impacts as ship freight disturbances.

3.1.2 Financial resilience

Physical disturbances such as climate change impacts not only directly impact the value chain, but also financially perturbs the sector. Financial turmoil in combination with physical disturbances can disrupt the PH value chain of the fishery sector and can negatively impact stakeholders that interact with these the value chains, for example, transport companies, storage facilities, consumers. Several factors can influence the sensitivity to these disruptions and can increase the resilience to financial turmoil.

A well-known strategy to reduce the implications of financial perturbations is diversifying the product's market. The interviewed stakeholders have a strategic market position and deliver products to a range of global costumers. Of the interviewed stakeholders, both feed producer and the equipment manufacturer were international players in their respective market with the feed producer being at the top of their international market segment, while the seafood producer had a strategic market position within Europe. A global (international) market position is however never fully safe from potential threats. The equipment manufacturer serves here as a perfect example as they have an important business footing in Russia. The geopolitical conflict that started in 2022 between Russia and the Ukraine drastically influenced financial markets due to financial measures towards Russia and trading embargoes that have been placed trades with Russia. With a large market share based in Russia (selling their equipment to Russia) and the resulting financial situation, it is likely that this event severely impacted the value chain of equipment manufacturer[48]. Similar global and financial events in line with the aftermath of COVID-19 can influence sectors directly as well as indirectly, in often unforeseeable ways. Resilience to these events is more difficult to achieve. Although instantaneous support against financial disturbances can be given by governmental relief funds and subsidies or other legislative decisions, these measures are short-term solutions and do not provide

[48] Although never confirmed through direct communication, this event provides relevant (financial) context for the sudden halt in collaboration, willingness and availability of time for interviews with the research institute.

constructive long-term solutions to stakeholders within a sector. Physical supply chain disruptions and their financial consequences can be buffered as indicated in section 0.

Business investments into sustainable innovations are also associated with financial risks. Investments can require large financial capital in order to acquiring new technology and/or adopt new management strategies. All interviewed stakeholders talked about this financial risk, but also mentioned that a shift in (financial) mind-set is occurring which will allow future investments in innovative technologies and industrial strategies.

The first, most important shift that already occurred was a shift in financial priorities. Investors and financial institutions are demanding more sustainability. The stakeholders mentioned that the earlier established view of sustainability was one of unnecessary expenses and unprofitable investments. This view shifted over the last two decades towards a sustainable investment view that may provide opportunities to increase efficiency and add value to products. Now, sustainable investments are seen as a new, secure, and profitable business model by investors and financial institutions. Furthermore, financial institutions such as banks require environmental, social, and corporate governance (ESG) criteria to approve (investment) loans. These institutions detail specific sustainability demands and require progress reports and monitor the progress to reach these goals. The interviewed seafood producer exemplified this perception shift through investors demanding energy scans, internal sustainability reporting, while the feed producer mentioned an internal need for life-cycle assessments (LCAs) and certified raw materials (sustainable soy sourcing policy). The perception shift towards sustainable investing creates financial capacity to invest into new technologies and strategies with higher start-up costs and long-term gains such as decreased energy requirements, GHG output or from efficiency of scale (resulting from higher product outputs which can compensate for the initial start-up costs). This allows for the implementation of technologies that initially require large investments, but of which the costs fall when used for a long-term period (due to efficiency of scale, resulting from higher product outputs which can compensate for the initial start-up costs).

Costumer's perception has also shifted, with a higher demand in more sustainable products. The seafood producer mentioned an increased need in certified (ASC or MSC) products. As indicated before, the feed producer also mentioned the increased demand for certified (MSC labelled fish products or FSC raw materials and sustainable soy sourcing policies) by both financial institutions and costumers, and an increased demand for sustainable packaging alternatives. The increased demand of these products creates an economic incentive for sustainable innovation on the stakeholder level. Such demand shifts are nonetheless sometimes restricted to specific market and may take time to install in others.

Financial resilience to disruptions and a capacity for innovation is further stimulated through usage of (innovation) grants. The seafood producer and feed producer both mentioned the use of governmental and research grants to boost research and development (R&D) of innovative fish products. The seafood producer further mentioned they make use of external consultancy services to research grant opportunities and acquiring the grant itself.

Interviewees were explicitly asked about management actions implemented and lessons learned from their experiences. Both the feed and the seafood producer mentioned that alternative technologies and industrial strategies are constantly in R&D and that experimental implementation provides learning opportunities. The feed producer exemplified this by discussing alternative feed and packaging specifically. In the interview, the feed producer mentioned that innovative alternatives for packaging and feed (novel ingredients, insect-based and algal-based meal) are already available at present, but that markets are not always ready or show any demand for these alternatives. The seafood producer similarly reported an alternative processing method, which made use of shrimp peeling processing equipment in local facilities instead of requiring peeling by hand elsewhere. Although this processing technique potentially improved product sustainability by increasing (output) efficiency and lowering transport needs, the product flavour was modified in the process, and this lowered overall product demand. Both examples demonstrate that sustainable processing and management options are always the best business decision, because financial revenue can be influenced by these modifications. And in competitive markets, it is therefore better to experiment with modified setups and approaches before it is incorporated in the business strategy.

3.2 Major financial constraints and reliability

The financial incentive for sustainability change indicated in previous sections can create certain constraints and reliabilities. The financial dependency on the investors and costumers can halt the innovation, and differences in dependency were seen between the interviewed companies.

For the feed producer the primary financial constraint was the compensation of additional production costs. Sustainability elevated diverse production costs associated with the supply chain. The final consumers of the fish feed products are very sensitive to increased products costs. This results in a need for cost compensation within the value chain, which is not feasible for all stakeholders. The feed producer already compensates some costs internally and externally through cooperation between stakeholders, but certain additional costs remain.

For the feed producer, the financial incentive in the decision-making process can further limit sustainable transitions. With the small financial margins in these sectors, decisions are always made from a financial perspective: if a decision is not logical from a business perspective, it will not be made. The investments that go beyond environmental or costumer requirements demand extra capital investment which is not always available and provide no additional business benefits. In other words, if a market does not demand more sustainable products, it makes no sense for the company to make additional efforts and costs to fulfil such demands.

Lastly, the financial dependency on investors increases even further the dependency on external incentives for sustainability related change. When relying solely on financial incentives could make decisions for sustainable within the company even more difficult. If the investors require more sustainability because it is seen as strategic, this driver will help transitioning the business. However, in cases where options that are seen as less sustainable but more strategic or more financially beneficial, the opposite can occur, and a transition to increased sustainability can be halted. For example, the feed producer mentioned that the Southern European market does not demand certified products, hence halting the introduction of such products in this market, and thus reducing the incentive to produce sustainable feeds in Southern Europe, despite being already available and sold in Northern Europe.

All interviewed stakeholders mentioned the dependency on investors for sustainable changes. One stakeholder in particular sees stricter regulations in addition to financial incentives as an effective method to improve the sustainability within the sector: more stringent policies increase the environmental performance of business uniformly in a sector. Other research similarly states that regulation and subsequent stringent environmental requirements are an effective method to stimulate sustainability within businesses (Bar, 2015; Epstein et al., 2017). These policies, and associated penalties in case of non-compliances, force businesses towards environmental practices by making the neglect of sustainability a disadvantage. This would make sustainable practices the only viable practice for the sector.

4 Greenhouse Gas Emissions

4.1 GHG emissions in the value chain

Each subprocess of the PH processing industry has specific environmental effects and the inclusion/exclusion of subprocesses can influence identified impacts during environmental impact assessments (Parker, 2012). As stated previously, the stakeholders consulted in this CS do not have a complete control of the PH value chain, from raw materials to finalized products, and therefore cannot have complete control over the GHG emissions produce in these sections. Still, the stakeholders may exert some influence on the sections of the chain before and after their own specific part of the chain (*s.s.*) through their market position (offer and demand) and collaboration with companies that to earlier or later processing steps. However, the stakeholders are unlikely to steer large changes that would affect the entire chain.

It appears that for all three stakeholders, these uncontrolled sections represent the main source of GHG emissions in their value chains. For example, around 90 % of the feed producers' GHG emissions were calculated to be linked to the production of raw materials (e.g., soy) and land use change (LUC) associated to that production process. If fishmeal/oil production is included in the footprint calculations of specific fish products, the proportion of pre-processing emissions further increases. Similarly, the fuel consumption for fisheries and/or aquaculture production represents the main source of GHG emission for the seafood producer, while the sourcing and transport of raw materials for the manufacturing of fish processing equipment for the equipment manufacturer.

Although processing activities of the stakeholders (*s.s.*) represent a smaller proportion of the value chain impact, these are still responsible for GHG emissions and provide room for improvement. Throughout the fish feed production process, the most energy intensive processes are related to heat and drying processes. Those processes are necessary for the extrusion processes (creating the feed pellet) which consumes large amounts of water and energy. In addition, semi-finished feed products take up water and need to be dried for correct storage and later consumption. The extrusion process is still considered as an energy and emissions hot-spot and thus optimising the processes related to extrusion can reduce GHG emissions for these processes.

Fish and seafood processing activities carried out by companies such as the interviewed seafood producer can vary significantly depending on the raw materials used and the final product itself. Still, thawing and freezing have generally been identified as the most energy demanding processes. Seafood is highly temperature sensitive, hence needs to be kept at temperatures under 0°C to maintain its quality and increase its shelf life. The processes that aim to maintain quality throughout the value chain already requires lots of energy (i.e., cold storage and cold chain). Nonetheless, most seafood (fileting, cooking, portioning) cannot be processed when frozen, thus requiring them to be thawed. This requires energy, usually in the form of heat, to convert the ice contained in frozen fish tissue into water, while re-freezing involves the opposite. Both lead to direct GHG emission as energy is used during both of these processes, and indirectly as "lost" energy in the form of quality and water loss (evaporation, ice formation) and waste production. Optimising these processes can reduce GHG emissions, while also maximizing the processing plants efficiency.

Finally, no details were obtained on the GHG emissions linked to internal processing activities carried out in the manufacturing of fish processing equipment. Details were asked but not provided during the interview. The only numbers collected for the feed and seafood producers were dated and were found in sustainability reports of 2020 and 2017 respectively. These reports mention the emissions per kilogram of product as globally averaged for the feed producer and specifically for the Belgian facility of the seafood producer[49]. The feed producer reported that for every tonne of fish feed product they produce, the facility consumes 343 kWh of energy and 670 litres of water, and produces 74 kilograms CO_2 emissions and 9 kilograms of waste. As a comparison, in the 2017 sustainability report of the seafood producer it is mentioned that the Belgian facilities consume per tonne product 790 kWh of electricity, 0.377 kWh of gas, and 10.67 m^3 (10,670 litres) of water, and 13.08 kilograms of flammable waste.

However, it must be emphasised that the numbers are dated and represent a snapshot of those values per stakeholder. Because CSs are specific and conditions differ between companies, these values cannot be generalised for a whole industry or sector.

4.2 Alternate distribution systems

Throughout the PH industry, aiming for the most cost-efficient distribution system is constant, leading to the inclusion of alternative methods and/or changes that directly or indirectly lead to reduced GHG emission. However, the findings of the interviews indicate that the overall reduction of GHG emission is not in the focus of the distribution chains discussion, as distribution efficiency and costs reduction is considered more relevant.

Alternative distribution systems for the identified GHG emission hotspots (see section 0) were not identified. Except for the seafood producer, where an example was given of the processing and transport of shrimp. In this case, in order to reduce GHG emissions and costs caused by the on-road freight and processing (thawing, peeling, and re-freezing) of shrimp abroad, a shrimp peeling machine was presented and tested. Although this machine solved some issues related to the technology and transport as the machine could be implemented locally, the new transport strategy was never adopted as it led to a lower customer demand and the new processing technology changed the taste of the product.

Furthermore, the stakeholders mentioned the use of external parties for transportation services. This outsourcing of transport services can reduce data availability and the implementation of sustainable alternatives. Because transport companies are the only party with direct access and control of their emissions related to transportation, the PH companies have limited control over this process and subsequent sustainability decisions. Although beyond the seafood producer company’s reach, the number, size, and frequency of trucks used to pick up and transport the finalized product to the retail stores did shift throughout the years to maximise efficiency and reduce GHG emissions. Instead of doing more frequent trips with smaller trucks, larger trucks and less frequent trips are now preferred.

Still, regarding raw material transport for both the feed and seafood producers, sea freight is seen as the most (cost) efficient and sustainable way of transport. For example, bulk ingredients come from far and generally do not need to be kept fresh. Nonetheless, shortening the supply chain by placing the raw material production or at least some of the raw material production (if possible) and fish feed production close to the processing plant and/or customer is constantly under assessment. These shorter chain production-consumption distribution systems would reduce transport costs and the climate impact of aquatic feeds. Aquaculture production in many different European and the Middle Eastern locations, is still seen as far from efficient but a possible future alternative to reduce long distance transport dependency. In addition, such strategy would help to cope with the

[49] Both sustainability reports have additional numbers besides the mentioned output numbers, they provide for example the same parameters for preceding years. This alongside additional insights through textual explanations provides important context for the environmental parameters. Full sustainability reports are available in the web links present on the company sheets (see Supplementary 1).

increasing fees for sea freights.

With regards to transport of the processed products toward the customer, the feed producer reported that the bulk transport of fish feed products was arranged in cooperation with a competitor to ensure efficient product delivery for the consumer (i.e., aquaculture farms). This streamlined the transportation process for all parties and helped reducing costs and environmental impact of the feed. Specifically, instead of sending multiple ships for both feed producer, a single ship with feed of both producers on board was organised.

No insights on transport optimisation were obtained for the equipment manufacturer.

4.3 Limitations for structural improvements in GHG emissions

Applying structural improvements to reduce GHG emission is not straightforward and will in most cases represent efficiency and/or cost trade-offs. These are therefore unlikely to happen unless top-down force limitations and/or motivations are present (e.g., law, investment) or if the consumer demand asks for it.

When interviewing the stakeholders, it was found that most changes occurring in the PH value chain are driven by the need to meet portfolio requirements for investors, which have shifted toward more sustainable business targets in the last decade. This is achieved through the implementation of sustainability requirements and reporting, and monitoring environmental key performance indicators (KPIs) related GHG emission reductions. However, in case of short-term investment models (e.g., private equity), such as for the seafood producer, investments are constrained to short terms, as results and profits are expected to be obtained at the end of the investment timeframe (i.e., 7 years). Big structural changes (e.g., renewal of processing lines, cold storage, change of refrigeration system) require large investments, which will not be made available unless the return of investment can be met in a reasonable time frame.

Similarly, using microbial and insect-based protein and oil sources to produce fish feed is currently under research but still entails a trade-off, making these innovative raw materials unfeasible or less profitable alternatives for the moment. Nonetheless, future production systems may make these alternatives as efficient as the current used raw materials.

The usage of LCA’s for determining sustainable alternatives can be complicated as well. As mentioned in earlier paragraphs, primary data are not always available, and secondary data are often used as regional averages. This can result in over/underestimation of environmental impacts. Because LCA’s are dependent on the used statistical methods, input data, and included processes and impacts (i.e., system boundaries), calculations can vary. This complicates the interpretation of LCA results and thus the decision process for the determination of sustainable alternatives, and can create differences between stakeholders. To counter this, the Product Environmental Footprint Category Rules (PEFCRs) have been developed by the European Commission (Hognes, 2016; Marine Fish PEFCR, 2021). Still, the implementation of these rules needs to be ensured in the industry, as the feed producer mentioned that this was not yet the case.

Cooperation between companies needs to go beyond the identical implementation of the LCA method and is necessary to find the most sustainable alternative for the value chain. Decisions made on company levels are not always beneficial for the value chain. Process changes (such as alternative feed, shifts in packaging materials, changing peeling methods, adapting new freezing technologies and strategies, etc.) can similarly seem beneficial on its own, but in the context of the supply chain they can increase environmental impacts (lower FCRs require larger feed quantities, reduction of product shelf life, or by changing product quality). Stakeholders need to collaborate to ensure that the best decision can be made for all involved parties and need to share data and insights to find the solution with the most advantages.

Remarkably, stakeholders consulted in this CS showed to be eager to follow a more sustainable path but need the product demand to apply themselves to changes necessary for more sustainable processing. For example, market demands (e.g., improved by certification) for tropical shrimp are significantly different between regions and countries in Europe Northern countries demand exclusively certified products, while Southern European countries do not demand such certification but prefer large and fresh specimens. Although, certified products can certainly be introduced in the market and gradually guide the demand toward it, this will represent significant time and financial investments, while top-down changes, such as legal restrictions or requirements, are more likely to steer changes at a faster pace.

Regulation and politics however are not always advantageous for sustainable development and can hinder the progress. The seafood producer noted that improvements in wastewater management were hindered due to the proximity of the facility to populated areas and political resistance. Similar situations are commonly observed with installations of windmill farms because the windmills are known to cause nuisance for local citizens. Depending on the location of the facilities, these types of issues can occur frequently and must be considered in the (sustainable) development of an industrial facility.

5 Reducing GHG emissions by technical means

This section delves deeper into the specific methods used and mentioned in the stakeholder interviews. The section investigates which technologies and strategies have been applied in the past, over a period of 20 years prior to the interview, and explores technologies and strategies that are useable in the future.

5.1 Trends in technological evolutions and industrial strategies

5.1.1 Industrial strategies

The interviewed stakeholders indicated that sustainability becomes more prevalent in the sector, through both consumer and investor awareness. This demand increased the need for sustainable alternatives and helped shift this business towards that direction.

Delivering sustainable alternatives can provide a market advantage as well: the feed and seafood producers mentioned this perception shift during the interview and both companies profile their sustainability specifically to their clientele. The feed producer mentioned that they started reporting their sustainability 20 years ago, through environmental footprint calculators aimed at the consumers. The calculator focussed on the sourcing of the fishmeal and fish oil and considered the needed amount and distance of these raw materials to travel. This was converted into a number which would be presented to their clients and could be used to pick the most sustainable alternative. Since this initial step, they have continued to profile their sustainability and have continued to work on the sustainability of their products. The seafood producer mentioned that they were pioneers in providing MSC/ASC labelled products on the Belgian market. With the market starting to demand more of these products, being a pioneer provides competitive advantages even if the initial product costs are higher. The seafood producer noted that this market shift was not omnipresent in the product demand. This stakeholder noted that in European markets, Northern countries demand more sustainable products while Southern countries have a higher demand for fresh products, but not specifically certified products. The seafood producer mentioned that it can help guide the market towards a direction, by for example being a pioneer in sustainable products, but that it still depends on the customer needs.

The sustainability demand of investors became more apparent in recent years. They demand sustainable investments and require monitoring for the insights in the progress of their investments. Both the feed and seafood producer mentioned that investors demanded detailed internal sustainability monitoring, through sustainability reports and KPIs. Investment funds assess the sustainability of their investments through the global sustainable development goals (SDGs) provide by the United Nations (UN) or through ESG criteria specifically aimed at sustainable cooperate practices. Further, the seafood producer mentioned specifically that because of their position as private equity, investors demanded specific sustainability actions such as periodical energy scan of the facilities which help exposing energy-inefficient processes.

This prioritization of sustainability through financial incentives and market demands stimulated the implementation of these practices in the sector.

5.1.2 Technological evolutions

In addition to higher sustainability demands from both costumers and investors, technological aspects of the value chain changed as well. Both the feed and seafood producers mentioned for example their ongoing improvements in resource (water and energy) consumption and their waste and GHG production.

The change in energy used in the facilities is a change that interviewed stakeholders both indicated during the interview. With the increased accessibility and availability of green energy sources such as solar, hydro and wind energy, the transition to utilising these sources became more accessible. The implementation of these energy alternatives still needs to be handled at a local level, with selection of the optimal alternative for a specific operational site. This decision process must account for local conditions, available alternatives, and associated costs. The feed producer further mentioned the green energy use can be stimulated by financial incentives as well, because oil prices and emission penalties can create an economic burden on a business. Decisions and expertise for the energy optimisation is often achieved in collaboration with specialised external consultancies.

Sustainability monitoring and the associated insights further help with optimising the processes within the facilities of the companies. Keeping track of the environmental parameters throughout the years helps revealing among others, knowledge gaps, useful process parameter adjustments and their potential influence on the whole fish processing value chain, and transferability of optimised processes to other sites. The interviewed stakeholders mentioned that monitoring as such helped to reduce waste generation, water, and energy consumption and associated GHG emission per product over the last 20 years. An example was given by the seafood producer, where they had an energy gain after shifting to LED lighting in their facilities. The benefits of this technological implementation were identified through energy scans requested by the investors. No other specific examples of improvements and associated benefits were given during the interviews.

Sustainability improvements associated with improving the product packaging were mentioned by both stakeholders. The feed producer mentioned that initially packaging of fish feed shifted from 50 kg to 25 kg bags due to human labour and associated safety regulations. More recently however, products are more often delivered in bulk by making use of big bags. Big bags of one tonne reduce waste generation by reducing needed amounts of packaging materials and by allowing the reuse of these big bags. The seafood producer also mentioned a reduction of generated waste. The seafood products are packaged in 2 kg bags and cardboard boxes, which results in large amounts waste. Historically, plastics and other waste would be shipped to China for recycling but in recent years they work together with local companies to recycle the plastic and other material. Furthermore, currently used raw materials can also have a sustainability certificate, and if possible these materials will be used. An example of this would be the FSC labelled cardboard boxes.

Packaging is also influenced by consumer needs. The feed producer mentioned that in recent years, increased awareness of the environmental impacts resulted in a higher demand of responsible packaging or at least packaging that can be reused. This translated itself in an increased responsibility taken by the producer for their own packaging materials and reuse of those materials. This has increased the demand for alternative materials and recyclable packaging. The seafood producer mentioned that alternative and innovative biodegradable packaging for their products is available, but that the implementation of such packaging still depends on consumers demand.

5.2 New processing and logistic techniques and their challenges

5.2.1 Processing optimisation

Historical process improvements can be further applied and explored to continually improve operations in the future. Both the feed and seafood producer mentioned for example the continuation of the green energy exploration. The seafood producer explicitly mentioned this decision from a financial perspective. With a dependency on external energy sources and souring prices, it can be strategical to create energy-independent processing lines. A secondary benefit of this transition is the reduced environmental footprint of the operations.

Another processing improvement with potential secondary positive environmental impacts is the implementation of automation in the value chain. The seafood producer mentioned that automation would be implemented to remove the dependency on human labour, and not because of a reduction in efficiency or costs, or environmental improvements. The seafood producer elaborated about the difficulty in finding labour force for the job and mentioned that automation avoids processing interruptions due to a drop in available workforce. If automation would be further implemented, it can result in additional environmental benefits. Automated processing lines allow for constant and consistent product monitoring and efficient processing, which helps to increase the rate of the production chain and has the potential to reduce waste generation and energy needs.

Internal optimisation of the production chain further depends on each of the intermediary steps of the processing line. Both the interviewed stakeholders, that is the feed and seafood producer, highlighted different aspects. The feed producer mentioned in the interview that heating and drying processes are the most energy intensive within their production chain. The processes make use of high amounts of water, steam and energy, and optimisation can positively impact the GHG emissions of the production chain. The feed producer has been looking into heat recovery systems, improved steam boiler efficiency and drying operations. The seafood producer also mentioned specific improvements for their production chain. The most energy intensive processes for the seafood producer are thawing and refreezing steps. This stakeholder has been looking into alternatives for thawing in water, such as microwave and infrared thawing, which are currently experimental and innovative techniques (see respective technology sheets). However, the product yield of these alternatives was lower, and the implementation has stopped. The seafood producer mentioned that they keep exploring alternatives for future improvements. For freezing, the seafood producer combines both liquid nitrogen and mechanical freezing. The mechanical freezing evaporates water on the surface of the product. From above statements it can be concluded that the seafood producer is still investigating alternatives that use less electricity and result in less weight loss from evaporation.

The implementation of alternative processing methods is a continuous process, with setting up research on and development of alternative methods and technologies or by experimentally testing an alternative setup and reporting the conclusions from the experiments. For the investigation of sustainable alternatives, LCA's are an important tool that will be continued to be implemented. The feed producer use the LCA tool to determine the sustainability potential of alternative raw material and fish feed products, and need to make sure that there is a net gain in sustainability throughout both the production chain as the value chain. If a product has a lower environmental footprint but requires higher quantities of raw materials to result in a similar product as currently is produced, the overall sustainability may be lower. The interviewed stakeholders both mention the use of the LCA tool in the decision-making process, the feed producer specifically mentions the potential to use this tool beyond their processing steps. A broad application of this tool helps to decide for the most sustainable alternative methods and technologies, with the biggest positive environmental impact on the production chain as well as over the entire value chain.

5.2.2 Value chain optimisation

The broad application of the LCA tool delivers insights into the processing steps and beyond, and allows for the detection of the GHG hotspots. Both the feed and seafood producers mentioned the presence of GHG hotspots in steps preceding the fish processing, more specifically in the raw material production and shrimp farming for the feed and seafood producer respectively. In order to improve the sustainability of the value chain, it must also include preceding steps and requires cooperation between stakeholders.

The feed producer remarked on several cooperative focus areas during the interview. The company mentioned that the LCA tool requires more optimization, with different or changing primary data leading to calculation differences. Environmental parameters are often grouped over large areas, whilst regional variation can impact the parameters, and this can notably change the calculations. The feed producer mentioned that the footprint of the soy sourcing for example is calculated on a regional level, whilst within region impact differences occur between the certified and non-certified soy farms. On a regional level, an average value is calculated which can over/underestimate the specific impact. In order to further optimize the LCA analyses, companies need to work together to collect more primary data with increased data quality, thus avoiding over/underestimations as much as possible. The data quality improvement and subsequent improved LCA tool would increase the accuracy of the impact estimations and can help optimise the value chain throughout.

The certification of raw materials and final products in general was a topic that was emphasised by both the feed and seafood producers. Improving the certification of fish products and raw materials used, improves the sustainability throughout the value chain. Stimulating certified soy products for example, ensures that soy originates from farms with sustainable practices and avoids deforestation and subsequent environmental LUC impacts. Similarly, the certification of fish products aims at decreasing several different impacts of the value chain mainly focussed on environmental impacts. Utilising MSC labelled fishery products avoid sourcing fish from unsustainable fisheries, whilst ASC labelled products promote sustainable aquaculture practices by increasing standards for quality, waste management, etc. Cooperation between stakeholders therefore increases the quality of the raw materials sources and helps decreasing the footprint of the whole value chain.

This cooperation can be further extended to the whole value chain, and further collaboration within the sector can help to improve the standard practices throughout. Global, regional, and sectorial cooperative organisations can boost sustainability of different market players and ensures that no competitive advantages are present from the non-participation in the sustainability transition.

6 Conclusions and issues

6.1 Concluding remarks

This CS report joins findings and insights of three different stakeholders of the fishery PH value chain, namely a feed producer, a seafood producer and an equipment manufacturer. Insights for the feed and seafood producer were gathered by investigating available grey literature and interviewing company representatives. For the equipment manufacturer, mostly grey literature was consulted due to unusual circumstances (see section 3.1.2 in the current CS). For details on the specific interviewed stakeholders, a reference is made to Supplementary 1.

Considering the full scope of impacts of fishery products, findings suggest that the PH activities have fewer environmental consequences as compared to other parts of the value chain. In the interview, raw material production and fish feed production were identified as the most environmental intensive parts of the PH value chain for both the feed and seafood producers respectively.

Within the PH production chain, the most impactful activities were related to the temperature regulation of the product. For feed producer it was specifically the heating and drying process, while for the seafood producer it was the thawing and (re)freezing processes. The environmental impact of these processes was higher due to their higher energy demand. Energy and water resource usage and waste management were identified and targeted as sections with potential for improvement. Research in improvements of PH practices such as packaging, alternative feed raw materials, alternative processing methods, and raw material certification are ongoing and are constantly explored by the interviewed stakeholders.

However, due to the presence of more dominant environmental impacts beyond their PH production chains, sustainability is not the main priority of the introduced improvements of technology and industrial strategies. Financial gain is identified as the main motivator for change, and secondarily sustainability can provide possible financial gains. This can be directly through marketing and supplying for market demands, and indirectly through increases in efficiency (by lowering processing cost), quality (by lowering waste generation and subsequent needed processing) and meeting legislation (by receiving fees and grants, or by avoiding fees and penalties). Implementation of new technologies and strategies always aim at improving other processing aspects such as efficiency and quality, whilst sustainability is often of secondary or tertiary importance.

The financial gain from sustainability has been part of a shifting focus of investing parties towards alternative increased financial gain. While sustainability used to be seen as a financial burden, it is now seen as a strategic and safe investment option. This shift in focus explains the increased presence of sustainable marketing towards costumers, as well as the more stringent environmental requirements (such as internal sustainability reporting, monitoring of environmental KPIs, and ESGs) in investment portfolios.

Because sustainability is not identified as the company’s main priority (due to the large environmental impacts associated with pre-processing value chains, no explicit demand or lack of financial margin for these improvements), intrinsic motivation for change is low. For this reason, interviewed stakeholders see regulation as the most effective method of transitioning the sector towards sustainable practices. By enforcing legislation throughout Europe, stakeholders will be compelled to take part in the sustainable transition.

There is a large potential to improve the value chain throughout because sustainability of the PH value chain is not a priority and many challenges still remain. Transforming the fisheries and their subsequent value chain, both the GHG hotspots and the PH chain itself, must be achieved by incorporating all the stakeholders in the transition. Interviewed stakeholders deem regulation as one of the most effective methods to stimulate this overhaul of the entire chain.

6.2 Challenges during the CS

Whilst preparing and performing this CS, several issues surfaced. The main issue revealed in this CS and project is related to the availability of raw data. During the literature review and interviews, the difficulty of acquiring insight into environmental data and supply chain details quickly became clear.

This difficulty is mainly related to the willingness of the stakeholders to share data with research institutes and related to availability of the data from the stakeholders themselves. Acquired numbers in this CS were collected from (dated) sustainability reports and give only a superficial insight into the ongoing processes. When asked about specifics during the interview, stakeholders would mention the exact numbers from the sustainability reports or would mention that environmental parameters and supply chain specifics are only communicated internally. The feed producer mentioned that sustainability reporting and results of energy scans are exclusively communicated with investors, while the seafood producer mentioned similar internal communication. The confidentiality and subsequent lack of open communication with research institutes make it difficult to gather insights directly in the PH sector.

Furthermore, specifics on the full PH supply chain are not always (directly) available for all involved stakeholders. When asked about the efficiency increase related to insulation, availability of grants, and details for used transportation modes, stakeholders mentioned the outsourcing of these services to external consultancies. Because services are outsourced, not all data may be directly available to the interviewed stakeholders.

Consulting literature also proved to be difficult for collecting information on raw material and energy flows of the supply chain. Research institutes and papers run into similar data communication issues. Additionally, the specifics of the PH value chain are less studied from an environmental point of view and mostly focus on technical information with relation to food quality, shelf life and the engineering required to reach food quality and improved shelf life. This resulted in papers for this CS being too specific or not specific enough for the scope of the project.

Lastly, the cooperation between companies and research institutes can be further impeded by unforeseen (global) events. As an example, in the current CS, the communication towards the equipment manufacturer suddenly halted and was not due to a lack of trying. In the initial communication the equipment manufacturer already proved to be hesitant to collaborate, but the interaction was further halted when the Ukrainian-Russian conflict started. Although never confirmed explicitly, it can be assumed that companies with large market shares in Russia where heavily impact from the globally invoked financial sanctions. Similarly, to possible financial fallout due to the COVID-19 pandemic, geopolitical events pressure companies of different sectors.

All these issues complicate data collection on the PH value chain for research institutes and uncover some weaknesses for possible sustainability transitions. Further studies may investigate these challenges and focus on working around the issues.

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Supplementary 1: Company sheets

Company sheet: feed producer

A. Brief description of the company

The feed producer is a leader in the global **fishmeal processing** and **aquatic animal feed market**, where it provides innovative and sustainable nutrition for the aquaculture sector. While present in 19 countries, the stakeholder helps provide fish and shrimp feed for a wide range of farmed species. The annual production output is around 2.6 million tonnes of aquatic animal feed.

With their large presence on the market, they are the largest aquatic animal feed producer in the world and house a total of 3,500 employees. The central major operations of the stakeholder are based in Norway. The company itself is a wholly owned subsidiary of a larger animal feed group in the Netherlands, where the stakeholder represents the division responsible for aquatic nutrition and services.

One of the central dogmas of the company is their idea of “feeding the future”. The company wants to ensure that the rising food needs linked to the increasing human population are met in sustainable ways. Their goal is achieved by constantly working on innovative feed solutions, raise the efficiency and nutritional value of their products and by reducing the environmental impact of such feeds.

B. Value chain

The production chain of the fishmeal processing sector can be subdivided into three parts: raw material production and transport, feed mill (and subsequent processing) and the transport to the farm. The seafood producer is most active in feed mill and processing, but also actively takes part in the rest of the value chain.

The first aspect of the production chain includes the raw material production and transport and is the input stream of the sector. While previously mainly fishmeal (sardines, anchovy) was used as a major raw ingredient of aquatic feed, low fish stocks and the push for sustainable fisheries has incentivised the fishmeal processing sector into alternatives. The animal oils have today been largely replaced by plant-based oils; however, the raw materials (plant material) must be sourced globally. Vitamins, protein, minerals, and spore elements also must be sourced globally and come from a vast number of different raw material sources. All the raw materials or ingredients need to be transported via different transportation modes (trucks, air freight, water freight) to the processing facilities.

The second part of the production chain, the feed mill and subsequent processing represents the actual processing and core of stakeholders’ activities. The ingredients that end up in the finished aquatic feed product follows a clearly defined industrial flow that is similar for most aquatic feeds. The ingredients are stored in silo’s, the ingredients are cleaned, grounded in a mill to fine powder, mixed (this can take multiple rounds), pelletised via an extruder, adapted for specific needs, which can include adding moister, coating, removing moister (drying) and cooling, and finally the pellets are packaged. This entire flow is often highly customisable for specific consumer needs. Important to note is that during this process, transport does not come into play.

The third subgroup focuses mostly on transporting the final product to the customer or consumer of the aquatic feed products.

C. Insights from the grey literature review and interview

Environmental and economic impact and resilience

- Raw resources have undergone environmental pressure (fishery pressure, climate change impacts, etc.) that challenge their availability. The stakeholder had to shift to plant-based oils and started researching other alternatives. Commercial viability and environmental impact of these alternatives is being investigated.

Technological changes and their drivers

- The large environmental impact in the value chain is the raw material production, and associated LUC (Land Use Change). Within the feed producers' processes, energy intensive practices such as heating and drying (extrusion processes) are the most impactful.
    - Through cooperation with stakeholders, raw materials (soy, palm oil, fishmeal and fish oil) will be sourced responsibly. This will be achieved through certified practices, deforestation policies, and specific Codes of Conduct.
    - A portion of R&D focuses on alternative feed products such as algae, bacteria, yeas, and fungi. In the RoadMap 2025, the overarching animal feed company aims at sourcing 5 – 10 % from these sources.
- For a specific customer, the stakeholder improved transportation by bulk shipping product together with the competitor to a shared client, to jointly reduce GHG of both operations. Short chain production-consumption chains (with raw material and feed production in proximity of costumers) are a potential alternative to reduce transporting footprints in the future.
- Factors limiting the structural improvements:
    - Lack of uniform GHG emissions within the industry and/or accurate primary data makes it difficult to assess the most sustainable options.
    - Lack of cooperation within the value chain can limit the effects of the sustainable improvements: sustainable improvements need to provide the most positive changes for different stakeholders and cooperation is needed to achieve this.
- Low amounts of waste are produced in the processing steps: products of inadequate quality are internally reprocessed. Packaging waste has also been reduced by delivering products in larger big bags (1 ton) or by bulk delivering. Furthermore, recyclability of the packaging has been improved over the years.

Industrial strategies and their drivers

- Sustainability became a focus area 20 years ago:
    - Initially this was through environmental footprint calculators, carbon footprint measurements (starting in 2009) sustainability reports (starting in 2013), and sustainability roadmaps.
    - The feed producer has a target to stop using oil/fuel-based energy sources by 2030 and shifting to renewable energy sources.
- GHG hotspots have been identified through LCA's. Previous efforts focussed on improving scope 1 and scope 2 impacts (which are in the stakeholders' direct control). Future work will focus on GHG hotspots (scope 3) and will be achieved through cooperation with stakeholders.
- Financial investors have shifted towards sustainability, where sustainability is seen as profitable, interesting, and financially secure. This creates an incentive to move the industry towards more sustainable practices.

- Sustainability costs are not always absorbed in the value chain. Some sustainability costs are absorbed by the stakeholder or by cooperation between stakeholders, but the "Who pays for the sustainable transitions" question remains essential in the sustainable transformation of an industry.

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Company sheet: Seafood producer

A. Brief description of the company

The seafood producer started in 1954 as a fish salting and exporting company but changed toward cooling and freezing activities of tropical shrimps due to the imposing quotas and lower fish abundance (i.e., cod) in the 70's and 80's. The seafood producer is currently a private equity seafood **processing company** and **private label supplier** with a very strong position in the European market for chilled and frozen seafood products. The stakeholder forms also part of the Shore NV "group" which also integrates a second company, a German seafood supplier with a strategic position in the German, Austrian and Swiss retail, and food processing industry market.

The seafood producer imports tropical and cold-water fisheries and aquaculture shrimps and to a lesser extent other related products such as crayfish, squid, mussel meat, scallops, and surimi, from countries such India, Vietnam, Indonesia, Bangladesh, Pakistan, Argentina, Peru, Ecuador, Canada, China, and the Netherlands. Shrimps are shipped to Belgium, processed and finally predominantly to the European retail sector and food service markets, and a smaller proportion to the seafood industry. The stakeholder currently counts with approximately 120 employees in Belgium and 4 in Germany and represents annual turnovers of around 130 million euros.

B. Value chain

The stakeholders' activities in the seafood PH value chain are restricted to the sourcing, processing, and packaging of seafood products. The company also represents the intermediary between seafood producers (aquaculture/fisheries) and customers (retail, food service and industry). Raw materials (tropical shrimps) are purchased and shipped to Belgium in frozen block batches which constitute the entire season's harvest/ catch, hence including specimen of all sizes. The supplier's selection is driven by the price, the total volume caught/harvested that season and due to specific customer demands, such as the meeting of international sustainability certifications and label (ASC, MSC, Naturland).

Once in Belgium, the shrimps are thawed, cooked, or blanched, frozen (IQF), packaged and stored in cold warehouses. The specific process raw materials will follow will vary based on the product required by customer. Although products are bought in catch/harvest batches (whole catch), these are thawed and processed gradually based on the markets demand. Quality controls are performed throughout the whole process by internal and external laboratories. Although the seafood producer has direct control over the processing activities, these are mainly driven by customer input and requirements for specific products (e.g., species), presentation, type of packaging and prices. Finally, and beyond stakeholders' activities scope, the stored product is sold and sent across Europe by road transport.

C. Insights from the grey literature review and interview

Environmental and economic resilience

- Buying shrimp frozen in bulk/batches allows to get better prices and reduces the effect of price fluctuation, while also satisfying different customers' demands (i.e., sizes, presentations).
- Although it requires re-adapting the supply chain, the company can shift between suppliers aiming for the most cost-efficient alternative.
- They have observed a strong shift due to climate change (e.g., seasonal shifts, drought, intense rains) which affects their suppliers.
- No direct impact of climate change has been felt in their activities.
- Quite sensitive to sea freight prices for supply and there are no alternatives.

Technological changes and their drivers

- Thawing and re-freezing are the most energy demanding activities.
- The implementation of sustainability measures is driven from top to bottom. GHG emission are becoming more relevant in investment portfolios, hence establishing the need of meeting certain environmental standards (e.g., certification). This change has been observed in the latest 5-6 years (apparently linked to new investment legal requirements).
- Processing efficiency optimization is the main driver of technological development and implementation. There is a positive attitude toward trying alternatives, but these must bring an economical added value. For example:
  - Sustainable thawing alternatives (infrared, micro-wave) have been tested, but not implemented as they reduced the processing efficiency (i.e., yield, quality).
  - Shrimp peeling technology was used to reduce the GHG emissions produced to transport shrimps to be manually peeled in Morocco, but not maintained as customer didn't like the different flavour.
  - LED implementation in cold storage, lead to energy savings.
  - Reducing water consumption is financially driven.
- Law will accelerate/oblige change when no economic benefits are involved.
- Expert and routine controls (e.g., insulation, energy efficiency, light) might be expensive but are paid back in savings. Sustainability scans/controls are increasingly being demanded by investors, but long-term cost reduction is still the main driver of changes.
- In the last 20 years waste, electricity, GHG emission production per kilo of product has been reduced.
- Technicalities are discussed and then managed by a contractor

Industrial strategies and their drivers

- Sustainability through certifications is governed by the customer rather than the stakeholder. We provide what the local market asks for. For example:
  - Northern Europe: ASC and MSC certified products
  - Southern Europe: Product quality is dominant over certification
- They are involved/lead projects to help fisheries/aquaculture to obtain the MSC/ASC certification. Nonetheless, this is still driven by the big retailer's demand.
- They are driven by making sure to provide access to the product before the competition.

- There is interest in building a new processing line to cope with increasing energy prices (100 % renewable).
- Transport is not managed by the company, but some shifts are being observed (e.g., reduce number of trips).

D. References

Morubel. 2015. Act Pure Achieve More. Sustainability report 2014-2015. http://ristic.jumik.be/getattachment/Sustainability/Sustainability/Morubel_Sustainability-report-14_15.pdf.aspx

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Company sheet: Equipment manufacturer

A. Brief description of the company

The equipment manufacturer, was founded in 1983 as a family company that initially focused on traction control systems for use on board fishing vessels. Since the start-up, the company added motion-compensated marine scales, land and on-board grading of fish, and fixed weight portion cutter for salmon to their expertise. Presently, the focus of the stakeholder lies on the **production** of high technological portioning- and sorting **devices for food processing companies**. More specifically, the PORTIO, an intelligent fixed weight portion cutter, is the manufacturers crown jewel. Over the years, they also expanded their expertise beyond the sea, working on grading and weighing solutions for the meat and poultry industries.

The stakeholder is based in Nieuwpoort Belgium where they have a production facility of 6500m² that doubles as sales and demo room and offices. In 2021 the equipment manufacturer opened a sales office in Russia and in 2022 another in the United States of America. They also have a virtual demo room which can be visited on their website. All the machinery and software is developed in-house but most of their profits comes from shipping as they achieve a 95 % export rate to over 50 distributors worldwide.

The Industrial Food Portioning Machines market revenue has grown in the last five years and is expected to grow further in the next five years. The major players and competitors of the stakeholder are Hollymatic, TREIF, Marel HF, JBT and Vemag Maschinenbau. In 2015, Marel HF filed a lawsuit for patent in the Northern Georgia against the stakeholder. The top countries buying appliances from these companies are the United States of America, Canada, Germany, UK, France, Italy, Spain, Russia, China, Japan, South Korea, Australia, Thailand, Brazil, Argentina, Chile, South Africa, Egypt, UAE, and Saudi Arabia.

B. Value chain

The marine and fish department of the equipment manufacturer has three focal points in their PH activities: weighing, portioning, and grading. The stakeholder developed an in-house integrated software to combine the activities, called MATRIX PRO. They have PH systems for fish are specifically designed for lobsters, and round- and flatfish, which can be whole or filleted.

They have two types of scales, the "normal" scales and flow scale. The normal ones vary from 3 to 75 kg and are IP 67 class made of AISI 316L stainless steel. They measure accurately up to one gram and use 230 VAC or 24 VDC batteries. They are controlled by LCD touchscreens. One type can be programmed to have up to 1500 species and size combinations and has a TCP/IP connection. These scales are motion compensable to be able to be used at sea. MARELEC also produce a weighing terminal which is customizable and can register batches or allocate orders and works with boxes. The terminal is part of the bigger process flow developed by the stakeholder. All scales can be attached to a MARELEC labeller or other MARELEC tools through the MATRIX PRO. Most items are customizable to the client's needs.

Two types of portion cutters are available at the company: the "normal" cutters and a waterjet cutter. All are built in a way to optimize the yield and use algorithms and high accuracy scans to have supposedly zero waste. The number of cameras in the portion cutters varies from one to three, and use 400HZ laser vision technology to produce a 3D model of the fish and through the software calculate how to maximize the portion weights. To increase the lifetime and reduce the maintenance, the belt is modular. Every part of the machine is reachable and in place cleaning rinses the belts. All electronics are in sealed cabinets and a unique drying and heating systems prevents condensation to be build up in the machine. One "normal" fixed weight portion cutter for fish uses a camera system to scan the volume of the fish fillet. It has one lane with a camera and can make 17 cuts/second. It weighs 950 kg. This can be upgraded with two more cameras for higher accurate models and output and a second lane for more throughput on a relatively smaller area. These weigh up to 1800 kg. Both whole fish and filleted fish can be portioned with these machines. The smallest one can only grade fish fillets and weighs 740 kg. The waterjet cutters also come in different varieties working with fish fillets from 1.25 to 1.50 kg working through 2000 to 8000 kg/hour. They use 40 to 80 kW/hour and 200 to 800l of water per hour. To function they need 3 x 400 VAC + N + PE63A or PE125A. The weight varies from 1500 kg to 3000 kg. All the portion cutters can be integrated with the other MARELEC tool with the MATRIX PRO software.

The graders offer vary according to costumer's needs, which is linked to the species and space. The graders consist of infeed, weighing, and sorting and/or batching units. All the machinery that is mentioned above can be combined into trimming lines and fully operated using the MATRIX PRO. This software can be run on a single device or on the entire line to ensure that everything runs smooth and is monitored real-time to maximize the yield and capacity of the machines. Adding labelling and printing devices gives way to order management and traceability throughout the products refinement from fish to portioned cut fillets.

C. Insights from the grey literature review

Because no interview has taken place, findings below are found in consulted grey literature (website and product sheets) alongside with the interpretation of the findings.

Sustainability

- Technology (equipment and associated software) developed by the company aim to maximize the fish processing efficiency, while no direct action toward sustainability can found within the company's marketing framework.
- The automation of processes provides a faster and more reliable alternative to manual fish processing, which maximizes profit and reducing wastes. This indirectly increase the sustainability of the processing value chain by reducing the resources used per kg of product produced.
- The manufacturers' software and technology modularity and adaptability (i.e., sizes, species) provides a unique solution that fits most fish processing value chains.

Technological changes and their drivers

- Although no insights on internal changes were found during the review, as a technology producer, the stakeholder is a key element providing sustainable alternative equipment to the fish processing industry.
- The marketing of the company and its products relies mainly in provide tools to make fish processing more efficient, by increasing the portion of the fish that can reach the final customer, while reducing waste.

Industrial strategies and their drivers

- From 1983, the stakeholder has evolved as a company, shifting its main activities, and offered product. This also means its influence on the PH value chain has increased through the years.
- However, this does not seem to be driven by sustainability goals but rather by the natural evolution of the company within the PH value chain market.

D. References

Hightech Food Processing Solutions - MARELEC. (2022). Retrieved June 1, 2022, from https://www.marelec.com/home/

CASE STUDY 23: MULTIPLE - WITH A FOCUS ON THE COMMON CUTTLEFISH (*SEPIA OFFICINALIS*) – UK/EU

SUMMARY REPORT

Adapting postharvest activities in the value chain of fisheries and aquaculture to the effects of climate change and mitigating their climate footprint through the reduction of greenhouse gas emissions

Photo: Live common cuttlefish (*Sepia officinalis*).

Harry Owen

LIST OF ABBREVIATIONS

Term	Description
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CS	Case Study
EHO	Environmental Health Officers
EU	European Union
g	Gram
GHG	Green House Gas
kg	Kilogram
km	Kilometre
kW	Kilowatt
kWh	Kilowatt hour
LCA	Life Cycle Analysis
ROI	Return on Investment
UK	United Kingdom

1 Background

The focus of this CS is a seafood company based in the UK, henceforth referred to as 'the processor', which is a multi-species wholesaler, processor, importer and exporter (both nationally and internationally). The majority of the species traded by this company are coastal species caught locally around South East England, but fisheries products are also purchased within UK markets, as well as imported from markets in the European Union (EU), and North America. This company has historically exported to the EU, as well as Asia, though this will not be discussed in this CS.

The processor deals in fresh, live and frozen seafood products, which it picks up from suppliers and delivers to customers utilizing its own fleet of delivery vans (if within a 100km range) or via a third-party delivery firm if further. All deliveries are made with good packaged in either polystyrene or waxed carboard boxes, depending on the product and the needs of the customer.

To highlight and examine the steps in the PH value chain for the processor, where data was available, we focus on the common cuttlefish (*Sepia officinalis*). This species is caught locally and bought, processed and sold by the UK based seafood company nationally. Data on the value chain associated with common cuttlefish is a useful benchmark for the costs and GHG emissions associated with processing fisheries products by the processor.

To remain competitive, but also reduce costs and increase profitability, there is a need for continual restructuring as well as enhancing the use and complexity of technology within PH chains. Therefore, this CS examines how the selected UK seafood company (the processor) structures its entire distribution chain and how the structure of the distribution chain impact total Green House Gas (GHG) emissions. This will include the contribution of different steps in the processing chain to overall GHG emissions, the identification of emissions hotspots, and where and how best to focus resources in order to most effectively reduce such emissions within the company's PH value chain.

Findings on the contribution of different steps in the processing chain to the global warming score are reported. A summary is made of the overall technological evolutions undertaken by the processor (as continual changes are known to be made within this company) aimed at improving energy efficiency and reducing GHG emissions across their entire value chain. Such technological evolution includes the use of packaging machines, solutions for recycling used packaging, water recycling, green technology in delivery and transport, the use of insulation materials, and refrigeration used for conservation of products for reduction of CO^2 and GHG emissions.

2 Approach

This CS was developed drawing on the centralised literature review carried out in relation to GHG emission in the value chain. Following this there was direct stakeholder engagement with the processor utilising the cross-CS questionnaire that was developed to ensure data consistency across all CSs. This stakeholder engagement took the form of an interview, conducted at the processor's premises, and a tour of the factory to better understand the product flow and processes in place. Following this the processor was contacted by phone to provide additional information as required.

The information provided in the interview and literature review was then processed into a format in line with the CS template and various databases were consulted to provide conversion factors for GHG emissions from various activities and rates of energy/fuel consumption. The databases consulted as part of this CS were:

- The Fourth IMO Greenhouse Gas Study 2020 (https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx);
- ETC/WMGE Report 3/2021: Greenhouse gas emissions and natural capital implications of plastics (including biobased plastics) (https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/greenhouse-gas-emissions-and-natural-capital-implications-of-plastics-including-biobased-plastics); and
- UK Government, 2021, Government conversion factors for company reporting of greenhouse gas emissions (https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting).

2 GHG emissions in the value chain

This section maps, where possible, the GHG emissions data for each activity within each segment across the value chain for locally caught common cuttlefish within the UK. This includes the flow of energy, including losses (food wastage), processing yields, fractions, as well as inputs such energy, water, ice, packaging material and transportation. This information has come from the results from the literature review, publicly available databases and stakeholder consultation.

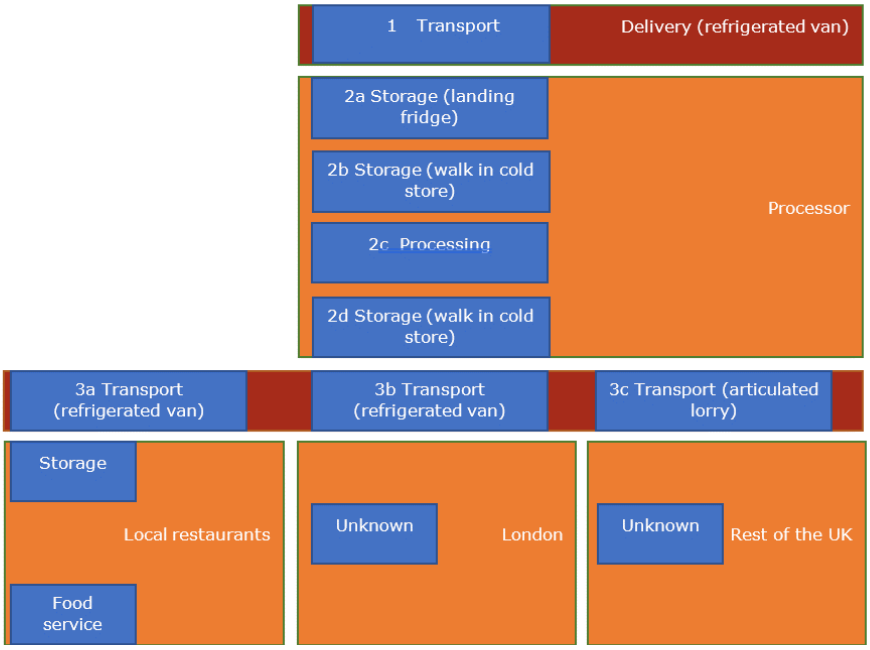

Figure 1: The major routes for common cuttlefish within the CS processor's value chain. Blue = step in the value chain; Red = transport stage; Orange = a period of possession by an actor in the value chain (e.g., processor, wholesaler, importer/exporter, restaurant).

2.1 Common cuttlefish value chain description and analysis

There are three major stages (Stage 1: Transport; Stage 2: Processing; Stage 3: Delivery of processed product) in the PH supply chain for common cuttlefish that are covered by this CS. This encapsulates information from the point of landing (which is predominantly around Portsmouth Harbour and the Solent (Figure)), through processing and transport to the point of sale (Figure). Below we utilise this description of the value chain for this species and describe in detail each designated stage within the post -harvest value chain in a systematic way to highlight the inputs and outputs, as well as any areas of uncertainty in terms of data deficiency.

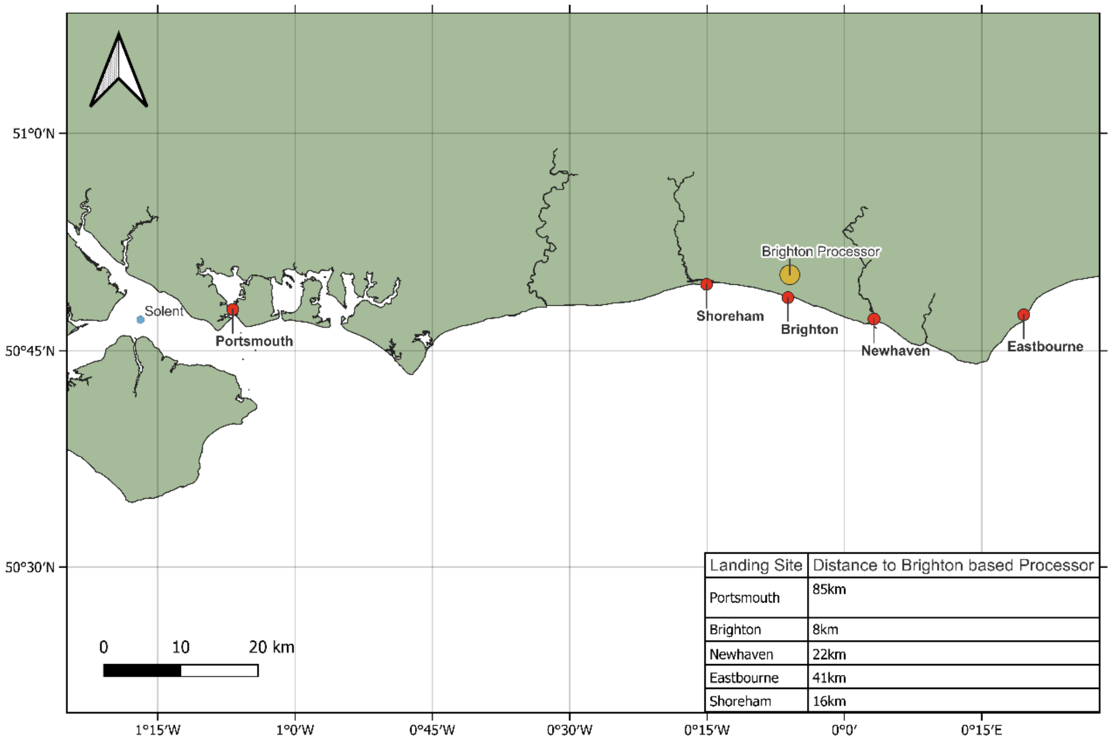

Figure 2: Map of the CS location on the south coast of the UK, showing the processor's site in relation to the key landing sites for the fishers that supply it.

2.1.1 Stage 1: Transport

Between 01 January 2022 and 01 June 2022, the processor sold approximately 40 tonnes of common cuttlefish. This is all transported from the vessels and landing sites (primarily Portsmouth Harbour, but also others including Eastbourne Harbour, and Newhaven Harbour; Figure) to the processer in Brighton, via their own delivery vans (usually with an empty trip out, returning with a full load capacity). Ice is applied (within the delivery vans) to the raw material at a rate of 350 kg per tonne (Figure).

In total, a tonne of common cuttlefish picked up at Portsmouth Harbour by an empty van and delivered to the processor (170 km round trip) will result in 119 kg CO_2e emissions[50] and use 350 kg of ice. Although this process will also release emissions associated with ice production, such data is unavailable for this analysis. Therefore, between January and June 2022, the estimated GHG emissions associated with transport of common cuttlefish from the landing sites to the UK company was 3,800 kg CO_2e[51], with 14,000 kg of ice was used.

[50] 0.7022 CO_2e associated GHG emissions (kg per tonne per km) according to the EcoTransit and IMO Fourth Greenhouse Gas Study 2020 (https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx)

[51] This is a conservative estimate as Portsmouth is the farthest of the key landing sites from which the processor purchases common cuttlefish.

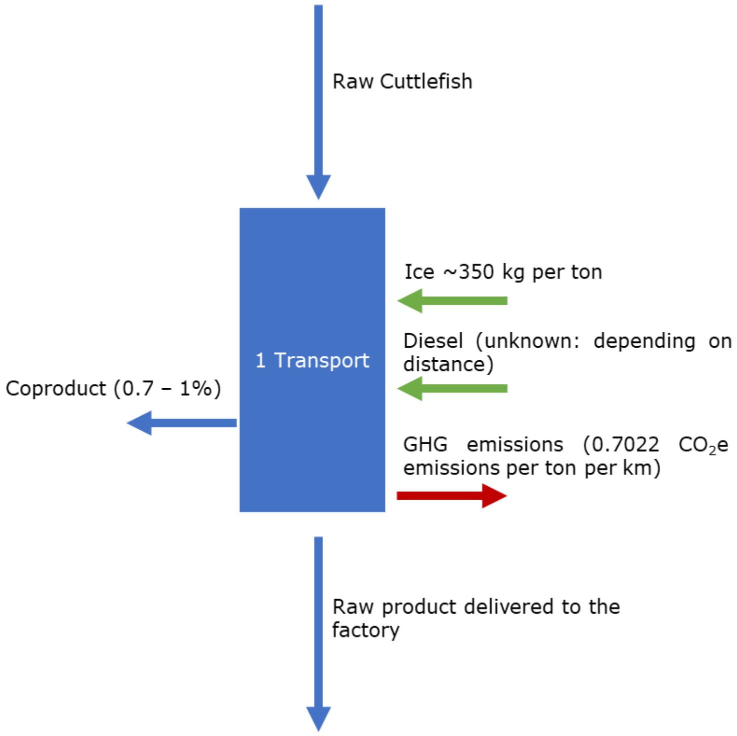

Figure 3: Flow of product, including inputs and outputs, for stage one of the processors postharvest value chain for common cuttlefish (incoming transport)

2.1.2 Stage 2: Storage and processing

Common cuttlefish delivered to the processor are stored in the walk-in cold store, and are iced at a rate of approximately 300kg per tonne of raw material (Stage 2a: Figure). Some common cuttlefish are then processed (Stage 2b) and some are sold whole to their customer base, which includes other wholesalers, exporters and processors, retailers, and the food service industry.

If processed (Stage 2b), the filleting and cleaning of the common cuttlefish is undertaken by the processor and has an average yield of between 67 to 72 % (finished product). This equates to an average of 310 kg of by-product per tonne of raw material processed. All by-product from the processing of common cuttlefish is sent to a fishmeal factory in Grimsby (~400 km) by articulated lorry[52] to be processed into fishmeal - this can be considered coproduct. One tonne of coproduct transported from the processor in Brighton to the fishmeal factory results in 34 kg CO_2e emissions.

The finished product, either whole or filleted and cleaned, is packaged in polystyrene boxes (cardboard is rarely used for the packaging of cuttlefish), which hold a total of 6, 10 or 15 kg (product and ice). However, the majority of finished product is packaged into 15 kg boxes. These boxes each weigh 290 g and will hold ~12 kg of finished product and 3 kg of ice. Therefore, a tonne of finished product (when using 15 kg polystyrene boxes) will use 24 kg of polystyrene packaging and use 500 kg of ice (Figure).

[52] 0.0848 CO_2e associated GHG emissions (kg per tonne per km) according to the EcoTransit and IMO Fourth Greenhouse Gas Study 2020 (https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx)

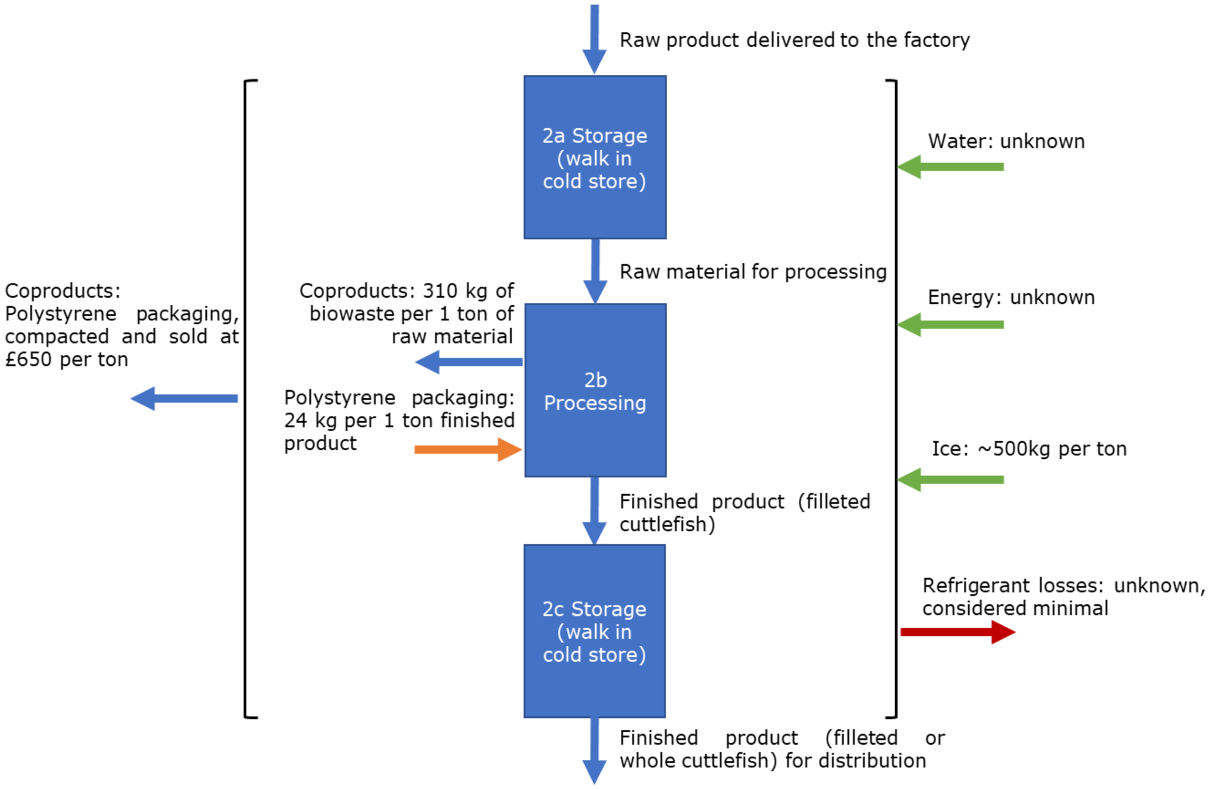

Figure 4: Flow of product, including inputs and outputs, for Stage 2 on the processors postharvest value chain for common cuttlefish (storage and processing).

NB. Whole cuttlefish as a finished product is not encapsulated in 2b, with the processing of this product moving from 2a to 2c directly.

2.1.3 Stage 3: Transport (local restaurants and London)

In Stage 3, the finished product (i.e., filleted or whole cuttlefish) will be picked up pre-packaged and iced from the cold store and sent out for delivery. If transported up to 100 km from the processor (e.g., restaurants and other wholesalers or retailers in London), this will usually be via the processor's diesel refrigerated delivery vans. However, where delivery is further then generally this will be made by a third part specialist contractor using a lorry (Figure).

A tonne of finished product, packed in 15 kg polystyrene boxes, picked up by an empty van and delivered to restaurants within Brighton and London, will be accompanied by approximately 250 kg of ice and polystyrene (total). Each tonne (product and packaging) will be responsible for CO_2e emissions of 0.7022 kg per km. Therefore, average emissions from the processor to restaurants in London will be (87 km = 0.7022 CO2e* 87).

In addition, each tonne of packaged finished product will result in approximately 24 kg of waste polystyrene, which can be compacted by the processor and sold as a coproduct. Therefore, between 1 Jan and 1 June 2022, 960 kg of waste polystyrene were compacted and sold for £624 (at £650 per tonne).

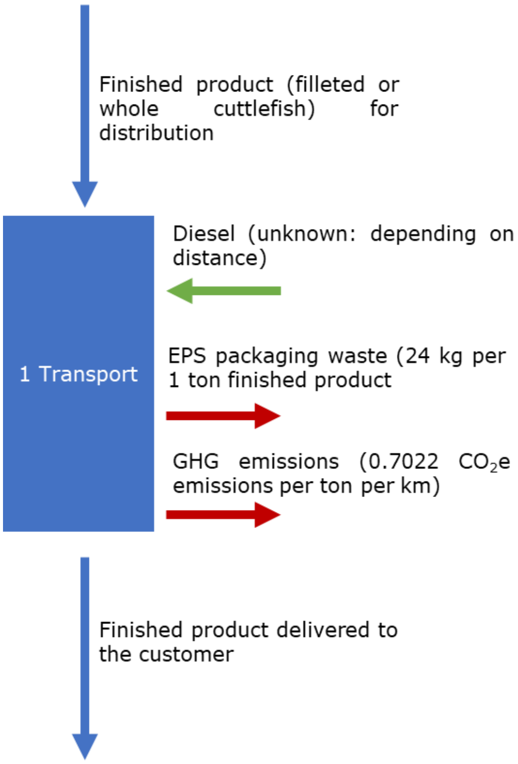

Figure 5: Flow of product, including inputs and outputs, for stage three on the processors postharvest value chain for common cuttlefish (outgoing transport)

2.1.4 Full cycle of the entire operation

Due to the diversity of species and pick-up locations (i.e., harbours and markets around the UK) for raw material utilised by the processor, the variety of products kept in the factory (>600 seafood products) for varied lengths of time (i.e., between 0 – 5 days for fresh products), and the variety of processing options for each product, it is not possible to determine the total fuel (diesel[53], electricity, propane[54]), water or packaging[55] use associated with each product.

Despite this, the processor provided approximate annual rates of fuel use (diesel, electricity, propane), water use and packaging (Table), and their annual product throughput (~1,404 tonnes of seafood). Therefore, the approximate total GHG emissions associated with the processors PH value chain are 224 kg CO_2e per tonne of product if the cardboard packaging is disposed of in landfill or 171 kg CO_2e per tonne of product if the cardboard packaging is disposed in a closed loop / incinerator.

We can also use the average rate of GHG emissions associated with the processors PH value chain to common cuttlefish passing through the processors facilities (as outlined in Stages 1, 2 and 3). In this respect, throughout the entire time with the processor each tonne of processed common cuttlefish will use roughly 850kg of ice, and produce approximately between 224 to 170 kg CO_2e, ~310 kg of fish coproduct and ~24 kg of

[53] For delivery vans.
[54] For the forklift.
[55] Both polystyrene and waxed cardboard boxes are used to package seafood, depending on the product and the needs of the customer.

waste polystyrene (which can be compacted by the processor into a coproduct and sold on to a recycler).

There are still unknowns that are not considered in the above calculation. These include emissions from vehicles owned by third parties (e.g., goods delivered by contractors), compacted polystyrene processing and transport, and the emissions associated with moving the packaged goods to the market (both nationally and internationally).

Table 1: Annual resource flow within the processors postharvest chain

Resource flow (input / output)	Resource (postharvest)	Annual consumption	Unit	Associated GHG emissions (kg CO_2e)
Input	Polystyrene†	29,000	kg	111,940
	Diesel (for delivery vans)*	38,000	Litre	102,810
	Cardboard supply*	73,000	Kg	59,950
	Electricity*	70,837	kWh	15,040
	Propane*	900	Kg	2,698
	Water supply*	312,000	Litre	46
Output	Cardboard (landfill)*	73,000	Kg	76,051
	Cardboard (closed loop / incinerated)*	73,000	Kg	1,554
	Water treatment*	312,000	Litre	85
	Organic waste**	155,000	Kg	5,410

† Conversion factors from www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/greenhouse-gas-emissions-and-natural-capital-implications-of-plastics-including-biobased-plastics
* Conversion factors from https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting
** (150 tonnes of biowaste to Grimsby (400 km) via Lorry + 5 tonnes to Polegate (33 km) via delivery van) Conversion factors from EcoTransit and IMO Fourth Greenhouse Gas Study 2020 (https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx)

2.2 Alternate distribution systems

The processor buys, sells and processes a range (>600 distinct products) of fresh (e.g., whole, gutted, filleted, pin-boned, skinned, scaled and mixed), frozen and live seafood (e.g., live crustaceans and molluscs). This processing annually generates considerable volumes of biowaste, waste water and packaging materials. As disposal of all three types of waste product can be exceptionally expensive, waste disposal including alternative distribution systems for waste, is an area of focus for the processor.

The processor must dispose of approximately 155,000 kg of solid organic waste annually (Table), comprised predominantly of offcuts from processing raw material (i.e., gutting and filleting). The disposal of organic waste (mixed food and drink[56]) will produce emissions of between 9 kg CO_2e per tonne if composted/anaerobically digested and up to 627 kg CO_2e per tonne if placed in landfill. Therefore, the 155,000 kg equates to emissions of 1,395 – 97,185 kg CO_2e, depending on the method of disposal (in addition to any transport related emissions).

The processor has secured an alternate distribution method for disposing of solid organic waste, sending most of the organic waste to a fishmeal processor in Grimsby, UK (~150 tonnes per year * 400 km) and the rest to a pet food company in Polegate, UK (~5 tonnes per year * 33 km). Therefore, the transport involved in sending organic waste to Grimsby

[56] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

and Polegate will emit ~5,410 kg CO_2e[57] annually, with further emissions from the processing of the organic waste into fishmeal or pet food.

Utilising what would otherwise constitute a waste stream for the production of fishmeal will reduce reliance on fisheries directly supplying fish for fishmeal and the emissions associated with the capture process. This can have a big impact on the overall carbon footprint of the fishmeal, due to significant emission associated with the capture sector. In fact, substituting the 155,000 kg of waste fish for fishmeal provided by the processor, with fish caught directly for this purpose would be associated with an additional 1,700 kg CO_2e per tonne of fish, or 263.5 tonnes of CO_2e in total[58].

Since Brexit there have been increased costs associated with exports of fish to the EU, resulting in fish previously shipped to the EU (e.g., Dover sole (*Solea solea*)) now being sent to suppliers in the UK. This has the potential to reduce GHG emissions associated with these value chains, however, it was noted that while the processor sends fewer fish to the EU, shipments are being made by larger companies, and in larger quantities, which can afford to offset additional cost through economies of scale. Therefore, any potential reduction in the GHG emissions associated with this shift will require further investigation.

Since the processor relocated to a new site at the end of 2021, a new integrated scales system for weighing fish has been installed. This system is reported to have improved the efficiency with which fish are weighed, sorted and packed, with less time spent outside a cold storage area. This increased efficiency has the potential to reduce the GHG emissions associated with this part of the PH value chain due to incremental efficiency savings (e.g., reduced time spent outside cold storage during grading/sorting will increase the cold retention of the fish and reduce the burden on the cold storage units. However, the processor does not collect empirical data related to this so quantifying any effect this scale system is having is not possible.

2.3 Limitations for structural improvements in GHG emissions

There may be local and national regulations and structures affecting the value chain and the channels by which GHG emissions can be reduced. For example, resource availability including access to funding, knowledge and guidance were all mentioned by the processor as factors limiting further reductions in GHG emissions. In addition to this, the expectations of local Environmental Health Officers (EHO) were also cited as competing with measures that could be taken to reduce the processors GHG emissions.

Polystyrene production is the single largest direct contributor to the processors GHG emissions (Table). This is exacerbated by single use of polystyrene boxes, due to concerns raised over the reuse of these boxes during local food hygiene inspections. This means that where before boxes were cleaned and reused as standard, now this is only done in exception circumstances with all other boxes compacted for recycling.

The availability of funding can also be problematic, because trailing new systems can be expensive and ultimately unsuccessful. For example, it was reported that there had been previous attempts to use a polystyrene compactor to facilitate recycling, but fish residue (e.g., fish slime and scales) would often cause the machine to seize. This resulted in lost time and money hiring and transporting the machinery and it was only recently that this

[57] 150 (tonnes) x 400 (km) x 0.0848 (associated GHG emissions (kg per tonne km) – very large lorry) + 5 (tonnes) x 33 (km) x 1.9507 (associated GHG emissions (kg per tonne km) – delivery van). GHG conversion

[58] https://stecf.jrc.ec.europa.eu/c/document_library/get_file?uuid=924c1ba8-94af-440d-94cb-f9cb124d2d57&groupId=12762#:~:text=for%20each%20ton%20of%20live,species%20into%20%E2%80%9Ccold%E2 %80%9D%20ecosystems.

issue was resolved. The current compactor is running well. Other systems have been trailed but found ultimately unsuccessful include various options for packaging (e.g., EcoFishBox, corrugated plastic packaging, and BluWrap packaging), which lacked either the required structural integrity or thermal properties. The use of biofuels for the delivery vans was also trialled but discontinued due to the smell and the perceived incompatibility with a food service business.

Ultimately, structural improvements in the PH sectors GHG emissions rely on innovations and changes with a Return on Investment (ROI) that is seen as acceptable. In this CS a five-year ROI was given as the upper limit for any such changes, while other financial concerns including cash flow and outstanding liabilities need to be taken into account. These are reasons why access to and help accessing funding are considered the most important limiting factor by the processor in implementing, structural improvements in systems to reduce GHG emissions.

3 Reducing GHG emissions by technical means

The literature review was utilised to highlight a range of technologies that could be used to reduce the processor's GHG emission within their PH value chain. These technologies, where applicable, were all within the processors sights and have been trialed, discussed for as something to trial or are currently in use on site.

3.1 Trends in technological evolutions and industrial strategies

There are many reasons to reduce the emissions associated with the PH value chain, but for the processor interviewed for this CS, the main driving factor is cost reduction. There is also a desire to reduce the company's environmental impact, which is evident from the various initiatives taken (discussed in this section), but without a cost incentive there is little impetus for change. This is highlighted by the lack of emissions monitoring and the fact that when asked to list the top "*processes within your company that have the greatest impact on GHG/carbon emissions*" the processor listed: 1. Electricity use for ice and refrigeration; 2. Diesel for transport; 3. Water. When, in fact, it is the business' use of polystyrene, diesel (for transport) and cardboard that contribute the most to GHG emissions within the company's value chain (Table).

In 2021, there was a fire at the processors old site and much of the building and equipment were lost. Following this the business relocated and now has a significant proportion of new, more efficient equipment and working practices. The following sections discuss technologies implemented by the processor with a view to reducing GHG emissions and cost within the PH value chain.

Polystyrene compactor

As shown in Table , polystyrene use is the single biggest contributor to the processor's direct GHG emissions. In an attempt to reduce the cost of waste disposal and the impact of the material on the environment, the processor purchased a Polystyrene compactor. The compactor compacts the polystyrene, reducing the materials weight to volume ratio, making the compacted product marketable for recycling. The compactor was purchased at a cost of ~£30,000 GBP, but the compacted polystyrene can be sold for £650 per tonne and reduces the processor's waste disposal cost by £160 per week. Therefore, the compactor will save the company ~£8,320 in waste disposal annually and produce a marketable coproduct in the form of compacted polystyrene.

The compacted polystyrene is sold as a coproduct, for recycling. This, therefore, provides the potential for indirectly reducing the processors GHG emissions, because the recycling of polystyrene could reduce the use of virgin plastics, which are often associated with a greater carbon footprint.

Freezers and chiller units

When the processor relocated, the new site was fitted with a new chiller and freezer units. These units were described as "*exceeding expectation*" when their efficiency was compared to the old system. However, no quantitative data are collected by the processor and so, while this has an anecdotal impact on the companies' energy use, it is not possible to determine the reduction this might be having on the business' overall emissions.

MarinaTex

Working with the University of Sussex, the processor was involved in the development of a biodegradable plastic alternative called MarinaTex[59], which is created with fish scales and red algae. This is still in development, but holds the potential to indirectly reduce GHG emissions in the PH value chain by utilising an industry waste stream to reduce the global reliance on plastic polymers that are associated with a relatively high carbon footprint. Although the processor does not have any ownership over this product, through partnerships like this with the University and other research organisations they can help drive change and indirectly reduce GHG emissions in the PH value chain and beyond.

3.1.1 Planned technological changes

Outside of what is currently being done by the processor to reduce their GHG emissions, there are some ongoing efforts to implement new, more energy efficient, technologies. These include the replacement of diesel vans with electric and a new solar panel system at the new site.

Solar panels

Prior to the fire (discussed above) the processor had solar panels on the roof at their old site. These were setup in a 40 kW system and the processor remarked during the interview that these significantly reduced their electricity bill. However, no quantitative data were provided by the processor on the energy production from their solar panels or the effect these had on their energy use. Therefore, while there is anecdotal evidence that these reduced the companies' net energy use, it is not possible to determine the reduction this might have had on the business' overall emissions. In addition, no solar panels have been installed at the new site, although this is something that the processor has requested quotes for from various companies and is actively pursuing as a means to reduce their net consumption of electricity.

Electric vans

Diesel is the second largest source of CO_2e within the processor's operations and, therefore, the second largest source of CO_2e associated with the PH value chain within this CS (Table). In fact, diesel use is responsible for an annual average 73 kg CO_2e emissions per tonne of seafood handled by the processor.

For this CS, diesel use covers most of the local transport (i.e., within a 100 km radius of the processor). This includes fish collected from local vessels (especially for cuttle which

[59] https://www.marinatex.co.uk/about-3

is almost exclusively picked up by the processor), transport to the processor and delivered to local restaurants, retailers and other wholesalers. These shorter journeys represent GHG emissions hotpots, because generally the shorter the journey the greater the emissions per km, due to the different vehicles associated with transport. For example, 1 tonne of fish from Brighton to London (~100 km) in a delivery van will emit 195 kg of CO_2e but if this fish went to Paris on a Large truck, it would emit only 25 kg. This highlights the importance of solutions for emissions from localised transport. The processor stated that previously upgrading the fleet of delivery vans (which pick up and deliver product within a 100 km radius of Brighton) to electric was difficult because of the purchase cost and short range (distance per charge) of the vans. However, the model that they are looking to purchase (Ford E-Transit L3H2) has a maximum range of 315 km with a purchase cost of around £50,000. The processor believes these vans would each save around £200 per week (£10,400 annually) and, therefore, fall within the five-year ROI necessary to incentivise the shift. A quote has been requested for five new vans, but due to a shortage of microchips reported by the seller, the quote and any purchase of new electric vans has been delayed.

Because these new vans are not yet in operation, it is not possible to determine the difference this would make on the processors overall GHG emissions. However, given the much more significant rate of emissions associated with diesel than electricity[60], and the GHG relatively large emissions associated with local travel, it is likely that any such change would significantly reduce the GHG emissions coming from the PH value chain assessed within this CS. This is why the processor is making attempts to purchase electric vans, and highlights the efficacy that better funding in this area could have on reducing GHG emissions in the PH value chain.

3.2 New processing and logistic techniques and their challenges

The greatest potential for gains in GHG emissions reductions from processing and logistical techniques appear to come from driving efficiency within the factory's workflow. Since relocating to a new premises there was an opportunity to design the factory layout with a more ergonomic flow, so that, for example, goods come in one end and come out the other. This was reported to have reduced the amount of time that fish remain outside chiller units, reducing heat loss and so increasing refrigeration efficiency. It also increases that speed at which fish can be processed and orders packed. It was reported that this is further aided by a new factory wide integrated scale system, that further improves factory efficiency.

However, as with the sections above, no quantitative data are collected by the processor on changes in efficiency on the factory floor. Therefore, all evidence is at this point anecdotal and represents a potential, but unverified, pathway for improving efficiency and thereby reducing energy consumption and associated GHG emissions.

4 Conclusions

The greatest contributor to the GHG emissions within this CS's PH value chain comes from the use and disposal of packaging. Here packaging accounts for 57-66 % of all associated GHG emissions, depending on disposal method for cardboard. The largest contributor to the GHG emission from packaging is polystyrene and this source of emissions is currently being addressed by the processor through the use of a polystyrene compactor that facilitates polystyrene recycling. Although the impact of this technological solution on the emissions from the value chain cannot be quantified, there is a clear financial incentive for

[60] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

this practice, in the form of reduced waste disposal costs and a marketable product that offer an ROI on the initial compactor machine purchase within a few years.

Other methods for packaging have been trialled; however, alternative forms of packaging have not been successful because the trial packaging lacks either the required structural integrity or the thermal properties. An alternative to this is a greater reuse of the polystyrene boxes, which was common place, but during local food hygiene inspections concerns were raised over the reuse of these boxes. These competing priorities, between minimising food hygiene concerns and minimising GHG emissions, has meant that where before polystyrene boxes were cleaned and reused as standard, now this is only done in exception circumstances with the majority compacted for recycling.

The purchase of electric vehicles to replace the diesel combustion engine fleet is now being pursued by the processor, thanks to changes in technology and purchase cost making these electric vehicles a viable alternative. This could have a significant effect on PH GHG emissions associated with fish because diesel use was identified as the second most GHG emitting aspect of the value chain within this CS. However, a global shortage of key components (e.g., microchips) is currently holding up this transition and thereby reducing the rate at which GHG emissions can be cut from the PH value chain.

Overall, there are several actions being taken by the processor in this CS to reduce their GHG emissions, both structural and technological. Many of these are easily replicable, but the main driving factor for change is cost savings, not a reduction in emissions. This could explain why, when asked which aspects of the business were most responsible for GHG emissions, only one of the answers given (diesel) was in the top three. Furthermore, when asked if there were any data collected on GHG emissions or the carbon footprint of the business the answer was to question why the business would do such a thing. Understanding and reducing GHG emissions, therefore, appears to be a question of priority and currently where there is no incentive to reduce their carbon footprint, outside of the associated reduction in costs with reduced resource consumption, the likelihood of a business prioritising reducing emissions appears low.

ANNEX 3: REFERENCE QUESTIONNAIRE

INTERVIEW-QUESTIONNAIRE-GUIDELINES

Background

Both the Common Fisheries Policy (CFP) as the Common Market Organisation Regulation (CMO) include a reporting obligation. By 31 December 2022 the European Commission will prepare a report on the functioning of both the CFP and CMO. In addition, the European Green Deal sets out objectives of resource efficiency, reaching net zero GHG emissions by 2050 and protecting, conserving and enhancing the EU's natural capital, with intermediate target of 55% reduction in GHG emissions by 2030 compared to 1990 levels (a reduction by 23% had already been achieved by 2018). The Commission also committed to strengthening climate-proofing, resilience-building, prevention and preparedness. Reaching these objectives includes further decarbonising the EU's energy system and economy. Accurate information is needed on the existing scientific evidences related to the value chain of postharvest activities within fisheries and aquaculture, including frozen products (but excluding on-board processing). To this effect, the European Commission has commissioned two consortia led by Wageningen Marine Research (Lot 1) and MRAG Europe Limited (Lot 2) to conduct the study on the state-of-the-art scientific information on the climate change impact mitigation and resilience and the improvement of the carbon efficiency of the postharvest chain in Europe. The study is implemented by the European Climate, Infrastructure and Environment Executive Agency (CINEA) on behalf of the Directorate-General for Maritime Affairs and Fisheries (DG MARE). The objective of the study is to provide a scientific basis on the activities and historic events of each of the postharvest chain segments and their relevance for assessing the physical and financial resilience to climate change, which lessons can be learned and which future contribution can be made by the postharvest sector to reduce Green House Gas (GHG) emissions. It is acknowledged that sectors within the value chain do not solely rely on marine products, adding complexity to studying the resilience of sectors to impacts of climate change. This information is mainly gathered to allow an informed debate. The study team will thus be collecting information and consulting stakeholders. DG-MARE and CINEA attach great importance to the successful outcome of this study. The study team would be grateful if all contacts could offer their collaboration and provide the consortiums with the information requested. All requested information is protected under GDPR regulation and personal information will not be present in the final reporting. Your contribution will play an invaluable role in ensuring the successful outcome of the study and in providing the European Commission with solid and useful scientific information.

Interview preparation

The study team is analysing the physical and financial resilience and technological aspects of each of the postharvest chain in 25 different case studies. Questions were developed based on a literature study, and based on the expertise of the consortium partners. These postharvest chain case studies will provide validation to the findings of the literature review as well as identifying additional aspects which may be overlooked by the scientific literature. As part of these case studies, the team will speak to upwards of 100 different stakeholders to give input on their specific section of the postharvest value chain. To enable the stakeholder interview to be somewhat structured and comparable across stakeholders, we prepared a set of questions from each TASK that are relevant to the stakeholder within their section of the postharvest value chain. Although not all aspects of the diversity and complexity of the postharvest value chain can be met with the outset questions below, flexibility of the interviewer in asking these or different questions is warranted. This flexibility may allow multiple questions of a single TASK to be combined, or even questions of multiple TASKS to be combined. Please record your interview notes in a traceable and recorded file. A full extended and perfected interview scripts is not required. Please return the answers to each TASK-Lead neatly, either in values or in report style, taking care to follow the structure of the interview-questionnaire in order to work smoothly and efficiently.

PART 1: DETAILS INTERVIEWEE

Name interviewee:
Organisation:
Location (city or municipality) and country:

Type of organisation (select one of the following options):

- ☐ Auction
- ☐ Processor (incl. packaging)
- ☐ Importer/Exporter
- ☐ Wholesale (only seafood)
- ☐ Wholesale & distribution (not only seafood products)

- Trade agent & distribution
- Transport company (shipping, truck/car or air born)
- Storage warehousing (cold, fresh/wet or dry food products)
- Marketing
- Retailer
- HORECA
- Technology provider

Species:
Link to website organisation:
Email address:

PART 2: TASK 1 - VALUE CHAIN RESILIENCE

Questions indicated in dark blue are suggestions of important questions for all sectors.

PAST (until 15-25 years back)

d. Were there in the past climate driven events that affected your organisation (e.g., changes in supply of fish, changes in transportation, algal blooms, floods, abundance or shifting of fishing stocks)?
   a. If yes, which events and what was the effect?

PRESENT (now and 5 years ahead)

e. Are there any currently or foreseen (within 5 years) climate driven event(s) that affect your organization? If so, can you give examples?
f. E.g. floods by intensive rainfall or waves, rising sea water levels, increasing water temperature, summer heats, colder winter periods, changing seasons etc.
g. Fill in the SWOT confrontation matrix with regarding to climate change that currently (or expected within 5 years) affects your organization:

		External factors (out your circle of influence as organization)	
		Opportunities	**Threats**
Internal factors (Within your circle of influence as organization)	**Strengths**	• ..... • ..... • *Interesting direction to invest your effort into*	• ..... • ..... • *Threats which are not that impactful to the organization*

	External factors (out your circle of influence as organization)	
	Opportunities	**Threats**
Weaknesses	• ..... • ..... • *Where other organizations win the competition with you*	• ..... • ..... • *Here you need a better defence strategy as organization*

f. What drives/motivates or stimulates you as organization the most to take action on climate change? For instance do you monitor and report about your footprint (e.g. CO2) forced by others (your retailer, investor/financial bank, eco-label etc.) or is it your own interest/initiative?

g. Do you perceive any advantages or disadvantages as organization by climate change?
   a. Which disadvantages? E.g., relocate production facilities, shifting or migrating fishing stocks, higher mortality rate among seafood to harvest, higher production costs due to longer transport or scarcity of raw materials and resources, lower quality raw material (due to increasing temperatures, higher risk of perished seafood products etc.).
   b. Which advantages (e.g. new or upcoming species in regional fishing areas, better competition position due to climate impact elsewhere globally etc.)

h. Are there any legislation or restriction (e.g. Fit for 55, CO2 tax, energy, drink water use or waste water disposal taxes) in place or expected related to sustainability or climate that affects your organization?

i. Did you your organization made adaptions to mitigate or fortify financial or physical resilience? *See table 1 for an overview of potential climate change adaptions (appendix, at the end of this document).*
   a. Where these successful or unsuccessful? Could you elaborate why and how?

j. To what extend is your financial turnover/revenue as organization affected by climate driven events?
   a. E.g., did operational financial (production) costs increase?
   b. If so, which costs and to what extend?
   c. Do you have higher or lower purchasing costs for seafood products due to climate change related costs made by suppliers?

FUTURE (15-25 years ahead)

k. Do you expect in the future climate driven events that will affect your organisation in 15-25 years?
   a. If yes, what are these climate driven events?

l. Which are the three most important impacts/risks for your organization?
m. (see Table 2 in the appendix. A list with examples of impacts and risks)?
n. What could your organization do to deal with these climate impacts and risks?

o. What are the main opportunities and barriers to cope with these climate impacts and risks?
p. E.g.: legislation, industry size/strength, costs, management, knowledge
q. Which different trade flows due to climate change do you expect in 15-25 years from now?

r. Which type and to what extent increased costs (and therefore increased fish prices) do you predict due to climate change in 15-25 years from now?

s. Which opportunities do you see from climate change driven events (e.g. new species, change in fish consumption etc.)?

t. How do you inform and involve consumers (B-2-C) and distribution channels (B-2-B) to change their purchasing/consumption patterns by taking climate change into account? (e.g. which marketing instruments do you apply, and how to ensure that less familiar species to retailers and consumers are promoted?)

u. How could your clients and consumers be informed and involved to adapt their seafood buying behaviour to be matching with new/upcoming and/or local available species due to warming water temperature or other climate changing events?

v. Do you have any recommendations or technical solutions to reduce GHG emission within the value chain? If so, could our colleagues of task 3 contact you about this topic?

w. Do you have any question to us or any other business to discuss?

x. Would you like to receive the first results or draft publication just after summer 2022?

Table 1: Mitigation and adaptation strategies by seafood supply chain stakeholders to manage climate change impacts. *Source:* Fleming et al (2013). Climate change risks and adaptation options across Australian seafood supply chains – A preliminary assessment. Climate Risk Management 1 (2014) 39–50.)

Direct climate change impacts	Indirect climate change impacts	Potential climate change adaptations	Potential adaptation for other drivers and policy issues
Extreme weather events	Rising fuel and energy costs	Change industry structure (number of operators, licenses)	Improve public awareness and information (species differentiation, sustainability)
Changes in stock locations	Increased incidence of diseases	Improve marketing (labelling, information, increase appeal)	Simplify or overcome regulations (development restrictions, number)
Changes in stocks (volumes, seasons, speed of growth)	Increased energy use	Improve fuel efficiency (vessel efficiency, reduce transport links, more targeted fishing or transport times and fuel use)	Support training and accreditation and next generation workers
Increased temperature		Monitor/model impacts (acidification, dissolved oxygen, sea level, rainfall, salinity, disease)	Match demand
		Breeding programs	Increase focus on live
		Increase collaboration across supply chain	Reduce reliance on wild catch (spat/stock, feed)
		Change locations	Clarify fishery objectives to minimise conflict or confusion
		Change season times	Increase export
		Product enhancement (certification, accreditation)	Total times activity discussed
		Change species	
		Change fishing, harvesting options (larger cages, raising racks, new techniques, by-catch)	
		Change storage options (grow out in tanks, overseas storage)	
		Change marketing (new markets, new products)	
		Use alternative energy	
		Improve energy efficiency	
		Improve water efficiency	

Table 2: list of impacts and risks through the seafood value chain caused by climate change

Supply chain links	Typology of climate change impacts/risks
Processing	• damage or complete destruction of assets
	• absence or hick-ups in supply volumes of raw materials (landed or cultivated seafood)
	• increased costs of purchasing (first sales e.g. due longer fishing trips or transports, or scarcity due to heavy weather etc.)
	• liability risks
	• disruption of plants and production lines
	• regulation with regard to carbon emissions
	• changes in the effectiveness or efficiency of production processes
	• increased costs for energy and maintenance activities
	• increased cost of upstream operations and product quality
	• stimulation of investments in renewable energy and energy efficiency
	• deployment of lower carbon intensity operating practices (with lower GHG emissions)
Transport	• problems related to coastal defences
	• delays leading to paying compensation to operators and causing problems to customers
	• overhead cables brought down because of strong winds
	• landslip resulting from heavy rainfall
	• securing stability of structures
Storage	• vulnerability of infrastructure, personnel, communications, supply etc.
	• possible dislocation due to extreme weather events
	• higher energy costs to freeze or cool the seafood products with summer heats
Distribution/retailers/HORECA	• reputational risk in downstream sectors due to increased need for transparency
	• decline or out-of-sale (out of stock) of seafood products due to climate change driven hick-ups in the supply chain
	• new regulations regarding product labelling
	• increases in the consumer goods production costs and prices
Consumers	• need for improved product design aiming at the elimination of packaging material and the enhancement of product durability, reusability, recyclability, and materials efficiency
	• Inflation of seafood product due to climate change related cost increase
	• Out of stock of certain seafood products due to climate change driven hick-ups in the supply chain

PART 3: TASK 2 - REDUCING GHG EMISSIONS BY STRUCTURAL MEANS

In this work we aim to estimate greenhouse gas emissions related to the supply of seafood. To this end, we need to understand the emissions associated to all activities along the chain, from catch until point of sale to end-user (consumer). We take into consideration the direct emissions (like fuel use), but also indirect effects. For instance when using ice, this ice is produced in a machine that consumes electricity. All emissions are allocated to the sold products. This implies that when losses occur, the emissions per kg sold product are increased somewhat.

FISHERS

i. What is the country and harbor location of landing?

j. What volume of fish do you catch annually?

k. Fuel use:
    a. What type of fuel is used on the vessel?
    b. What is the annual fuel use of the vessel?

l. On-land energy use associated to the caught fish (until point of sale):
    a. What types of energy sources (including electricity) do you use related to the caught fish?
    b. What is the annual use of these fuels/electricity?
    c. if total electricity use is not given:
        i. How long is the fish stored between arrival and transport to client
        ii. Do you apply refrigeration in storage, or is the fish kept cool by ice?

m. Ice for refrigerating/storing fish:
    a. Do you add ice to the fish?
    b. If yes, do you produce ice with you own machine? (then ice production energy use will be included in the electricity consumption data)
    c. If you buy the ice, how much ice do you buy per ton fish?

n. Has fuel and energy use significantly changed last 20 years?

o. Do you foresee major energy use reduction coming 10 years?

p. Do you otherwise actively attempt to reduce climate impact? If so, how?

TRANSPORT

Fish from fishery to trader, from trader to client, from distribution centre to retailer or other clients.

d. What is the location of departure and destination? (country + city name)
    a. Alternative question: what is the transport distance from departure to destination?

e. By what type of vehicle is the fish transported from fisher to trader (large truck, medium truck, container truck, container coaster ship, container inland ship, airplane, etc.)

f. How much ice was added per ton fish?

TRADER

h. Energy use by trader (until point of sale):
    a. What types of energy sources (including electricity) do you use?
    b. What is the annual use of these fuels/electricity?
    c. if total electricity use is not given:
        i. How long is the fish stored between arrival and transport to client
        ii. Do you apply refrigeration in storage, or is the fish kept cool by ice?

i. Ice for refrigerating/storing fish:
    a. Do you add ice to the fish?
    b. If yes, do you produce ice with you own machine? (then ice production energy use will be included in the electricity consumption data)
    c. If you buy ice, how much ice do you buy per ton fish?

j. What percentage of the fish is rejected/lost?

k. Do you package the fish?
    a. When yes: which types of packaging material are used (including drip moisture absorption pads)? (examples: plastic, metal cans, paper, …)

l. What is the average weight of these material use per kg fish product?

m. Which other inputs are used (processing aids, oil additives, liquid nitrogen, CO_2, etc.)

n. How much of these per ton fish (or per ton fish product)

PROCESSOR

x. What is the location (country, city)?

y. What type of process do you apply (filleting, canning, …)?

z. Which food or feed products (or other products with economic value) do you derive from the fish?

aa. What is the volume of the product(s) relative to the volume of supplied fish? (in other words: what is the filleting/processing efficiency?)

bb. What is the ratio between economic ratios of the product streams?

cc. What is the destination of residues?

dd. What amount of residues is generated per ton supplied fish? (may be multiple products)

ee. What percentage of the fish is lost/rejected?

ff. What is the destination of these fish?

gg. What is the current destination of these residues?

hh. How long is the fish stored before processing?

ii. What is the plant's total electricity use per ton supplied fish? (may also be expressed per ton sold food product)

jj. If total electricity use cannot be given, we try to derive it from individual activities:
  a. Is the fish during storage cooled by the ice that was added before supply, or is it actively cooled by refrigeration storage equipment?
  b. If the fish is kept in powered storage room, how long is it kept there before processing?
  c. What is the electricity use in processing per ton fish (or per ton food product)?
  d. Do you add ice to the final products?
  e. If yes, do you produce ice with you own machine? (then ice production energy use will be included in the electricity consumption data)
  f. If you buy ice, how much ice do you buy per ton fish?
  g. how long do store the fish products after processing?
  h. Is the fish product during storage cooled by the ice that was added, or is it actively cooled by refrigeration storage equipment?

kk. Which other energy sources are used at the plant? (like fuel oil, natural gas, …)

ll. How much of these per ton fish (or per ton fish product)

mm. Which types of packaging material are used (including drip moisture absorption pads)? (examples: plastic, metal cans, paper, …)

nn. What is the average weight of these material use per kg fish product?

oo. Which other inputs are used (processing aids, oil additives, liquid nitrogen, CO2, etc.)

pp. How much of these per ton fish (or per ton fish product)

qq. Has processing energy use significantly changed last 20 years?

rr. Do you foresee major energy use reduction coming 10 years?

ss. Do you otherwise actively attempt to reduce climate impact? If so, how?

tt. Do you foresee changes in destination of residues

RETAILER/OTHER POINT OF SALES

Data is preferably given per individual fish product.

i. When applicable: how long is the fish in average stored between supply and putting it in the retail shelf?

j. How long is the average keeping period in shelf (from moment of supply and moment of sales)

k. Do you apply ice to the fish?

l. Do you produce the ice, is it supplied with the fish, or is it supplied separately?

m. How much ice is used per kg fish?

n. What percentage of the fish is wasted?

o. What is the destination of that wasted fish?

p. Do you apply packaging material?
    a. If so, what material, and how much per kg fish?

PART 4: TASK 3 - REDUCING GHG EMISSIONS BY TECHNICAL MEANS

The exhaustive list of questions below are relevant for each sector within the postharvest value chain. As not all questions can be asked in an interview with limited time and resources in addition to limited contacts, the interviewer can choose relevant questions for their interview related to TASK 3. Questions indicated in dark blue are suggestions of important questions for all sectors. Technical questions specific to different sectors can be found below the overarching questions (e.g., fish feed producer, retailers, distributors) and is especially important for the associations, technology providers, and the NGOs and public administrations. As the current projects aims to collect quantitative data as much as possible, asking quantitative questions and digging for the numbers is advised.

OVERARCHING QUESTIONS

General

These general questions are setting a baseline of knowledge of the stakeholder, first of the entire postharvest value chain and second of the specific knowledge of the postharvest segment the stakeholders are operating in.

d. According to your knowledge, which are the most important aspects/processes in the general postharvest chain that have the greatest impact on GHG/carbon emissions?
e. According to your knowledge, which are the most important aspects/processes within your company that have the greatest impact on GHG/carbon emissions?
f. How important are new technologies in the postharvest chain to reduce GHG/carbon emissions for your company?

Postharvest Technology

This section will dive deeper into postharvest technologies. We aim here to review trends in technological evolutions and identify possible new processing and logistic techniques and their challenges. This section is subdivided in specific topics (technology, investment, implementation, gain and limitations). These topics will also return for the specific technical questions for each sector. Many questions are yes/no answer based and will therefore exclude some of the repetitive questions. The interviewer has the flexibility to combine questions from a single topic, multiple topics or even multiple sections. However, we aim at gathering as much information as possible in a preferably orderly manner.

Technology

e. Has your company measured/monitored GHG/carbon emission in the last 20 years?
    a. If yes, which parameters were measured?
    b. If yes, how were these parameters measured?
f. Has your company implemented any technology in the last 20 years that have contributed to reduction of GHG/carbon emissions?
    a. If yes, have these technologies been integrated gradually (multiple but small changes) or has this been stepwise (few but large changes) over the last 20 years?
g. Has your company performed any equipment/technology upgrades?
    a. If yes, why were these changes made?

    b. If yes, when were these changes made?
h. Is your company measuring/monitoring GHG/carbon emission currently?
    a. If yes, which parameters are measured?
    b. If yes, how are these parameters measured?
i. Is your company going to measure/monitor GHG/carbon emission in the coming years?
    a. If yes, which parameters will be measured?
    b. If yes, how will these parameters be measured?
j. Is your company developing or contributing to developing new technologies with respect to reducing GHG/carbon emissions?
    a. If yes, which are those technologies (see matrix with potential technologies)?

Implementation

d. Has your company implemented any technology in the last 20 years, currently or going to in the future, that have contributed to reduction of GHG/carbon emissions?
    a. If yes, which technologies are those (see matrix with technologies)?
    b. If yes, how did they contribute to reduce GHG/carbon emissions?
e. Has your company implemented any new postharvest technologies that result in reduction of GHG/carbon emission in the last 20 years?
    a. If yes, which technologies were those (see matrix with technologies, past)?
    b. If yes, how did they contribute to reduce GHG/carbon emissions?
f. Is your company currently implementing any new postharvest technologies that result in reduction of GHG/carbon emission?
    a. If yes, which technologies are those (see matrix with technologies, current)?
    b. If yes, how do they contribute to reduce GHG/carbon emissions?
g. Is your company planning to implement new technologies in the next 5-5+ years that contribute to reduction of GHG/carbon emissions?
    a. If yes, which technologies are those (see matrix with technologies, future)?
    b. If yes, how do they contribute to reduce GHG/carbon emissions?
h. If your company has implemented any new technologies that result in reduction of GHC/carbon emission:
    a. How has your company implemented such technologies (collaboration, own tools, 3rd party, ...) (past)?
    b. How is your company implementing such technologies (collaboration, own tools, 3rd party, ...) (current)?
    c. How will your company implement such technologies (collaboration, own tools, 3rd party, ...) (future)?
i. Why is your company implementing such technologies (e.g., to reduce long term cost)?
j. What are the main technical difficulties you have encountered in implementing these technologies?
    a. Are there any specific technical challenges?
    b. Are there other limitations?

Investment

d. If your company has implemented any postharvest technologies in the last 20 years to reduce GHG/carbon emissions, what was the cost of the investment?
e. Is your company currently willing to invest into technologies that result in reduction of GHG/carbon emissions?
    a. If yes, is your company currently investing in these new technologies?
    b. If yes, which parameters or indicators does your company take into account when selecting a new technology to invest in?
    c. If yes, how much is your company willing to invest (e.g., % of profit)?
f. Does your company have future investment plans for novel technologies that could result in reduction of GHG/carbon emissions?
    a. If yes, how does your company identify new technology options when planning investments?
    b. If yes, are there specific investment plans?
    c. If yes, does the investment plan have a portion dedicated to Research and Development (R&D) of these novel technologies?
g. Do you know if there is any specific external funding (e.g., grants from Local/National Governments, EU-based, other) for implementing technologies with reduced GHG emissions?
    a. If yes, have you applied for such grant?

Gain

d. If your company has implemented any new technologies that result in reduction of GHC/carbon emission:
    a. What was the predicted or observed reduction in GHG/carbon emissions due to implementing new technologies (past)?
    b. What is the predicted or observed reduction in GHG/carbon emissions due to implementing new technologies (current)?
    c. What is the predicted reduction in GHG/carbon emissions due to implementing new technologies going to be (future)?
e. Are there other benefits from implementing GHG/carbon reducing technologies?
    a. Is reducing GHG/carbon emission the main reason to implement new technologies or are there other more important advantages?
f. Did the technology providers highlight the positive environmental effects or any other benefits of the technologies that you have implemented?

Limitations

d. How important is the financial aspect (e.g., cost, budgeting, taxes, etc…) as a limiting factor to develop, invest or implement new postharvest technologies?
    a. Are there any specific financial limitations?
e. How important are legal aspects in (limiting) the implementation of innovative postharvest technologies?
    a. Are there any specific legal limitations?
f. Are there any strategy or management limitations to the implementation of new postharvest technologies to reduce GHG/carbon emissions?

Matrix with technologies:

Technology	Past	Current	Future
Preparation: draining, weighting, sorting, grading, and slaughter			
Fish Draining and Weighing Systems			
RSW tanks for pre-cooling (butchering stage)			

Technology	Past	Current	Future	Technology	Past	Current	Future
Processing							
Heating				**Curing**			
Cooking (pasteurization)							
Pulsed electric fields (PEF)				**Smoking**			
Water immersion							
Water spray				**By-products**			
Steam and air				Enzymes			
Steam rotor				**Packaging**			
Ohmic heating				MAP - Modified Atmosphere Packaging systems			

Technology					Past	Current	Future
Irradiation				Smart packaging			
Thawing				EcoFishBox			
Still air combined with high voltage electric field (HVEF)				Innovative EPS box			
Canning				BluWrap packaging			
Heat Pumps				Edible packaging			
Oil extraction				**Auxiliaries**			
Supercritical CO_2 as solvent				**Cleaning**			
Freezing				Cleaning in place			
Immediate cooling				Recirculation systems			
High Pressure Processing				**Energy sources**			
Liquid ice				Private solar power system			
Rapid freezing				Green certificated energy			
Air Blast Freezer (superchilling)				Smart microgrid			
Isochoric freezing				Heat recovery system			
Cold storage				**Lighting**			
Dehumidifiers				LED			
Controlling water activity				**Other**			
Drying							
Microwave							
hybrid solar drying system							
Airless dryer (fish meal)							

Industrial strategies

This section will dive deeper into postharvest industrial strategies. Industrial strategies are defined as 'on the work-floor' operational strategies. We aim here to review trends in evolutions of industrial strategies and identify possible new strategies that are being developed and their challenges. This section is subdivided in specific topics (strategies, development, investment, implementation, gain and limitations). These topics will also return for the specific technical questions for each sector. Many questions are yes/no answer based and will therefore exclude some of the repetitive questions. The interviewer has the flexibility to combine questions from a single topic, multiple topics or even multiple sections. However, we aim at gathering as much information as possible in a preferably orderly manner.

Strategies

b. Did your company perform, currently performing or is going to perform any updates to industrial strategies that contribute to reduction of GHG/carbon emissions?
    a. When was this update made?
    b. Why did you change any of the strategies?
    c. What did you specifically change?
    d. How did you make those changes?
    e. Were there any specific technical challenges?

Implementation

g. Has your company implemented any new industrial strategies that result in reduction of GHG/carbon emission (past) over the last 20 years?
    a. If yes, which strategies were those (see matrix with industrial strategies, past)?
    b. If yes, how did these strategies contribute to the reduction of GHG/carbon emissions?
    c. Have you measured any parameters?
h. Is your company currently implementing any new industrial strategies that result in reduction of GHG/carbon emission (current)?
    a. If yes, which strategies were those (see matrix with industrial strategies, current)?
    b. If yes, how do these strategies contribute to the reduction of GHG/carbon emissions?
    c. Are you measuring any parameters to monitor new industrial strategies?
i. Is your company planning to implement new industrial strategies in the next 5-5+ years that contribute to reduction of GHG/carbon emissions (future)?
    a. If yes, which strategies are those (see matrix with industrial strategies, future)?
    b. If yes, how will these strategies contribute to the reduction of GHG/carbon emissions?
    c. Will you measure any parameters to monitor new industrial strategies?
j. If your company has implemented any new industrial strategies that result in reduction of GHG/carbon emission:
    a. How has your company implemented such strategies (self-developed, seen from others, expert advice, etc, ...) (past)?
    b. How is your company implementing such technologies (self-developed, seen from others, expert advice, etc, ...) (current)?
    c. How will your company implement such technologies (self-developed, seen from others, expert advice, etc, ...) (future)?
k. Why is your company implementing such industrial strategies (e.g., to reduce cost long term)?
l. What are the main technical difficulties you have encountered in implementing these industrial strategies?
    a. Are there any specific technical challenges?

Development

c. How important are industrial strategies to reduce GHG/carbon emissions for your company?
d. Is your company developing or contributing to the development of new industrial strategies to reduce GHG/carbon emissions?
    a. Which specific strategies are those (see matrix with industrials strategies, current)?
    b. Does this development of new strategies happen via an association of your postharvest segment sector or in collaboration with other companies?

Investment

d. Is your company willing to invest into industrial strategies that result in reduction of GHG/carbon emissions?
    a. If yes, is your company currently investing in these new strategies?

  b. If yes, are there any specific plans to invest in industrial strategies?
  c. If yes, how much is your company willing to invest (% of profit)?

e. Is there any specific funding in your company for implementing any new industrial strategies that result in reduction of GHG/carbon emissions?
f. Do you know if there is any specific external funding (e.g., grants from Local/National Governments, EU-based, other) for implementing industrial strategies for reducing GHG/carbon emissions?
  a. If yes, have you applied for such grant?

Gain

c. If your company has implemented any new industrial strategies that result in reduction of GHC/carbon emission:
  a. What was the predicted or observed reduction in GHG/carbon emissions due to implementing new strategies (past)?
  b. What is the predicted or observed reduction in GHG/carbon emissions due to implementing new strategies (current)?
  c. What is the predicted reduction in GHG/carbon emissions due to implementing new strategies going to be (future)?
d. Are there other benefits from implementing GHG/carbon reducing industrial strategies?
  a. Is reducing GHG/carbon emission the main reason to implement new industrial strategies or are there other more important advantages?

Limitations

c. How important is the financial aspect (e.g., cost, budgeting, taxes, etc…) as a limiting factor to develop, invest or implement new industrial strategies?
  a. Are there any specific financial limitations?
d. How important are legal aspects in (limiting) the implementation of new or innovative industrial strategies?
  a. Are there any specific legal limitations?

Matrix with industrial strategies:

Industrial strategy	Past	Current	Future
Processing			
General			
Cleaner production strategies			
Better insulation and more efficient refrigeration system			
Minimise the heat loads with better door control and reduced electrical loads			
Other			

Process specific questions

This section will dive deeper into the specific workings of the postharvest company and the processes used in that company. We aim here to gather comparable technical data for different postharvest segments. This data is not collected for interpretation but solely for collation and reporting purposes. This section is subdivided in specific topics (products, processes, inputs, outputs, and evolutions). These topics will also return for the specific technical questions for each sector. Many questions ask for specific values. We aim at gathering as much information as possible in a preferably orderly manner.

Products

d. Can you give an overview of the types and quantities of products that your company produces yearly?
e. Can you give an overview of the types and quantities of the by-products that your company produces yearly?
f. If this can be found in company reports, can you provide a link or forward to the report?

Processes

e. Which part of the processes run in your company has the greatest impact on GHG/carbon emission?
    a. Is this a positive of negative impact?
    b. Why does this part have such a big impact?
f. Which part of the processes run in your company has the lowest impact on GHG/carbon emission?
    a. Is this a positive of negative impact?
    b. Why does this part have such a small impact?
g. Can you provide us the technical sheets of the machines used in the postharvest process?
h. If this can be found in company reports, can you provide a link or forward to the report?

Inputs

g. Can you give and overview of the types, amounts and origin of the main raw material(s)?
h. Do you monitor electricity consumption overall or separated per part of the postharvest process in your company?
    a. How are these consumptions controlled or monitored (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
i. If natural gas is consumed, do you monitor the overall or separated per part natural gas of the postharvest process in your company?
    a. How are these consumptions controlled or monitored (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
j. Can you give an overview of the packaging format and material per product used?
    a. How important is the source of the packaging material for your company?
    b. Does your company monitor input of packaging materials?
k. Can you give an overview of the refrigerants (type and amount) that are consumed yearly?
    a. How important is the source of the refrigerants for your company?
    b. Does your company monitor the input of refrigerants?
l. Can you give an overview the yearly water consumption of your company?
    a. Do you monitor water consumption overall or separated per part of the postharvest process in your company?
    b. How is water consumption controlled or monitored (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
m. If this can be found in company reports, can you provide a link or forward to the report?

Outputs

e. Can you give an overview of the amount of (bio)waste your company produces?
f. Can you give an overview of the type, amount and final destination of other wastes (e.g., raw materials, packaging, refrigerants, heat waste, water waste)?
g. How are waste production and processing controlled and monitored in your company (own measuring/monitoring systems, 3rd party measuring/monitoring systems, calculations, …)?
h. If this can be found in company reports, can you provide a link or forward to the report?

Evolution

f. Has your company's electricity consumption been reduced in the last 20 years?
    a. If yes, how much has this consumption been reduced?
    b. Why was this consumption reduced?
    c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
g. Has your company's natural gas (or other fossil fuel) consumption been reduced in the last 20 years?
    a. If yes, how much has this consumption been reduced?
    b. Why was this consumption reduced?
    c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
h. Has your company's water consumption been reduced in the last 20 years?

   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?

i. Have your company's GHG/carbon emissions been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?

j. Has your company's waste been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?

Any other remarks or information that the stakeholder is willing to share?

FISH FEED PRODUCERS

The questionnaire specific for fish feed producers can be compiled from the overarching questions above. Quantitative data is also key to the current project and 'digging' for data is sometimes necessary to procure quantitative data. Therefore, ask as much as possible for actual values and numbers related to specific technology related questions.

RETAILERS AND DISTRIBUTORS

The questionnaire specific for retailers and distributors can be compiled from the overarching questions above. Further specific technical questions can be found below. Quantitative data is also key to the current project and 'digging' for data is sometimes necessary to procure quantitative data. Therefore, ask as much as possible for actual values and numbers related to specific technology related questions.

Postharvest technology

Investment

a. Which parameters or indicators does your company take into account when selecting a new technology to invest in?
   a. Is environmental impact a key factor?
   b. Are there other key impacts or factors?

Gain

c. Are there any legal incentives to bring a "green product" to the market?
d. Are there any other (e.g. technical) incentives to bring a "green product" to the market?

Industrial strategies

Gain

c. Does an "eco label" improve GHG/carbon emissions?
   a. How does the label impact emissions?
   b. In which part of your process or part of the value chain does a label bring a reduction of emissions?
   c. Do you monitor or estimate the emission values?
   d. How much does an "eco label" reduce emissions (per part of the chain)?

d. Are there other gains from "eco labels"?

Process specific questions

j. Has your company's electricity consumption been reduced in the last 20 years?
   a. If yes, how much has this consumption been reduced (per product/unit (kg, ton, etc.))?
   b. Why was this consumption reduced?
   c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?

k. Has your company's natural gas (or other fossil fuel) consumption been reduced in the last 20 years?
    a. If yes, how much has this consumption been reduced (per product/unit (kg, ton, etc.))?
    b. Why was this consumption reduced?
    c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
l. Has your company's water consumption been reduced in the last 20 years?
    a. If yes, how much has this consumption been reduced (per product/unit (kg, ton, etc.))?
    b. Why was this consumption reduced?
    c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
m. Have your company's GHG/carbon emissions been reduced in the last 20 years?
    a. If yes, how much has this consumption been reduced (per product/unit (kg, ton, etc.))?
    b. Why was this consumption reduced?
    c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
n. Has your company's waste been reduced in the last 20 years?
    a. If yes, how much has this consumption been reduced (per product/unit (kg, ton, etc.))?
    b. Why was this consumption reduced?
    c. Can you trace back in which part of the postharvest process in your company you have reduced this consumption?
o. How are the trucks registered (specific for seafood products or other transport targets)?
p. Which type of engine is used during transportation of your product?
    a. Fuel type (diesel, electricity, hydrogen, etc.)
    b. EURO engine level (EURO4-6)?
    c. Do you monitor fuel consumption or financial cost related to fuels?
    d. How much fuel is used?
    e. Are trucks equipped with technology to reduce fuel consumption (body kits, tires, trailer types, etc.)?
q. Which types of coolants are used in refrigeration trailers?
    a. Which are those coolants?
    b. Is coolant used monitored?
r. Are the refrigeration trailers certified for specific transport?
    a. Which are those certifications?

ASSOCIATIONS

The questionnaire specific for associations can be compiled from the overarching questions above. Further specific technical questions can be found below. This section of specific questions is subdivided in specific topics that are different from the above ones (members, training, funding, consultancy/coordination). Quantitative data is also key to the current project and 'digging' for data is sometimes necessary to procure quantitative data. Therefore, ask as much as possible for actual values and numbers related to specific technology related questions.

Postharvest technology

Members

e. Is reducing GHG/carbon emissions key for your members?
f. Have your members implemented or helped implementing any postharvest technologies in the last 20 years that have contributed to reduce their GHG/carbon emissions?
    a. If yes, which were those technologies (see above matrix with technologies, past)?
g. Are your members currently implementing or helping to implement postharvest technologies that contribute to reduce their GHG/carbon emissions?
    a. If yes, which are those technologies (see above matrix with technologies, current)?
h. Are your members planning to implement or help implement postharvest technologies for the next 5-5+ years that contribute to reduce their GHG/carbon emissions?
    a. If yes, which are those technologies going to be (see above matrix with technologies, future)?

Training

d. Is your association providing information/training to its members regarding technologies that reduced GHG/carbon emissions?
    a. If yes, about which technologies information/training is provided?

   b. What kind of information/training is provided?

e. Are your members asking for information/training regarding technologies that reduced GHG/carbon emissions?
   a. If yes, which kind of technologies are asked for?
   b. What kind of information/training is asked for?
f. Is there any third party (consultancy, technology providers, etc.) providing information/training to you as an association or your members regarding technologies that reduced GHG/carbon emissions?

Funding

c. Is your association receiving funding from national/other administrations to promote the implementation of technologies that reduce GHG/carbon emissions?
d. Are your members asking for funding or economic support for implementing technologies that reduce GHG/carbon emissions?

Consultancy/coordination

e. Have you coordinated in the last 20 years any initiative for implementing technologies that reduce GHG/carbon emissions of your members?
   a. If yes, which were those initiatives?
f. Are you currently coordinating any initiatives to implement technologies that reduce the GHG/carbon emissions of your members?
   a. If yes, which are those initiatives?
g. Are you planning to coordinate any initiatives to implement technologies that reduce the GHG/carbon emissions of your members? (e.g., within 5 years)
   a. If yes, which are those initiatives going to be?
h. Are you developing or contributing to develop (with other partners) new postharvest technologies to reduce GHG/carbon emissions of your members?

Industrial strategies

Members

d. Have your members implemented or helped implementing any industrial strategies in the last 20 years that have contributed to reduce their GHG/carbon emissions?
   a. If yes, which were those strategies (see above matrix with strategies, past)?
e. Are your members currently implementing or helping to implement industrial strategies that contribute to reduce their GHG/carbon emissions?
   a. If yes, which are those strategies (see above matrix with strategies, current)?
f. Are your members planning to implement or help implement industrial strategies for the next 5-5+ years that contribute to reduce their GHG/carbon emissions?
   a. If yes, which are those strategies going to be (see above matrix with strategies, future)?

Training

d. Is your association providing information/training to its members regarding industrial strategies that reduced GHG/carbon emissions?
   a. If yes, about which strategies information/training is provided?
   b. What kind of information/training is provided?
e. Are your members asking for information/training regarding industrial strategies that reduced GHG/carbon emissions?
   a. If yes, which kind of strategies are asked for?
   b. What kind of information/training is asked for?
f. Is there any third party (consultancy, technology providers, etc.) providing information/training to you as an association or your members regarding industrial strategies that reduced GHG/carbon emissions?

Funding

c. Is your association receiving funding from national/other administrations to promote the implementation of industrial strategies that reduce GHG/carbon emissions?
d. Are your members asking for funding or economic support for implementing industrial strategies that reduce GHG/carbon emissions?

Consultancy/coordination

e. Have you coordinated in the last 20 years any initiative for implementing industrial strategies that reduce GHG/carbon emissions of your members?
    a. If yes, which were those initiatives?
f. Are you currently coordinating any initiatives to implement industrial strategies that reduce the GHG/carbon emissions of your members?
    a. If yes, which are those initiatives?
g. Are you planning to coordinate any initiatives to implement industrial strategies that reduce the GHG/carbon emissions of your members? (e.g., within 5 years)
    a. If yes, which are those initiatives going to be?
h. Are you developing or contributing to develop (with other partners) new postharvest industrial strategies to reduce GHG/carbon emissions of your members?

TECHNOLOGY PROVIDERS

The questionnaire specific for technology providers can be compiled from the overarching questions above. Further specific technical questions can be found below. This section of specific questions is subdivided in specific topics that are different from the above ones (technology, clients, development, training). Quantitative data is also key to the current project and 'digging' for data is sometimes necessary to procure quantitative data. Therefore, ask as much as possible for actual values and numbers related to specific technology related questions.

Postharvest technology

Technology

h. What are the most important points of the value proposition of your products/technologies (e.g., lower price in the market, low consumptions, improve food quality, etc.)?
i. Which are the key factors that boost your new developments or the upgrading of your current equipment (e.g., reduce equipment cost, reduce electric consumption, increase kg/h, reduce processing time, etc.)?
j. Did you have to consider GHG/carbon emission in the past when designing new technology?
    a. If yes, when?
    b. If yes, how were new designs implemented?
    c. If yes, how much calculated/predicted gain was there?
k. Are you currently considering the GHG/carbon emissions when designing a new technology?
    a. If yes, how?
l. What exactly makes your technology more GHG/carbon efficient (e.g., energy use, speed, etc.)?
    a. What are the current calculated/predicted gains?
    b. If you have not considered this before, do you plan to reduce the GHG/carbon emissions of your products in the near future?
m. Is equipment that has a lower environmental impact more expensive than "traditional" equipment?
    a. If yes, where exactly is the extra cost?
n. Do your technologies follow any certification/norms?
    a. If yes, which are those?

Clients

f. Are your clients asking for technologies to reduce their GHG emissions?
    a. If yes, have your clients asked specifically for this in the past?
    b. If yes, when?
    c. If yes, what did clients specifically asked for?
g. Is there an increasing demand in the last years?
h. Are you giving calculated/estimated environmental impacts of your products/technologies to your clients?
    a. If yes, which are those parameters of impacts?
i. How important is certified equipment, or equipment build following a certain norm?
j. If there is an extra cost associated with more GHG/carbon efficient technology, who is paying for that cost?

Development

5. How important is cost as a limiting factor to develop new technologies with reduced GHG/carbon emissions?
6. How important are legal aspects or standard procedures in designing and developing new or innovative technologies?

   a. Are these advantageous or disadvantageous?
7. Do you know if there is any specific external funding (e.g., grants from Local/national Governments) for developing technologies for reducing GHG emissions?
   a. If yes, have you applied for such grant?
   b. If yes, how much are these grants?
8. Is there any third party (Research Centres, Universities, other technology providers, etc.) helping you in your development of technologies that reduce GHG/carbon emissions and input consumptions for building your products/technologies?
   a. If yes, who are those parties?
   b. If yes, what is their exact contribution?

Training

d. Are your clients asking for specific information related to reducing GHG/carbon emissions?
e. Are you giving this information to your clients?
f. Are you educating your clients even if there is no specific question for technology reducing GHG/carbon emissions?

NGOs AND PUBLIC ADMINISTRATIONS

The questionnaire specific for NGOs and public administrations can be compiled from the overarching questions above. Further specific technical questions can be found below. Quantitative data is also key to the current project and 'digging' for data is sometimes necessary to procure quantitative data. Therefore, ask as much as possible for actual values and numbers related to specific technology related questions.

Awareness

e. Are you doing specific campaigns to increase the awareness and commitment related to the reduction of GHG/carbon emissions in fish companies?
   a. If yes, which are those campaigns?
   b. If yes, which information do you provide in these campaigns?
f. In the last 20 years, have you developed specific funding programmes (e.g., grants, loans, etc.) to reduce the GHG/carbon emissions of the companies in the Seafood sector?
   a. If yes, which were those?
   b. If yes, how much funding was available to applying parties?
   c. If yes, which were the conditions to apply for funds?
g. Are you currently developing specific funding programmes (e.g., grants, loans, etc.) to reduce the GHG/carbon emissions of the companies in the Seafood sector?
   a. If yes, which are those?
   b. If yes, how much funding is available to applying parties?
   c. If yes, which were the conditions to apply for funds?
h. Are you planning to launch (in 5-5+ years) specific funding programmes (e.g., grants, loans, etc.) to reduce the GHG/carbon emissions of the companies in the Seafood sector?
   a. If yes, which are those going to be?
   b. If yes, how much funding will be available to applying parties?
   c. If yes, which will be the conditions to apply for funds?

ANNEX 4. DETAILS ON POSTHARVEST TECHNOLOGIES AND STRATEGIES

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1 THAWING, CONVENTIONAL TECHNOLOGIES

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☐ CS 23 Common Cuttlefish

Types of conventional technologies in thawing

- Water immersion-spray thawing
- Air thawing
- Microwave assisted thawing

Water immersion-spray thawing

Thawing in water is the standard practice in the food sector. The process involves the immersion of the product in water to thaw/temper it. Water for thawing is heated during the process to maintain the temperature of the system. Instead of immersion, water could also be applied to the product by spraying it on top of the product (Venugopal, 2006). The product can be packaged or unpackaged. The process can happen in batches or in continu4ous (thawing tunnel) applications. Conventional water-immersion thawing has the disadvantages of long thawing times, potential of cross-contamination, prolonged exposure of the outer surfaces to warm temperatures, use of large amounts of water, and generation of the possible large amounts of wastewater (Venugopal, 2006).

Together with air thawing, immersion/spray thawing is the traditional method for thawing fish products in the seafood post-harvest chains. Water immersion/spray improves heat transfer compared to traditional air thawing, avoiding also surface drying. Water immersion/spray thawing is conventionally applied at low temperatures (refrigeration temperatures to minimise microbial growth) to maintain the correct food properties (Li et al., 2020). Increasing the temperature of the water (e.g., 25°C) increases the speed of the thawing process but negatively affects the properties of the food product and increase the possibility for microorganisms to grow (Li et al., 2020). Although both air as immersion/spray thawing technologies have disadvantageous, they are still in use due to their simplicity, their low cost and high capacity (Lee et al., 2021).

Traditional water immersion/spray thawing has not change much in the last 20 years. In any case, some technological improvements have been made to improve the efficiency of the processes (e.g., improving water heating technology efficiency, improved control of water temperatures, reducing the use of water, including technologies for cleaning, and reusing the water, reducing heat losses by improving insulation materials of the kettles).

The potential for improving this technology in the next 20 years is relatively low. However, the process still has important challenges to resolve, especially the generation of wastewater could be tackled (an important handicap related to other thawing alternatives). Several alternative techniques have been studied for improving traditional thawing (water immersion thawing and air thawing), like the use of ultrasounds or microwaves. It is expected that some of them will replace traditional technologies in the coming years. Microwave assisted thawing is already on the market, but there are not many companies using this technology. Ultrasound assisted thawing is currently under development and is expected to be on the market in the following years. More information about them can be found in their corresponding files.

Air thawing

The process involves the thawing/tempering of the fish using air. Varying the temperature and the velocity of the air, the process can be optimised. The thawing process is most frequently applied on batch volumes (e.g., entire storage chamber). If the seafood product is not protected (e.g., packaging), surface drying may happen. Together with water immersion/spray thawing, air thawing is the traditional method for thawing fish in the industry. From a general point of view, air thawing presents lower thawing rate than water thawing (water conducts heat better than air). Thus, hours, and even days are needed to thaw the food. Although both techniques have disadvantages, they are still under use due to their simplicity, their low cost and high capacity (Lee et al., 2021).

Air thawing happens conventionally at low temperatures (normally refrigeration temperatures) to keep microbial growth to a minimum. Increasing the temperature of the air (e.g., 25°C) improves the speed of the process but negatively affects the properties of the food and microorganisms can growth (Lee et al., 2021). To reduce the thawing time without increasing the risk of microbial contamination, two-stage air thawing can be applied (Lee et al., 2021; Venugopal, 2006). In the first stage, excess heat is supplied through hot air circulation, which flows from the surface to the core of the samples and hastens the thawing process. In the second stage, the thawed food products are transferred to a cooler space.

Traditional air thawing has not changed much in the last 20 years. In any case, some efforts have been made to improve efficiency of the processes (controlling the process, improving air velocity homogeneity, etc.).

Air thawing has been optimised over the last 20 years and there is already little room for technological improvement. However, the process still has important challenges to resolve, especially the slow thawing rates.

Microwave assisted thawing

The unique property of microwaves to penetrate and produce heat in the interior of food materials (volumetric heating) allows to accelerate thawing and tempering (Li & Sun, 2002). A heat transfer medium like water is not necessary to apply this technique. This is an important advantage with respect to conventional water immersion thawing or to specific emerging thawing technologies like ultrasound assisted thawing. Microwave thawing has been successfully applied in households, in restaurants and industry for 50 years. On industrial scale, there are both batch and continuous (tunnel) units. Microwave assisted thawing requires shorter thawing time (minutes) and needs a smaller space for processing, reducing also drip loss and chemical deterioration (Li & Sun, 2002). However, this technique lacks uniform heating (James et al., 2017) and proper temperature control (Li et al., 2020). The preferential absorption of microwaves by liquid water is a major cause of overheating (Li & Sun, 2002). Microwave assisted thawing cannot be used with metal packaging (Li et al., 2020).

In the last 20 years microwave assisted thawing has advanced tremendously. Improvement of the temperature uniformity during microwave thawing has been done, optimising microwave conditions and using specific packaging materials that increase heating uniformity. The technology is already industrialised, although it is not the most common method for thawing/tempering. In commercial practice there are relatively few controlled thawing systems (James et al., 2017).

It is expected that the number of industrial units will increase in the next 20 years. In any case, it is necessary to improve more the uniformity of the treatments to be a mainstream thawing technology.

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2 THAWING, EMERGING TECHNOLOGIES

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice

☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of emerging technologies in thawing

- Ohmic thawing
- High hydrostatic pressure for thawing
- Radiofrequency assisted thawing
- Ultrasound assisted thawing

Ohmic thawing

Ohmic thawing is an electro-heating method that heats more uniformly than other electro-heating techniques. The rapid and relatively uniform heating of ohmic heating is achieved by the direct passage of electric current through the product (Liu et al., 2017). Ohmic heating has advantages over conventional heating such as higher heating rate, higher energy conversion efficiency or reduced processing time (Li & Sun, 2002). The heating is produced directly on the food (direct heating), so it is not necessary to use any intermediary medium (indirect heating), improving the efficiency. Thus, due to the higher energy conversion efficiency, this technology could allow to reduce the energy consumption of thawing/tempering and, indirectly, reducing the GHG emissions. Other positive point is the absence of water usage and generation of wastewater (Seyhun et al., 2014). Despite its potential, there are not many studies studying ohmic thawing and tempering (Liu et al., 2017; Miao et al., 2007; Seyhun et al., 2014). In the food industry, more attention has been paid to the application of ohmic heating on aseptic processing and pasteurisation of particulate foods (Li & Sun, 2002). Currently, this technology is not applied in the industry.

Ohmic thawing in seafood was proposed in the 90s. However, it has not advanced too much in the last 20 years. At present very little research on ohmic thawing has been carried out (Liu et al., 2017). In the last 20 years some efforts have been made to know the electrical conductivity of foods and improve the control of ohmic thawing process. However, more attention has been paid to the application of ohmic heating for pasteurisation or sterilisation of liquid foods.

Ohmic heating technology shows potential in supplying thawed foodstuffs of high quality. It is expected that the number of studies on thawing will increase in the coming 20 years and first pilot processing units could appear.

High hydrostatic pressure for thawing

High hydrostatic pressure (HHP; also called high pressure processing) is an emerging food processing technology that pressurises food up to 800 MPa (standard industrial devices up to 600-650 MPa) for up to several minutes (Puértolas & Lavilla, 2020). Previous research has shown that the application of HHP improves the thawing process of fresh fish, reducing drip loss and maintaining a good product quality if the treatment is optimised (Cartagena et al., 2021; Puértolas & Lavilla, 2020). The HHP treatment can be applied during thawing (pressure assisted thawing), before freezing or before other thawing techniques are applied (Cartagena et al., 2021).

The application of HHP for pasteurising food products has been extensively studied and is currently used mainly for seafood products, especially for prepared meals. (Puértolas & Lavilla, 2020). The use of HHP for improving thawing was proposed around 20 years ago. Even though HHP has been intensively researched, especially in fish products, its application is not yet been industrialised. This is related to technical challenges of scale up and/or their high cost related to the specialised equipment necessary to generate and maintain the high pressures during thawing process, where pressure must be applied during the entire thawing process (minutes) (Cartagena et al., 2021).

Despite all the research carried out to study the potential of HHP for thawing, further economic and environmental studies are needed to elucidate whether this technology is cost-effective in both these fields. If these studies would obtain positive results, the first industrial use of HHP for thawing could be achieved in the next few years. In any case, the technique will be applied on high-value product where the reduction of drip loss could amortise the cost of the treatment.

Radiofrequency assisted thawing

Radiofrequency is a thermal processing technology based on the dissipation of electromagnetic energy within the product. The unique property of radiofrequency radiation is to penetrate and produce heat in the interior of food materials (volumetric heating) allowing to accelerate thawing and tempering. A heat transfer medium like water is not necessary for this application. This is an important advantage with respect to conventional water immersion thawing or to specific emerging thawing technologies like ultrasound assisted thawing. At industrial scale, there are both batch and continuous units (tunnel). Radiofrequency assisted thawing requires shorter thawing time (minutes) and less space for processing, reducing also drip loss and chemical deterioration. However, it lacks uniform heating (James et al., 2017) and proper temperature control (Li et al., 2020) like in microwave treatment. Furthermore, the preferential absorption by liquid water is a major cause of overheating (Li & Sun, 2002).

In the last 20 years radiofrequency assisted thawing has advanced extensively, and in the last five years the first industrial units have been sold to the general food industry, and for the seafood industry (STALAM[61]). Improvement of the temperature uniformity during the thawing process has been made to optimise thawing conditions.

It can be expected that the number of industrial units will increase in the next 20 years. In any case, it is necessary to improve more the uniformity of the treatments to be a mainstream thawing technology.

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[61] STALAM is a leading supplier of radio frequency (RF) equipment for the drying and thermal processing of raw materials and semi-finished and finished industrial products

Ultrasound assisted thawing

The process involves the application of ultrasound during water immersion thawing/tempering, improving uniformity and saving time with respect to traditional water immersion thawing (Bhargava et al. 2021; Li et al., 2020). This could be based mainly on the improvement of the heat transfer (Bian et al., 2022; Qiu et al. 2020; Li et al., 2020). The physical effect caused by ultrasound can convert sound energy into heat energy, improve the rate of heat transfer in the thawing process, facilitate the thawing process and significantly improve the efficiency of thawing (Bian et al., 2022; Qiu et al., 2020). For example, cod blocks required about 71% less time to thaw through ultrasound-assisted immersion in water when ultrasound at 1500 Hz frequency and power of 60 W was applied, as compared to conventional water immersion (Bhargava et al. 2021). Processing conditions must be optimised because high-power single-frequency ultrasound may damage the muscle structure of the product (Bian et al., 2022; Qiu et al. 2020). It is worth noting that ultrasonic waves have the disadvantages of high energy consumption and instability in practical applications (Bian et al., 2022).

The application of ultrasound for food processing is an emerging technology that has been extensively studied during the last 20 years (Bhargava et al. 2021; Li et al., 2020). However, compared to other thawing technologies, the use of ultrasound-assisted thawing methods has not been studied comprehensively. Several recent studies have shown the feasibility of ultrasound-assisted thawing in meat, fruit and fish (Bian et al., 2022; Li et al., 2020; Qiu et al., 2020).

After initial studies highlighted the potential of ultrasound-assisted thawing, more research is needed to reduce the energy consumption of ultrasound systems (Bian et al., 2022). Future work should take ultrasonic parameter optimization into consideration to alleviate the thermal effects induced by powerful ultrasounds (Qiu et al., 2020). Furthermore, different food materials have different inherent characteristics and the ultrasound parameters for thawing processes of different food products should also be optimized to enhance the thawing process in order to preserve the food properties (Qiu et al., 2020). The distribution of ultrasonic sounds in the thawing water can be non-uniform and more fundamental research is needed to build thawing devices for an even distribution of ultrasonic wave intensity (Qiu et al., 2020). Finally, ultrasound should be treated cautiously, because it may be harmful to human health as it entails work safety hazards (adverse tissue injury, electrical shock, and burns and indirect damage) (Qiu et al., 2020). Ultrasound assisted thawing is currently in research stage. Large efforts will have to be made for its large-scale industrial applications to be feasible.

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3 CONTROL OF WATER ACTIVITY, DRYING

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of drying systems

- Microwave drying
- Airless dryer
- Freeze-drying
- Heat pump drying
- Hybrid heat pump drying
- Osmotic dehydration
- Sun drying
- Solar drying

Microwave drying

Microwave heating has extensive applications in drying technologies because it can heat the product without a heat transfer medium like water or air (Viji et al., 2022). As the heat is generated inside the product, the technology has great potential (decrease processing time, and increase energy efficiency) compared to traditional drying processes, where the heat goes from the surface to the inside of the product (Duan et al., 2011; Viji et al., 2022). In general, microwave processing is time saving, energy efficient and yields good quality fish products with high nutritional value (Darvishi et al., 2013; Viji et al., 2022).

In the last 20 years microwave technology has advanced a tremendously. Improvements of the temperature uniformity during microwave treatment have been made by optimising control of microwave conditions. However, the application of this technology for drying seafood products has a lot of room for improvement and, to the best of knowledge of the authors, its industrial application is very scarce. Limited studies focussing on energy consumption and microwave drying kinetics of fish have been performed up to now (Darvishi et al., 2013). A major disadvantage of microwave drying is overheating of the product (Viji et al., 2022). A combination of microwave drying with other technologies can overcome these drawbacks of microwave drying. For example, vacuum assisted microwave drying or hot air microwave drying are successful developments, aimed to improve the product quality (Duan et al., 2011; Viji et al., 2022). In hot air microwave drying, the hot air allows evaporation of moisture from the surface, resulting in a porous structure which restricts the shrinkage in addition to developing a crispy texture in the final product (Viji et al., 2022).

It is necessary to further improve the uniformity of the treatments for microwave drying to be a mainstream technology. Single microwave heating has a few drawbacks such as development of hotspots and overheating at the edges due to non-uniform temperature distribution (Viji et al., 2022). Additionally, as dielectric properties of fish products vary with its composition, specific microwave frequencies must be chosen for each product for better results (Viji et al., 2022). A combination of microwave and conventional drying or other emerging technologies has a vast potential to alleviate these drawbacks (Viji et al., 2022). More research and development efforts are expected in this area in the following years and should be reflected in an increase of the number of pilot and industrial microwave dryers (alone or combined with other drying technologies).

Airless dryer

The Airless Dryer is a semi-closed drying system which was a first-time patent application in 1987 (Stubbing, 1993). This system consists of a rotary-dryer that uses superheated water steam as drying medium. Heat is transferred from a heat exchanger to the drying medium to evaporate moisture from wet feed in the dryer.

Being a loop of drying medium that works at atmospheric pressure, it is necessary to bleed the water steam evaporated from the feed, which generates an "oxygen free" environment into the system.

Some benefits of this system are reduction of energy usage as dryer exhaust (water vapour) can be condensed for energy recovery or used as a heat source somewhere else in the plant. In addition, as this drying process creates an oxygen free environment, it presents a minimum risk of fire in the dryer and feed oxidation rate decreases.

Freeze-drying

Freeze-drying, also called lyophilization, has been extensively used to dry food since the end of the nineteenth century (Boziaris, 2014). Freeze-drying is a drying process that uses the sublimation of ice as its main drying mechanism. This differentiates the process from the conventional drying methods that rely on the evaporation of liquid water for drying (Boziaris, 2014; Waghmare et al., 2021). Freeze-drying provides dried products with a porous structure, small or negligible shrinkage, superior flavour and aroma retention, and improved rehydration capacity compared to products dried with other methods (Boziaris, 2014). However, freeze-drying has a high capital and operating costs due to the long processing time and the energy consumption (Boziaris, 2014). Thus, it is mainly used on high-value products.

Over the last 20 years, suppliers of freeze-drying technology have improved efficiency, and reduced freeze-dryer and process costs. There are many suppliers of freeze dryers and seafood products on the market. Different kinds of freeze-drying systems are used for industrial applications, among them the tunnel freeze-dryer and fluidized bed dryer are the most common (Merone et al., 2020). From a research perspective, it has been demonstrated that freeze-drying coupled with other processing technologies such as infrared, microwaves, ultrasound, and pulsed electric field reduces the drying time, increasing the drying rate, and saves energy (Waghmare et al., 2021).

Freeze-drying coupled with other processing technologies such as infrared, microwaves, ultrasounds, and pulsed electric field diminishes the drying time, increasing the drying rate, and saves energy (Waghmare et al., 2021). For example, the use of ultrasound shortens the drying time and, therefore, can save up to 70% of the total energy required by the conventional process (Merone et al., 2020). It is expected that in the following years, some of these combined processes will be industrialised.

Heat pump drying

A heat pump dryer is based on the use of hot and dry air of controlled temperature and relative humidity. The system involves a heat pump and a drying chamber. The humid air of the drying chamber passes through the evaporator, where the moisture is condensed into water. After the evaporator, the dried air is heated in the condenser and goes to the drying chamber again. Heat pump dryers have been in widespread commercial use since the 1970s (Boziaris, 2014). The heat pump presents an efficient and environmentally friendly technology due to its low energy consumption (Boziaris, 2014), its high coefficient of performance and the high thermal efficiency of a correctly designed dryer.

Some research efforts have significantly increased the energy efficiency of heat pumps (for example, by 35% through multi-staging) (Chua et al., 2010). The integration of heat-driven ejectors into the heat pump (ejector augmentation) has improved system efficiency by more than 20% (Chua et al., 2010). Additionally, the development of better compressor technology has reduced the energy consumption of heat pump systems (potentially up to 80% of savings) (Chua et al., 2010).

Hybrid heat pump drying

A conventional heat pump dryer is based on the use of hot and dry air of controlled temperature and relative humidity. These hybrid heat pump dryers are gaining a lot of attention in the last years as they are efficient and environmentally friendly due to their low energy consumption, and their easy use of a renewable energy source (solar, geothermal or biomass energy) (Hamdani et al., 2018; Singh and Gaur, 2021).

Hybrid heat pump dryers are currently a focus of researched and developed, especially in Asian countries (Hamdani et al., 2018; Singh and Gaur, 2021). For the success and commercialization of any technology, it is essential to know if it is economically feasible. According to different studies, hybrid dryers are profitable because they improve the efficiency of the process (Hamdani et al., 2018). Particularly, the solar biomass hybrid dryer has attracted great interest because this system operates with biomass energy when there is no sun, so it can potentially operate year-round on renewable energy sources.

Osmotic dehydration

Osmotic dehydration is a common process to partially remove water from food by immersion in a hypertonic solution and introducing solutes at the same time. It is a common step used in salting, smoking, and marinating (Boziaris, 2014). Osmotic dehydration is basically carried out by immersing the seafood in concentrated osmotic solutions of salt, sugar, or other low molecular weight compounds (water in the product diffuses to the osmotic solution). Osmotic dehydration reduces damage created by heat and decreases the energy costs in comparison to other drying techniques (Boziaris, 2014). However, it is a slow process, and it is not possible to obtain food with the same low water content as with other more aggressive drying techniques that focus on the application of heat. To decrease the processing time and improve the diffusion of solutes, the pre-treatment of fish with other processing technologies that may enhance mass transfer phenomena [62]during subsequent osmotic process can be applied, like pulsed electric fields or ultrasounds (Boziaris, 2014; Semenoglou et al., 2020).

Osmotic dehydration has not changed much in the last 20 years. To reduce waste and improve the overall efficiency, different approaches for reusing the hypertonic solution are nowadays applied in the different companies (e.g., membranes, recirculation, UV decontamination, filtration, etc.). From a research perspective, it has been demonstrated that osmotic dehydration coupled with other processing technologies such as ultrasound and pulsed electric field reduces the drying time, increases the drying rate, and saves energy (Boziaris, 2014; Semenoglou et al., 2020).

Sun drying

Sun drying is the most widespread and the cheapest method for drying fish (Boziaris, 2014). In Europe, it is used mainly by artisanal companies in the Mediterranean and Northern countries. Although it is named sun drying, the process happens at low temperatures (even below 10°C; cold and fresh weather), while ambient humidity and time play key roles. Because sun drying does not need an external energy source, this drying process is probably one of the most environmentally friendly processing techniques with the lowest impact in terms of energy and GHG emissions. However, the most important problems of sun drying are the loss of quality due to contamination with dust and excreta from birds and animals, and difficulties related to controlling the process and the drying parameters (Boziaris, 2014). In this process, heat is transferred by convection from the surrounding air and by absorption of direct and diffuse radiation on the surface of the fish and fish products. The converted heat is partly conducted to the interior, leading to an increased temperature of the fish and fish products, and is partly used for water and vapour migration from the interior to the surface (Boziaris, 2014). Natural convection supported by wind removes the evaporated water from the air surrounding the fish and fish products (Boziaris, 2014).

Solar drying

Solar drying is an evolution of traditional sun drying. It differs from sun drying because the solar dryer is an enclosed structure that traps heat inside the dryer and uses it efficiently (Immaculate et al., 2012). Sun drying also saves a lot of time, occupies a smaller drying area, improves the quality of the final products, and makes the process more efficient as well as protecting the environment (Boziaris, 2014; Catorze et al., 2022). In comparison to other drying techniques that employ hot air or heat pumps, solar drying saves energy and can potentially reduce GHG emissions (Catorze et al., 2022). Solar dryers can use natural convection (passive dryer) or forced convection (active dryer). Normally the process is very slow compared with other drying technologies such as heat

[62] Mass transfer phenomena is the net movement of mass from one location, usually meaning stream, phase, fraction, or component, to another.

pump drying. Trying to increase the processing speed, some solar dryers use electricity to support and maintain the process if there is no sun (Catorze et al., 2022).

Solar drying has been traditionally used for seafood and agricultural products, so it has not changed much in the last 20 years. It is used only by a few European companies, related always to very traditional food products (it is not a mainstream technology).

It is expected that the companies using solar drying in Europe will decrease in the following 20 years, substituting solar dryers by other better controlled drying techniques. In any case, due to climate change and the low GHG emissions of solar drying, more research may be expected or provide a good opportunity to improve the efficiency of the solar dryers. If the results are positive, an increment on the number of industrial solar dryers could occurs.

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4 CONTROL OF WATER ACTIVITY, MARINATING

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops

☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☐ CS 23 Common Cuttlefish

Types of marinating systems

- Cold, cooked, fried and pasteurized marinating
- Injection marinating
- Vacuum impregnation marinating

Cold, cooked, fried and pasteurized marinating description

Marinating is a process like brine salting, in which the seafood is treated with a marinade solution containing salt, sugar, spices, and/or other substances to modify the sensory properties of the product and increase its shelf life (Boziaris, 2014). Traditionally, marinating involves immersing seafood into a marinade solution, allowing the penetration of solutes through a diffusion process over time. Nowadays, there are several methods including cold, cooked, fried and pasteurised marinating (Boziaris, 2014). Cold marinating (at refrigeration temperature) is the most used method, representing about 92% of the market in Europe (Boziaris, 2014). The process involves immersing seafood in a cold marinade during hours/days/weeks. In cooked, fried, and pasteurized marinated seafood products, the marination occurs at the same time of the heating processes, reducing the processing time. As it is not necessary to maintain the seafood during hours/days/weeks at cold temperatures and the product is heat treated at the same time as the marinating processes, these methods reduce the energy and economic costs and the corresponding environmental impact. However, as the heat treatments involves high temperatures, the characteristics of the final product are completely different from those of cold marinating.

Marinating has not changed much in the last 20 years. To reduce waste and improve the overall efficiency, different approaches to reusing the marinade are nowadays applied in different companies (e.g., recirculation, UV decontamination, filtration, and others). Research has demonstrated that a pre-treatment of other processing technologies such as pulsed electric field, high pressure processing, ultrasounds, or laser micro perforation reduces the processing time and improve the marination process of meat and fish (Figueroa et al., 2020). However, to the authors' knowledge, these combined processes are not currently applied at industrial level and there are no economic and environmental impact studies to elucidate the suitability of combined systems.

Conventional marinating is normally a slow process. To decrease the processing time and improve the diffusion of solutes, the combined application of other food processing technologies that may enhance mass transfer phenomena [63]during subsequent marinating process may be applied, like pulsed electric fields, ultrasounds, high pressure processing or laser micro perforation (Figueroa et al., 2021). It can be expected that in the following years, some of these combined processes will be industrialised, supported by the development of the technologies on which these pre-treatments are based. In any case,

[63] Mass transfer phenomena is the net movement of mass from one location, usually meaning stream, phase, fraction, or component, to another.

there is no information about the economic and environmental impact to elucidate the convenience of the combined systems.

Injection marinating

Over the last decades, marinating by automatic marinade injection into the seafood flesh by multi-needle systems has become common practice (Boziaris, 2014). The process reduces the diffusion distance of the brine and, therefore, accelerate the marinating and yield (Boziaris, 2014). As the marinade is injected directly into for example the fish muscle, injection marinating also reduces the amount of marinade required compared to conventional immersion marinating. However, this marinating method can increase risk of cross contamination with microorganisms and metal from the needles and, if marinade is injected at high pressure, it can damage the fish muscle (the final product). Injection marinating is normally applied at low temperatures to avoid microbial grow, so its impact in terms of energy consumption and GHG emissions is lower than for other fish post-harvest technologies used to control product water activity that need to heat the product.

Over the last decades, marinade injection has been increasingly used to speed up marinating, increase automation, homogenously distribute the solutes within the seafood tissue and improve processing yields. Each technology supplier modified the settings used, such as needle types, needle density, injection speed and the pressure applied, to improve the process and adapt it to the seafood product and the industrial goals. Research has demonstrated that a pre-treatment of other processing technologies such ultrasounds, pulsed electric fields or laser micro perforation improve the marinating process (Figueroa et al., 2021). However, according to the authors' knowledge, these combined processes are not applied at industrial level today.

To decrease the processing time and improve the diffusion of salt, the combined application of other food processing technologies that may enhance mass transfer phenomena during subsequent marinating process may be applied, like pulsed electric fields, ultrasounds, or laser micro perforation (Figueroa et al., 2020). It is expected that in the following years, some of these combined processes will be industrialised, supported by the development of the technologies on which these pre-treatments are based.

Vacuum impregnation marinating

The application of vacuum impregnation during marinating process could reduce processing time and promote a more homogeneous distribution of the solutes in the product (Figueroa et al., 2020). Vacuum impregnation is the application of a partial vacuum pressure to remove native liquid and gases trapped in seafood tissues, and subsequent impregnation with a solution in which the seafood is immersed when atmospheric pressure is restored (Tomac et al., 2020). The process can be also used in a pulsed way, called pulsed-vacuum impregnation (Martins et al., 2019). Advantages compared to injection marinating processes is that the seafood tissue itself remains untouched, reducing the chances of cross-contamination, thus increasing hygiene, while also decreasing the chance of damaged seafood products, thus retaining a high product quality.

According to the authors' knowledge, vacuum impregnation marinating is not applied at industrial level today. It remains in the research and development phase. In fact, studies regarding vacuum impregnation applied in fish products are uncommon (Figueroa et al., 2020; Martins et al., 2019; Tomac et al., 2020). To decrease the processing time and improve the diffusion of solutes in vacuum impregnation marinating, the combined application of other food processing technologies that may enhance mass transfer phenomena during subsequent marinating process may be applied, like laser micro perforation (Figueroa et al., 2020).

Based on the promising results obtained at research scale, it can be expected that further studies will be carried out and progress will be made towards the industrialisation of this technology in the seafood sector.

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Tomac et al. (2020) https://doi.org/10.1016/j.lwt.2019.108892

5 CONTROL OF WATER ACTIVITY, SALTING

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☐ CS 23 Common Cuttlefish

Types of salting systems

- Dry, pickle and brine salting
- Injection salting
- Vacuum impregnation salting

Dry, pickle and brine salting

Salting is one of the oldest ways of fish preservation (Boziaris, 2014). It is centred on the diffusion of salt into the fish muscle and the removal of water from the fish muscle, lowering water activity (Rui Costa, 2010). Due to the increased salt concentration in the fish muscle, protein denaturation and aggregation occurs, which affects the sensory and other quality properties of the food. Salting is traditionally performed either by dry (kench), pickle or brine salting (Rui Costa, 2010). In dry salting fish is stacked with alternating layers of dry salt and kept for several weeks (Boziaris, 2014). Nowadays, the fish is piled with alternating layers of salt into a plastic tub with a hole in the bottom for draining the liquid extracted from the fish. In pickle salting, the procedure is the same as for dry salting, but the liquid extracted while the salt is penetrating the fish muscle is not drained and the fillets are gradually immersed in saturated brine. However, the ratio of brine to fish is much lower than the ratios that are usually used in brine salting. Brine salting is performed by immersing fish directly into brine. Salting consists of using only one or a combination of these methods (Rui Costa, 2010). For example, brine salting is used as a pre-step of dry salting to reduce dry salting time (Boziaris, 2014). Dry (kench), pickle and brine salting are normally applied at low temperatures to avoid microbial grow, so its impact in terms of energy consumption and GHG emissions is lower than that of other fish post-harvest technologies used to control product water activity that need to heat the product.

In order to reduce waste and improve the global efficiency, different approaches for reusing of the brine are nowadays applied in the different companies (e.g., recirculation, UV decontamination, filtration, and others). Research has demonstrated that a pre-treatment of other processing technologies such pulsed electric field, ultrasounds, or laser micro perforation reduces the processing time and increase the salt concentration in the fish (Cropotova et al., 2021; Olivares et al., 2021). However, according to the authors' knowledge, these combined processes are not applied at industrial level today.

Conventional salting, especially dry salting, is a slow process. To decrease the processing time and improve the diffusion of salt, the combined application of other food processing technologies that may enhance mass transfer phenomena [64]during subsequent salting process may be applied, like pulsed electric fields, ultrasounds, or laser micro perforation (Cropotova et al., 2021; Olivares et al., 2021). It is expected that in the following years, some of these combined processes will be industrialised, supported by the development of the technologies on which these pre-treatments are based.

Injection salting

Over the last decades, salting by automatic brine injection into the fish flesh by multi-needle systems has become common practice (Boziaris, 2014). The process reduces the diffusion distance of the brine and, therefore, accelerate the salting and increase yield (Boziaris, 2014). As the brine is injected directly into the fish muscle, injection salting also reduces the amount of brine required compared to conventional brine salting (immersion). However, this salting method can increase risk of cross contamination with microorganisms and metal from the needles and, if brine is injected at high pressure, it can damage the fish muscle. Injection salting is normally used at low temperature to avoid microbial grow, so its impact in terms of energy consumption and GHG emissions is lower

[64] Mass transfer phenomena is the net movement of mass from one location, usually meaning stream, phase, fraction, or component, to another.

than for other fish post-harvest technologies used to control product water activity that need to heat the product.

Over the last decades, brine injection has been increasingly used to speed up salting, increase automation, homogenously distribute the salt within the seafood tissue and improve processing yields. Each technology supplier modified the settings used, such as needle types, needle density, injection speed and the pressure applied, to improve the process and adapt it to the seafood product and the industrial goals. From a research perspective, it has been demonstrated that a pre-treatment of other processing technologies such pulsed electric field, ultrasounds or laser micro perforation improve the salting process (Cropotova et al., 2021; Olivares et al., 2021). However, according to the authors' knowledge, these combined processes are not applied at industrial level today.

Vacuum impregnation salting

The application of vacuum impregnation during brining process could be used as a method to reduce processing time and promote a more homogeneous distribution of the salt in the product (Tomac et al., 2020). Vacuum impregnation is the application of a partial vacuum pressure that allows the removal of native liquid and gases trapped in food tissues, and the further impregnation with a solution in which food are immersed when atmospheric pressure is restored (Tomac et al., 2020). The process can be also used at in a pulsed way, called pulsed-vacuum impregnation (Martins et al., 2019). For example, the use of vacuum impregnation for mild salting of hake can reduce processing time by 75% (Tomac et al., 2020).

According to the authors' knowledge, vacuum impregnation salting is not applied at industrial level today. It remains in the research and development phase. In fact, studies regarding vacuum impregnation applied in fish products are not so common (Martins et al., 2019; Tomac et al., 2020).

Based on the promising results obtained at lab scale, it is expected that further studies will be carried out and progress will be made towards the industrialisation of this technology in the seafood sector.

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6 CONTROL OF WATER ACTIVITY, SMOKING

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☐ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel

☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
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☐ CS 15 Mussels
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☐ CS 17 Nephrops
☐ CS 18 Imported shrimp
☐ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☐ CS 23 Common Cuttlefish

Types of smoking systems

- Hot and cold smoking
- Liquid smoking
- Electrostatic smoking

Hot and cold smoking

Smoking is a preservation technique that also allows flavour and taste ingredients to be introduced into the fish muscle by exposing it to smoke (Boziaris, 2014; Venugopal, 2006). Nowadays, the main purpose of smoking is to enhance the sensory quality. In hot smoking the temperature is maintained above 30°C (normally between 70°C and 80°C) (Boziaris, 2014; Venugopal, 2006). In cold smoking, the temperature is maintained below 30°C (Venugopal, 2006). Compared to hot smoking, cold smoking is a slower process but increased retention of the original textural properties of the products (Boziaris, 2014). A combination of hot and cold smoking is also often used (Boziaris, 2014). Concerning the smoking equipment, the traditional technique consists of suspending the fish in smokers over slowly burning wood chips (normally hardwood). In mechanical smoking, the smoke is produced from smoke condensates (solid or liquid form). Then the smoke (gas form) is conducted to the smoking chamber/area, controlling the flow. Considering the environmental impact, hot and cold smoking implicates the slow burning of wood, directly or indirectly, so its impact on GHG emissions and other combustion substances could be high if the system is not well controlled. Furthermore, undesirable compounds (e.g., polycyclic aromatic hydrocarbons, PAHs) can be generated and pass to the fish products.

Hot and cold smoking have not changed much in the last 20 years. To reduce waste and improve the overall efficiency, different approaches are nowadays applied in the different technology suppliers trying to minimise the use of smoke and increase the smoking speed by better controlling the process variables. Both, technological suppliers, and processors, are also optimizing the smoking techniques to reduce the generation of undesirable compounds (e.g., PAHs). In the last decades, the replacement of these traditional systems by more modern and controllable ones (e.g., liquid smoking) is gradually taking place.

In any case, artisans and small smoked fish producers will probably continue to use traditional methods.

Liquid smoking

In liquid smoking, the fish product is introduced in a liquid in which smoke concentrate is dissolved (Boziaris, 2014; Nithin et al. 2020). The liquid concentrate transfers the aroma and flavour of smoke into the fish muscle. Liquid smoking extract is prepared by the dry distillation of wood. This extract is subsequently concentrated and dissolved in water or oil. Comparing to conventional hot and cold smoking, liquid smoking is faster, produces a more homogeneous smoking and reduce the risk of the presence of (known) toxic compounds deriving from combustion processes (e.g., polycyclic aromatic hydrocarbons, PAHs) (Boziaris, 2014; Nithin et al., 2020). In addition, liquid smoking has lower operation costs, less environmental pollution and is less time consuming than other smoking methods (Boziaris, 2014; Simon et al., 2005).

In the last decades, the traditional hot and cold smoking is being gradually substituted by liquid smoking (Simon et al., 2005). The use of liquid smoke (and smoke flavourings) in food industry is gaining importance due to its ease of use and because this technique avoids contaminating seafood products with PAHs, without compromising the flavour and preservative properties of smoke (Nithin et al., 2020). To improve the overall efficiency, different approaches are nowadays applied in the different companies trying to increase the smoking speed by better controlling the process variables. Different mixes have been developed by the suppliers, trying to give different flavours to the products. The production process of the liquid smoke has been also advanced, trying to minimise the presence of (known) toxic compounds.

Electrostatic smoking

Electrostatic smoking is an evolution of traditional hot and cold smoking based on electrostatic precipitation (Baron et al., 2008). In this process, fish are treated with smoke in an electrical field (Boziaris, 2014). The electricity is applied between the discharge electrode (corona effect) and the ground electrode (conveyor belt in case of continuous process) (Baron et al., 2008). The electrical field acts on the ionised smoke particles, accelerating the smoking process, thereby shortening the smoking period. Electrostatic smoking is fully mechanized. Therefore, it could lower labour and production costs compared to traditional hot and cold smoking while maintaining high-quality final products (Boziaris, 2014). The process scan be applied in continuous mode and can reduce the smoking operation time (Baron et al., 2008). Although the technology has been known since the 1950s, it is not 100% widespread at industrial level.

In the last decades, the traditional hot and cold smoking are being gradually substituted by other improved smoking techniques (Simon et al., 2005). To improve the overall efficiency, different approaches are nowadays applied in the different companies trying to minimise the use of smoke and increase the smoking speed by better controlling the process variables. Although the electrostatic smoking has been known since the 1950s, it is not widespread at industrial level. The electrostatic smoking process is a promising technology which should be investigated in more detail before full implementation by post-harvest chains (Baron et al., 2008). It can be expected that the evolution of the technology will follow will indeed focus on increasing process efficiency and product quality.

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7 PASTEURIZATION STERILIZATION CANNING, CONVENTIONAL TECHNOLOGIES

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of conventional technologies in pasteurization sterilization canning

- Microwave pasteurisation sterilisation
- Steam pasteuriser
- Steam and air retort
- Saturated steam retort
- Water immersion retort
- Water spray retort

The canning and sterilisation of seafood products is a traditional practice in the sector, which allows to manufacture products that are stable at room temperature and have a long shelf life (Hall, 1997). To apply the necessary sterilisation temperatures (around 121°C), different retort configurations are used in the sector (Venugopal, 2006). They are batch systems, but there are semicontinuous configurations that allow to improve the plant capacity and save time (Hall, 1997).

Microwave pasteurisation sterilisation

Microwaves can inactivate microorganisms, including spores, so it can be used for pasteurising or sterilising food (Viji et al., 2022; Xue et al., 2021). To apply this technology, it a heat transfer medium like water or air is not necessary. However, pasteurisation or sterilisation with microwaves lacks uniform heating (Viji et al., 2022) and proper temperature control (Li et al., 2020), so there are very few equipment using microwaves. In pasteurisation, and especially in sterilisation, very high temperatures must be reached in the product (>120°C) so the problems concerning lack of uniform heating are more relevant than for other applications. The preferential absorption of microwaves by liquid water is a major cause of overheating (Viji et al., 2022). In addition, microwaves cannot be used with metal packaging (Li et al., 2020). As the heat is generated inside the product, the technology has great potential compared to the traditional heating process, where the heat goes from the surface to the inside of the product. Thus, in general microwave processing is time saving, energy efficient and yields good quality fish products with high nutritional value (Viji et al., 2022).

In the last 20 years microwave technology has advanced extensively. Efforts to improve the temperature uniformity during microwave cooking has been made by optimising control of microwave conditions and using specific packaging materials that increase heating uniformity. However, the application of this technology for pasteurising or sterilising seafood products has a lot of room for improvement and, to the authors' knowledge, its industrial application is rare.

It is necessary to improve the uniformity of this method to become a mainstream technology. Single microwave heating has several disadvantageous such as development of hotspots and overheating at the edges of the product due to non-uniform temperature distribution (Viji et al., 2022). A combination of microwave heating and conventional heating or other emerging technologies has vast potential to alleviate these drawbacks (Viji et al., 2022). The lack of knowledge on the actual temperature profile during microwave sterilization is major challenge for the commercial application of this technique (Viji et al., 2022). This hiatus in knowledge necessitates focused research towards a reliable and real time record of temperature distribution in food products (Viji et al., 2022). Additionally, as dielectric properties of seafood products vary with its composition, a specific microwave frequency must be chosen for each individual product for better results (Viji et al., 2022). Development of packaging materials also needs special attention as packaging can help to enhance uniform penetration and heat generation within the product (Viji et al., 2022).

Steam pasteuriser

The use of steam is currently a standard in fish post-harvest chains for pasteurising seafood products. The systems are like the ones used for cooking. The main difference is that the product is packed, normally in glass pots or plastic pouches. These systems combine steam and force air to improve the heat transfer and reduce processing time. Steam has a higher thermal conductivity than hot air used in conventional ovens, so it has the potential for a rapid heating with minimal side effects (Orlando et al., 2020; Venugopal, 2006). Both batch (cabinets) and continuous systems are used in the food industry. Continuous ovens can be linear or spiral, depending on the process, the seafood product itself and the needed capacity of production.

Although the technology is well optimised in general and many improvements have been made during last 20 years, it can be expected that more optimisation efforts from technology providing companies, especially regarding the control of the process and the energy consumption (optimisation of capacity (more amount of product treated with similar energy consumption), improved insulation, and others). Furthermore, the advances made in other heating technologies, like microwaves or ohmic heating, could also be implemented as a combined process to reduce energy loss.

Steam and air retort

The steam and air retort are an overpressure process, like water immersion or water spray retorts. Overpressure is reached by pressurised air that enters the retort with the steam (Allpax). To prevent cold areas in the autoclave and improve the efficiency of the process, fan systems are used to mix the steam with the air (Allpax). The fan is used in conjunction with a baffle inside of the retort to conduct the heated steam-air mix to the retort centre (Allpax). It can be used with rotating configurations for maximised efficiency (heat distribution, processing time. Because it is an overpressure process, the machine can handle more fragile containers (Venugopal, 2006). This technology consumes similar amounts of energy and produces similar GHG emissions compared to conventional saturated steam retorts. Compared to the rest of conventional retorting technologies, this configuration consumes the lowest amount of water (Hall, 1997), except when water tanks are used for water immersion and water spray retorts.

The technology is optimised in general and not too many improvements are expected in the following years. In any case, it is expected more optimisation effort from technological companies, especially regarding the control of the process and the energy consumptions (optimisation of capacity (more amount of product treated with similar energy consumption), best insulation, etc.).

Saturated steam retort

The canning and sterilisation of seafood products is a traditional practice in the seafood post-harvest chains, which allows the manufacturing of products that are stable at room temperature and have a long shelf life (Hall, 1997). To apply the necessary sterilisation temperatures (around 121°C), different retort (autoclave) configurations are used in the sector. There are batch systems, but there are also semi-continuous configurations that improves the plant’s capacity and save time (Hall, 1997). Retorts are normally based on the utilisation of steam (Hall, 1997). The simplest and oldest one is the saturated steam retort. During sterilisation it employs direct steam heating at atmospheric pressure, thus there is no overpressure (Allpax). However, there may be air-overpressure applied during the cooling steps to prevent container deformation. Its main advantage is the low capital investment (Allpax). However, it employs a lot of steam and uses a lot of energy, so the technology is not that efficient (Allpax). Furthermore, this method normally only can process traditional cans instead of pouches or plastic bottles, which are more fragile (Venugopal, 2006).

The technology is optimised in general and not many improvements are expected in the following years. Some of their limitations (high energy and steam consumption) seem impossible to overcome because they are an inherent part of this technology. In any case, it can be expected that more optimisation efforts from technology providing companies, especially regarding the control of the process and the energy consumptions (optimisation of capacity (more amount of product treated with similar energy consumption), improved insulation, and others). In the next 20 years it can be expected that the use of these kind of retorts will decrease. The current units will gradually be replaced by other more efficient retorts (see other tech sheets).

Water immersion retort

The canning and sterilisation of seafood products is a traditional practice in the sector, which allows to manufacture products that are stable at room temperature and have a long shelf life (Hall, 1997). To apply the necessary sterilisation temperatures (around 121°C), different retort configurations are used in the sector (Venugopal, 2006). There are batch systems, but there are semi-continuous configurations that improve the plant’s capacity and save time (Hall, 1997). In water immersion retorts, the products are submerged in water and treated at above atmospheric pressure (Allpax). Overpressure is created by introducing air, steam, or a mix on top of the water (Allpax). The heated air agitates the water as it flows to the surface and serves to pressurize the processed load. It can be used with rotating configurations to maximise the efficiency (heat distribution, processing time). Because it is an overpressure process, the machine can handle more fragile containers (Venugopal, 2006). From an energetic perspective, the simple models consume more energy and produce more GHG emissions than conventional saturated steam restoring.

To reduce the energy consumption and GHG emissions, and improve process efficiency, water immersion retorts can include a storage tank for water. The captured process water after sterilization is hot and can be used for the next cycle. This increases the machines price, but it also drastically reduces the needed energy and, therefore, the processing cost.

The technology is optimised in general and not many improvements are expected in the following years. In any case, it can be expected more optimisation efforts from technology providing companies, especially regarding the control of the process and the energy consumptions (optimisation of capacity (more amount of product treated with similar energy consumption), improved insulation, and others). In the next 20 years it can be expected that the use of these kinds of retorts will decrease. The current units will gradually be replaced by other more efficient retorts.

Water spray retort

The canning and sterilisation of seafood products is a traditional practice in the sector, which allows to manufacture products that are stable at room temperature and have a long shelf life (Hall, 1997). To apply the necessary sterilisation temperatures (around 121°C), different retort configurations are used in the sector (Venugopal, 2006). There are batch systems, but there are also semi-continuous configurations that improves the plant’s capacity and saves time (Hall, 1997). The key difference between water spray retort and the conventional saturated steam retort is that the first one employs overpressure, generated by introducing air or steam into the vessel during sterilization (Allpax). To overcome the insulating effects of the air, spray nozzles introduce the steam and mix it with the air (Allpax), and it can be used with rotating configurations to maximise the efficiency (heat distribution, processing time). Because it is an overpressure process, the machine can handle more fragile containers (Venugopal, 2006). This technology consumes a similar amount of energy and produces similar GHG emissions compared to conventional saturated steam restoring.

Like water immersion retorts, the water spray version can also include a storage tank for the water. The captured processed water after sterilization is hot and can be used for the next cycle. Specifically, to reduce the energy consumption and GHG emissions, and improve process efficiency, water spray retorts can use a heat exchanger and a pump to recirculate both sterilizing water and cooling water during the process. It is included in most of the marketed options. This increases the machine price, but it also drastically reduces the needed energy and, therefore, the processing cost.

Suppliers have made efforts to improve the performance of the steam pasteurisers. For example, improving the control of the air flow (vertical air flow, reversible up or down airflow), hygienic design, cleaning (including Clean in Place (CIP) sanitation systems), temperature control (sensors, software for control applications), humidity control, vapour injection (nozzles), insulation materials, and others. All these improvements are focused on reducing processing time and/or reducing processing costs and, indirectly, reducing energy consumption (normally electrical energy).

The technology is optimised in general and not many improvements are expected in the following years. In any case, it can be expected that more optimisation efforts from technology providing companies will be made, especially regarding the control of the process and the energy consumptions (optimisation of capacity (more amount of product treated with similar energy consumption), improved insulation, and others).

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8 PASTEURIZATION STERILIZATION CANNING, EMERGING TECHNOLOGIES

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
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☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of emerging technologies in pasteurization sterilization canning

- Microwave assisted thermal sterilization
- Pressure assisted thermal processing
- Cold plasma decontamination

- High hydrostatic pressure pasteurisation
- Pulsed light decontamination
- Ultrasound assisted pasteurisation
- Ultraviolet decontamination

Microwave assisted thermal sterilization

Microwaves can inactivate microorganisms, including spores, so this technology can be used for sterilising food (Viji et al., 2022). However, microwave-based methods lack uniform heating (Viji et al., 2022) and proper temperature control (Li et al., 2020). To avoid these bottlenecks, the use of microwave assisted thermal sterilization (MATS) has been proposed (Barbosa-Cánovas et al., 2014). It is based on the use of water as a heating medium in combination with direct exposure of the food to microwaves (Barbosa-Cánovas et al., 2014). By using water as an intermediate step to heat foods, some of the drawbacks of the technology, such as non-uniform heating and edge effects (overheating surfaces), can be minimised (Barbosa-Cánovas et al., 2014). These systems consist of four parts, including preheating, microwave heating, heat holding, and cooling (Barbosa-Cánovas et al., 2014). They can operate as batch and continuous systems, reducing processing times from 1/4 to up to 1/10 of time required for conventional thermal methods (Barbosa-Cánovas et al., 2014). Some of the advantages of this innovative technology in contrast to conventional sterilization (retorting) include higher production rates and less operational costs (Barbosa-Cánovas et al., 2014). Using microwaves for heating (electricity; heat generated inside the product and water), MATS has potential to reduce the environmental impact of sterilization and diminish GHG emissions.

In the last 20 years microwave technology has advanced a lot. Improvements on the temperature uniformity during microwave treatment have been made, optimising control of microwave conditions and using specific packaging materials that increase heating uniformity. In parallel, MATS has proven to be successful on pilot scale (Barbosa-Cánovas et al., 2014). The MATS system is currently being commercialized and was installed in two US companies in 2014 (Barbosa-Cánovas et al., 2014). The authors have found no further information on its industrialisation. It is not known if there are more companies applying it today (2022) and if there are any in Europe.

Although MATS is already industrialized (Barbosa-Cánovas et al., 2014), to the authors' knowledge MATS is not currently a mainstream technology for sterilization. Despite all the research carried out to study the potential of MATS and achieve industrialization (Barbosa-Cánovas et al., 2014), further economic and environmental studies are needed to elucidate whether the treatment is economically cost-effective and environmentally positive. If these studies would show positive results, probably more companies will incorporate this promising technology in next years. In any case, lacking knowledge of the actual temperature profiles during microwave sterilization is a major bottleneck in the commercial application of this technology (Viji et al., 2022). This hiatus in knowledge necessitates focused research towards a reliable and real time record of temperature distribution in food products (Viji et al., 2022). Additionally, as dielectric properties of fish products vary with its composition, a specific microwave frequency must be chosen for each product for better results (Viji et al., 2022). Development of packaging materials also needs special attention to enhance uniform penetration and heat generation within the product (Viji et al., 2022).

Pressure assisted thermal processing

Pressure assisted thermal processing (PATP) involves the application of high pressures (up to 600 MPa) combined with mid-high temperatures (typically 60-12°C). It has received special attention in the last years as an alternative to conventional thermal treatments, mainly for microbial sterilization, cooking, modification of physical properties, enzyme inactivation and allergenicity reduction in different food matrices (Puértolas et al., 2022; Svenich et al., 2015). Although this technology shows promise, research into seafood specific applications is scarce (Puértolas et al., 2022). The process is based in the combined effect of pressure and temperature on the food properties and microorganisms (Svenich et al., 2015). The adiabatic heating, that is the increment of the temperature (up to 25°C) due to the increase of the pressure, is crucial for the reduction of the heating cost (Svenich et al., 2015). Even though with adiabatic heating as part of the process, it is currently not clear whether economically and environmentally PATP is a better solution than classical heat treatments.

The industrial application of high-pressure processing at low temperatures is nowadays a reality (Puértolas & Lavilla, 2020). However, its combination with mild-high temperatures, PATP, is not fully industrialised. In the last decades, much research was conducted to understand the potential of PATP (Svenich et al., 2015). One of the key disadvantageous is the non-uniform temperature distribution in the treatment chamber, which can vary for industrial units in range of ~10°C between the bottom and the top of a horizontal industrial scale high pressure system (Svenich et al., 2015). Some PATP units that combine pressure with mid-range temperatures (40-50°C) for mid cooking/tempering are already installed in some food companies. However, increasing the temperature increases the temperature distribution problems, especially in pasteurising and sterilising applications.

A technology such as PATP needs to be optimized to guarantee an economically viable method for the food industry (Svenich et al., 2015). This signifies that, the process line needs to be fine-tuned in terms of output, the heat up time of the vessel needs to be shortened, optimized intensifiers for quicker pressure build up, and tools need to be developed to guarantee safe and constant temperature-pressure distribution in the packed food (Svenich et al., 2015). Given the state of technology in 2022, it is difficult to know whether the application of PATP will be fully applied in the seafood sector in the next 20 years.

Cold plasma decontamination

Cold plasma decontamination is an emerging non-thermal technology that has been proposed for decontamination of food surfaces and food contact surfaces. Excitation of any gas (combined or individual) with an external source of energy exceeding the ionisation potential of the gas will change its state to the ionised form called plasma (Olatunde et al., 2021). During this process, various species such as negative and positive ions, radicals, neutral and excited molecules, electrons, and quanta of electromagnetic radiation (e.g., visible, and ultraviolet light) are produced, provoking the inactivation of the microorganisms that are present in the treated surfaces. As this technology uses electricity, it has been noted that it could have a positive potential from an environmental perspective (Olatunde et al., 2021).

To the authors' knowledge, this technology is not currently industrialised for the food sector in general and for fish post-harvest chains. During last 20 years it has been proven (on research scale) that cold plasma is a non-thermal decontamination process that can inactivate microorganisms in seafood.

Further research and development efforts at laboratory and pilot scale are expected in the coming years to try to optimise treatments and overcome the disadvantages/problems of this technology.

High hydrostatic pressure pasteurisation

High hydrostatic pressure (HHP; also called high pressure processing) is an emerging food processing technology that basically consists of pressurising foods up to 800 MPa (normal industrial devices up to 600-650 MPa) up to several minutes (Puértolas & Lavilla, 2020). It is considered as a non-thermal process because the treatment temperature could be maintained below room temperature, avoiding heat mediated modifications of food properties and improving food quality with respect to conventional thermal pasteurisation (Puértolas & Lavilla, 2020).

HHP is considered more expensive than thermal pasteurisation but turns out to have a lower environmental impact in almost all impact categories (Cacace et al., 2020). A possible explanation for this outcome is that while HHP makes use of more electricity than thermal processing, the latter makes use of steam, as a direct or indirect heating media, leading to significant energy inefficiencies in some cases (Cacace et al., 2020; Pardo & Zufia, 2012).

Although the main obstacle to become widespread may still be the perceived cost for the food industry regarding the use of emerging and novel technologies, investment in HPP usually lead to valuable innovations and launching profitable new products, as is reflected by the growing market of pressure-treated foods and the increasing number of companies that have successfully implemented HPP in the food sector from the last decade (Puértolas & Lavilla, 2020). Tolling services [65]for this technology are also growing, which allow producers an easier access to industrial equipment, without the need of high investments (Puértolas & Lavilla, 2020). Consequently, this technology is becoming a mainstream process in food industry, and seafood sector is not different to this trend.

Although HHP is currently a standard technology in some food sectors, like juices or meat products, its application in seafood post-harvest chains for pasteurising is relatively rare. The increase of research for optimising the processes for each specific product, and the expected reduction of industrial units' cost, could help in the following years to increase the number of industrial applications. From a technical perspective, some improvements are expected in the next 20 years, like reducing the energy consumption of the industrial sector.

Pulsed light decontamination

Pulsed light is an emerging technology that can be used to decontaminate surfaces by generating high-energy light pulses of short duration of a broad and intense spectrum (200-1100 nm). (Pedrós-Garrido et al., 2018). The antimicrobial effect has been attributed to DNA damage (due to the ultraviolet light emitted), although other structural damage to cell walls, membranes and intracellular structures may also be involved. (Pedrós-Garrido et al., 2018). As this technology uses electricity, it has been noted to have benefits from

[65] Tolling services are often defined as a simple arrangement, where one company processes raw material or near-finished goods for another in return for a "toll" or fee

an environmental perspective (Pedrós-Garrido et al., 2018), especially if the energy source to generate the electricity is environmentally friendly.

From an electrical and engineering point of view, pulsed light is more complex than ultraviolet technology. Because the caused effects are similar, ultraviolet light has received more interest from the industry than pulsed light. To the authors' knowledge, although there are industrial solutions for surface decontamination of packaging by pulsed light in other sectors (dairy, drinks), there are currently no companies in the seafood post-harvest chain applying this technology. As cold plasma or ultraviolet light, pulsed light can trigger or accelerate oxidation reactions (e.g., lipid oxidation) and causes negative effects on food quality, which has limited its development and industrialisation (Mahendran et al., 2019).

Further research and development efforts at laboratory and pilot scale are expected in the coming years to try to optimise treatments and overcome the disadvantages/problems of this technology for the treatment of seafood products. It is still necessary to evaluate the appropriate treatment conditions (number of pulses, etc.) to improve efficiency and minimise the occurrence of negative effects that reduce the quality of the product (Mahendran et al., 2019). Given the state of technology in 2022, it is difficult to know whether the application of pulsed light will be applied in the seafood sector in the next 20 years.

Ultrasound assisted pasteurisation

Ultrasound assisted pasteurisation involves the application of ultrasounds during water immersion heating, accelerating the heat and mass transfer [66]and, therefore, reducing processing times (Bhargava et al., 2021; Cichoski et al., 2015). It also reduces the loss of nutrients, development of off-flavours and deterioration of functional properties of foods that take place in thermal processing (Bhargava et al., 2021). The rate of the Maillard reaction is also increased compared to traditional water immersion heating (Siewe et al., 2020). The physical effect caused by ultrasounds can convert sound energy into heat energy and improves the rate of heat transfer (Bhargava et al., 2021). Processing conditions must be optimised because high-power single-frequency ultrasounds may damage food muscle structure (Bian et al., 2022). It is worth noting that ultrasonic waves have the disadvantages of high-power consumption in practical applications (Bian et al., 2022). For pasteurisation applications, the seafood products must be packaged to avoiding cross-contamination.

The application of ultrasound for fish pasteurisation is an emerging technology that has been scarcely studied during the last 20 years and, to the author’s knowledge, remains on research or pilot scale. Thus, its full industrialisation has not be completed.

After the studies highlighting the potential of ultrasound-assisted heating, more research is needed to reduce the power consumption and the instability of ultrasound systems (Bian et al., 2022). Furthermore, different food materials have different inherent characteristics, and the ultrasound parameters of different food products should also be optimised to enhance the process as well as better preserve the food properties (Bhargava et al., 2021). Finally, ultrasound should be treated cautiously, because it may be harmful to human health (adverse tissue injury, electrical shock, and burns and indirect damage) (Bhargava et al., 2021).

[66] Mass transfer is the net movement of mass from one location, usually meaning stream, phase, fraction, or component, to another

The potential use of ultrasound at industrial scale is relatively simple because conventional equipment used in the industry can be adapted (Cichoski et al., 2015). Among others, it is necessary to elucidate if the energy cost of ultrasound assisted pasteurisation is lower than the conventional thermal processes. Furthermore, the technology has potential for continuous processing and scale up designs (Cichoski et al., 2015). Because no information is available about the possible generation of toxic substances after ultrasound processing, further investigations must be carried out before implementing industrial scale-up (Cichoski et al., 2015).

Ultraviolet decontamination

Ultraviolet light (specifically Ultraviolet C) is an emerging non-thermal technology that has been proposed for decontamination of food surfaces and food contact surfaces (Pedrós-Garrido et al., 2018). Ultraviolet light C doses of up to 0.79 J/cm^2 improved the safety and extended the shelf life of refrigerated fish up to six days (Monteiro et al., 2021). The process is based on the emission of radiation within the ultraviolet spectrum (100-400 nm), more specifically the UV-C spectrum (200-280 nm), which has proven effective in inactivating microorganisms (Pedrós-Garrido et al., 2018). The antimicrobial effect is mainly due to the formation of DNA photoproducts (such as pyrimidine dimers) that inhibit transcription and replication and can lead to cell death (Pedrós-Garrido et al., 2018). As this technology uses electricity, it has been noted to have potential positive environmental impacts (Pedrós-Garrido et al., 2018), especially when the energy sources to generate the electricity are environmentally friendly.

From an electrical and engineering point of view, ultraviolet based technology is well known and relatively easy to produce cost-effectively. As a result, this technology has received more interest from the food industry than other non-thermal decontamination technologies such as cold plasma or pulsed light. In fact, there are some applications of ultraviolet light in seafood processing, specifically for the decontamination of surfaces in contact with foods, like conveyor belts or packaging. In seafood products itself, ultraviolet light can trigger or accelerate oxidation reactions (e.g., lipid oxidation), which has limited its development and industrialisation (Monteiro et al., 2021).

Further research and development efforts at laboratory and pilot scale are expected in the coming years to try to optimise treatments and overcome the disadvantages/problems of this technology for the treatment of seafood. Further studies are needed to optimise the process, as ultraviolet light can cause unwanted changes in the food (Monteiro et al., 2021). For example, a combination with free radical scavenger agents could mitigate the oxidative degradation and makes this application for fish tissues feasible (Monteiro et al., 2021). Given the state of technology in 2022, it is difficult to know whether the application of ultraviolet light directly in seafood will be done on an industrial scale in the next 20 years.

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9 COOKING AND FRYING, CONVENTIONAL TECHNOLOGIES

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☐ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☐ CS 25 Improved technology for GHG reductio

Types of conventional technologies in cooking and frying

- Conventional frying- oil immersion
- Air frying
- Grilling
- Water immersion cooking
- Steam oven-cooker
- Replacing water boilers with steam boilers
- Sous vide cooking

Conventional frying- oil immersion

Frying is a conventional technology used in seafood processing companies, the HORECA sector and in households. Traditional frying (oil immersion) or deep fat frying is a complex process during which foods are cooked, lose water, and absorb oil/fat (Fang et al., 2021). The high heat of frying, usually 180-200°C, generates distinct aromas called flavour, that gives fried food a rich taste and flavour (Fang et al., 2021; Venugopal, 2006). Usually bleached and refined vegetable oils are used for frying (Venugopal, 2006). Frying is most frequently used in coated products (Venugopal, 2006).

Traditional frying (oil immersion) has not change much in the last 20 years, even at industrial level. Essentially it is the same process. In any case, industrial units and household appliances have undergone some technological improvements to increase the process efficiency (e.g., improving oil heating technology efficiency, better controlling of oil temperature, reducing the use of oil, including technologies for cleaning, and reusing the oil, reducing heat losses improving insulation materials of the kettles). Over the last 20 years, conventional frying systems have gradually started to be replaced by new frying technologies, such as air frying, trying to reduce the use of oil mainly for health reasons (improving food quality), rather than to reduce food waste (oil waste). For some of them (e.g., air frying) there are both, industrial and household scale units.

Conventional frying by oil immersion has been optimised over the last 20 years and there is little room for technological improvement. However, the process still has important key challenges, especially waste generation (an important disadvantage related to other frying alternatives) (Fang et al., 2021). Several new techniques such air frying, electrostatic frying and vacuum frying have been designed that use low quantities of oil/fat while retaining the good flavour and texture which would be obtained with traditional deep-fat frying (Fang et al., 2021). It can be expected that these systems be progressively replace conventional frying equipment.

Air frying

Frying is a conventional technology used in fish companies, the HORECA sector and in households. It is a complex process during which foods are cooked, lose water, and absorb oil/fat (Fang et al., 2021). Air frying is an alternative technique to dehydrate food products with hot air and oil droplets in the frying chamber, typically achieving fried food with a crust and very low-fat contents (Fang et al., 2021; Yu et al., 2020). Air frying uses hot air circulation instead of hot surfaces, offering shorter processing times comparing to the conventional air drying, but a longer frying time than conventional frying (Fan et al., 2007; Fang et al., 2021). Air-frying imparts similar characteristics of traditional fried product, with a substantially lower level of absorbed fat in the product. The products resulting from this technique not only exerts great benefits to consumers health, but also has environmental advantages, such as lowering oil consumption and achieving the zero effluent discharge (Yu et al., 2020).

Air frying is starting to be applied more and more during the last 20 years, aiming at reducing the use of oil mainly for health reasons (improving food quality) rather than to reduce food waste (oil waste). Currently, there are both industrial and HORECA/household scale units.

Air frying still has room for optimisation (e.g., improving heating technology efficiency, better controlling of temperatures, even further reducing the use of oil, reducing heat losses by improving insulation materials of the kettles). It can be expected that these systems will be progressively more efficient, being a standard frying technique. Although the improvements over conventional frying is well established, it is necessary to compare it with alternative frying technologies (e.g., vacuum frying) to determine which is best suited per individual application and food product.

Grilling

Grilling or broiling is a common process in the food industry, the HORECA sector and in households, and involves the application of dry heat to the surface of food, commonly from above or below, cooking the food and generating a caramelisation process in the surface (grill marks are attractive for the consumer) (Venugopal, 2006). In a roasting or grilling operation high temperatures are needed. Conductive and convective heat transfer are mainly used (Matsuda et al., 2013). Conventionally, industrial and HORECA systems are based on an electric resistance or gas heaters. In household, the traditional grillers involve the use of charcoal briquettes and lumps (Jelonek et al., 2020), because it gives to the food special sensory properties that are difficult to imitate with other heat sources. This system could be a specific operation or could be part of a more complex process. Therefore, different grilling units specific for either industrial or household use can be found. In addition, a grilling function can be found integrated in another device (e.g., household (microwave) oven). Colour changes during grilling involve four steps: protein denaturation, water evaporation, a caramelisation reaction (browning), and a carbonization reaction (Yu et al., 2014). To get a high-quality grilled product, it is important to optimize the temperature parameters during the grilling process (Venugopal, 2006).

Trends in technological evolution of grilling

At industrial level, each supplier has made efforts for improving the performance of grillers. For example, improving the control of the air flow (vertical air flow, reversible up or down airflow), hygienic deign, cleaning (including Clean in Place (CIP) sanitation systems), temperature control (sensors, software control applications), humidity control, insulation materials, and others. All these improvements are focused on reducing the processing time and/or reducing the processing cost and, indirectly, reducing energy consumption (normally electric energy). In the last 20 years, the use of infrared lamps has been also implemented in industrial and HORECA grillers to improve the process efficiency.

Even though many studies have been conducted to assess air pollution and human health risks arising from exposure to charcoal-based grilling, limited standards and policies have been implemented internationally to assure grilling fuel quality (Jelonek et al., 2020). While charcoal briquettes and lumps are a popular fuel choice for grilling, almost no data specifying their ingredients and properties are available to consumers (Jelonek et al., 2020). Also, very few studies have been conducted to understand how the properties of raw fuels affects the quality of fuel gases and, subsequently, human safety and the environment (Jelonek et al., 2020).

Future of grilling

At industrial level, although the technology is in general well optimised and a lot of improvements have been made during last 20 years, it can be expected that more optimisation efforts from technology providing companies will be made, especially regarding the control of the process and the energy consumptions (optimisation of capacity (more amount of product treated with similar energy consumption), increased insulation, and others). Furthermore, the advances made in other heating technologies, like microwaves or ohmic heating, could be also related to the implementation of combined processes to reduce energy loss.

The use of charcoal briquettes and lump charcoal in domestic barbecues is common practice, as it gives food special sensory properties that are difficult to imitate with other heat sources. This system produces important GHG emissions and substances that negatively impact human health (e.g., PAHs). The development of solid fuels with the lowest GHG emission and reduced amounts of harmful substances could mitigate these problems, but not solve it. Thus, it can be expected that over the next 20 years this practice will become more limited, supported by European awareness of climate change and by the development of new appliances that allow similar results using heat sources that potentially have a lower environmental impact.

Water immersion cooking

Cooking/boiling in water is the conventional practice in the seafood post-harvest chains, especially when production flow and/or the added value of the product are low, meaning that the production cost must be as low as possible. Furthermore, it is a traditional culinary practice for many products. The process involves the immersion of the product in heated water (up to 100°C) to cook it (Feng et al., 2017; Venugopal, 2006). The water is continuously heated during the process to maintain the temperature of the system. The product can be cooked packaged or unpackaged. At industrial level, the process is happening in batch or in continuous boilers, the latter using conveyor belts. Conventional water-immersion technologies have disadvantages of long processing times, potential of cross-contamination (reduced hygiene), prolonged exposure of the external surfaces to warm temperatures, use of large amounts of water, and generation of the possible large amounts of wastewater (Venugopal, 2006). In addition, energy cost can be high when having to bring large volumes of water to the boiling point and maintaining those high temperatures. Despite the problems, it is still under use due to their simplicity, its low cost and high capacity (Venugopal, 2006).

Traditional water immersion cooking/boiling is essentially the same process over the last decades and even before. In any case, at industrial level some technological improvements have been made to increase the efficiency of the processes (e.g., improving water heating technology efficiency, better controlling of water temperature, reducing the use of water, including technologies for cleaning, and reusing the water, reducing heat losses by improving insulation materials of the kettles). During the last 20 years, older boiling systems are being replacing by convection ovens/cookers that use vapour and forced hot air flows.

It can be expected that traditional boiling systems will be progressively replaced by convection ovens/cookers that use vapour and forced hot air flows. The water immersion cooking/boiling has been optimised over the last 20 years and there is currently little room for technological improvement. However, the process still has important key points to resolve, especially the generation of wastewater (an important handicap related to other heating alternatives).

Steam oven-cooker

Steam or steam-air oven-cookers are currently a standard for cooking seafood products. They combine steam and force hot air flows to improve the heat transfer and reduce processing time. Steam has a higher thermal conductivity than hot air used in conventional ovens with the potential to induce rapid heating with minimal side effects (Orlando et al., 2020; Venugopal, 2006). In post-harvest chains both batch and continuous systems can be found. Continuous ovens can be linear or spiral, depending on the process, the seafood product, and the needed capacity of production. Small units for HORECA and households are also available on the market.

At industrial level, each supplier has made efforts to improving the performance of the ovens and cookers. For example, improving the control of the air flow (vertical air flow, reversible up or down airflow), hygienic deign, cleaning (including Clean in Place (CIP) sanitation system), temperature control (sensors, controlling software), humidity control, vapour injection (nozzles), insulation materials. All these improvements are focused on reducing processing time and/or reducing the processing cost, and indirectly reducing the energy consumption (normally electric energy). During last 20 years, some developments on HORECA and households' devices have been made (Orlando et al., 2020). Currently, these systems are relatively common in the HORECA sector, but they are not a standard in household because they are relatively expensive.

At industrial level, although the technology is well optimised in general and a lot of improvements have been made during last 20 years, it can be expected that more optimisation efforts from technology providing companies will be made, especially regarding the control of the process and the energy consumptions (optimisation of capacity (more amount of product treated with similar energy consumption), best insulation, and others). Furthermore, the advance made in other heating technologies, such as microwaves or ohmic heating, could improve the implementation of combined processes to reduce energy losses. Regarding small units for HORECA and households, it can be expected that the evolution made at industrial level during the last 20 years will be reflected step by step in future units.

Replacing water boilers with steam boilers

This considers a cleaner production strategy based on the use of steam oven-cookers instead of water boilers (water immersion) to improve the efficiency of the process, by reducing water and energy consumption (Thrane et al., 2009).

Replacing conventional water heater boilers with steam oven-cookers started in the 1990s (Thrane et al., 2009) and currently is a standard in many operations in the fish sector. This strategy is very common in companies when they want to implement a more sustainable production strategy. These initiatives must be viewed considering a general commitment to continuously develop products and improve the efficiency of processes. Important to note is that the total financial and time investments were significant (Thrane et al., 2009).

Although steam boilers already exist for a long time, there are a lot of small and/or traditional companies in Europe that are still using conventional water boiling, especially in the canning industry. Thus, it can be expected that this strategy will be incrementally applied in the following years by the companies that have not already done so.

Sous vide cooking

Sous-vide cooking has gained popularity because of its mild cooking conditions on meat and fish preparations. It is applied in the HORECA sector or in households. Sous-vide is a French term meaning "under vacuum". Thus, the fish is packed in heat-stable vacuumized pouches and then cooked in water using low temperatures (60-95°C) for up to 48 h (Ismail et al., 2022; Redfern et al., 2021). The use of vacuum sealing in sous-vide provides a very efficient and consistent transfer of heat from water to food products and increases the shelf life of products due to the absence of oxygen in the vacuum sealed pouch. The sous-vide process improves the preservation of natural sensory and nutritional characteristics of fish due to the low temperatures used in comparison with conventional water immersion cooking/boiling.

Although the process needs lower temperatures than conventional boiling, but because processing times are higher (hours) the energy consumption could be higher (depending on the process) compared to conventional boiling and cooking.

Sous-vide cooking technique has not change much in the last 20 years. However, because its use has increased over time in the HORECA sector, especially in restaurants, specific sous-vide units appeared in the market to optimise the temperature control.

The potential for improvement of this process in the next 20 years is relatively low. However, it can be expected that an increase in use in the HORECA sector but also at in households will be observed. In parallel, an improvement of sous-vide devices can be expected, especially in terms of better insulation materials of the kettles and more efficient heating elements to reduce energy consumption (conventional kettles are normally used).

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10 COOKING AND FRYING, EMERGING TECHNOLOGIES

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☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☐ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna

☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of emerging technologies in cooking and frying

- Electrostatic frying
- Vacuum frying
- Microwave oven
- Ohmic heating
- Ultrasound assisted cooking

Electrostatic frying

Frying is a conventional technology used in seafood processing companies, the HORECA sector and in households. Traditional frying (oil immersion) or deep fat frying is a complex process during which foods are cooked, lose water, and absorb oil/fat (Fang et al., 2021). Electrostatic frying uses a discharge plate equipped in the bottom. This technology is commercialised by a Japanese company (Denba, Tokyo, Japan) but their basic principles are not well explained (Fang et al., 2021). In theory, it reduces frying time, acrylamide levels and oil uptake compared to traditional fryer (Fang et al., 2021).

Electrostatic frying is a new technology that began to be marketed by a Japanese company (Denba, Tokyo, Japan), mainly for the HORECA. However, the advantage of this technology is under study. For example, Fang et al (2021) did not see any difference between traditional frying and electrostatic frying. It is not known whether it is being applied by any company.

More studies will be necessary in the next 20 years to understand the process and determine their advantages/disadvantages with respect to conventional frying and alternative frying technologies (e.g., air frying). If there are no clear advantages with respect to air frying or vacuum frying, this technology will probably not be used beyond research applications or only in specific environments (e.g., commercial application for households).

Vacuum frying

Vacuum frying is defined as frying under pressures below atmospheric levels, preferably below 6.65 kPa (Andrés-Bello et al., 2010). Due to the low pressure, the boiling point of the water in the food product is lowered. This reduces the processing temperature and the Miallard reaction or browning reaction during processing (Andrés-Bello et al., 2010; Fang et al., 2021). Thus, vacuum frying offers some advantages, including the reduction of the oil content in the fried product, and the preservation of natural colour and flavours of the products (Andrés-Bello et al., 2010). In addition, as the adverse effects on oil quality is reduced (Andrés-Bello et al., 2010), the same amount of oil can be used during multiple treatment cycles, and thus the generation waste oil is potentially lower than in conventional frying (oil immersion at atmospheric pressure). To the authors' knowledge, vacuum frying is not applied at industrial level, or it is applied only in several very specific cases. However, it is a technique that it is used in the HORECA, especially in "haute cuisine" restaurants, using household appliances designed for vacuum impregnation, like Gastrovac® (Andrés-Bello et al., 2010).

During the last 20 years, studies on vacuum-fried products have been focussed on fruits and vegetables, while the use on fish products has not been well analysed (Andrés-Bello et al., 2010).

It can be expected that in the next 20 years the use of vacuum frying will be studied in more detail and as a result may be used more on industrial scales. Although the improvements over conventional frying is well established, it is necessary to compare it with alternative frying technologies (e.g., air frying) to determine which is technology is best for each specific situation.

Microwave oven

Microwave cooking has been successfully applied at home, in restaurants and industry for 50 years. Industrially, microwave heating is a common practice in the food sector as a pre-operating step in many cooking processes (Viji et al., 2022). The unique property of microwaves to penetrate and produce heat in the interior of food materials (volumetric heating) allows to accelerate cooking (Viji et al., 2022). It is not necessary to use a heat transfer medium like water or air. This is an important advantage with respect to conventional air and steam ovens. At industrial scale, there are both batch and continuous (tunnel) units. However, microwave cooking lacks uniform heating (James et al., 2017, Viji et al., 2022) and proper temperature control (Li et al., 2020), so it is not a very used technology in the sector. In the first industrial attempts, some companies that started to use microwave cooking finally stopped because this technique lacked uniform heating and due to challenges related to applying microwave cooking to different sizes of fish at the same time (Thrane et al., 2009). The preferential absorption of microwaves by liquid water is a major cause of overheating, especially at the outer surfaces of the food products (Viji et al., 2022). Another disadvantage is that microwave cooking cannot be used with metal packaging (Li et al., 2020). Nonetheless, microwave processing is time saving, energy efficient and yields good quality fish products with high nutritional value (Viji et al., 2022).

In the last 20 years microwave cooking has improved. The temperature uniformity during microwave cooking has been improved by optimising control of microwave conditions and using specific packaging materials that increase heating uniformity. However, this technology still has a lot of room for improvement. The technology is already industrialised in food sector, although it is not the most common method for cooking.

It can be expected that the number of industrial units will increase in the next 20 years. In any case, it is necessary to improve the uniformity of the heat treatment for it to become mainstream technology. Single microwave heating has a few drawbacks such as development of hotspots and overheating at the edges due to non-uniform temperature distribution (Viji et al., 2022). A combination of microwave heating and conventional heating or other emerging technologies has vast potential to alleviate these drawbacks (Viji et al., 2022). Focused research ensuring reliable mapping of the temperature at different places inside the product is necessary for improving the process and try to reduce hotspots (Viji et al., 2022).

Ohmic heating

Ohmic heating has been proposed for cooking and pasteurising seafood (Jin et al., 2020). It is an interesting new technology due to its ability to heat food quickly (with minimal destruction) and to provide higher energy conversion efficiencies, more uniform heating and/or reduced processing time than conventional thermal processing (Jin et al., 2020; Li & Sun, 2002). The heating takes place directly in the food (direct heating), so it is not necessary the use an intermediary heating fluid like water (indirect heating), improving the efficiency. Thus, due to the higher energy conversion efficiency, this technology could reduce the energy consumption of heating and, indirectly, reducing the GHG emissions. The rapid and relatively uniform heating is achieved by the direct passage of electric current through the product (Liu et al., 2017). Another advantage is the absence of water usage and thus avoids generating wastewater (Seyhun et al., 2014). Despite of its potential, the application of this technology for fish has been limited (Jin et al., 2020). In the food industry, more attention has been paid to the application of ohmic heating on aseptic processing and pasteurisation of particulate foods (Li & Sun, 2002). Currently, this technology is not applied in the industry.

Ohmic heating in seafood was proposed in the 90s of the past centuries. However, it has not advanced much in the last 20 years. At present, very little research on ohmic heating has been carried out. In the last 20 years some efforts have been made investigate the electrical conductivity of different foods, improve the control of ohmic heating process, and effort went into designing batch and pseudo-continuous ohmic heating processes (Jin et al., 2020).

Ohmic heating technology shows potential in supplying cooked and pasteurised foodstuffs of high quality. It can be expected that the number of studies to optimise this heat treatments will increase in the coming 20 years and first pilot processing units could appear in fish post-harvest chains.

Ultrasound assisted cooking

Ultrasound assisted cooking involves the application of ultrasound during water immersion heating, accelerating the heat and mass transfer [67]and, therefore, reducing processing time (Bhargava et al., 2021; Cichoski et al., 2015). This technique also reduces the loss of nutrients, development of off-flavours and deterioration of functional properties of foods that take place in thermal processing, such as structural damage due to cell bursting (Bhargava et al., 2021). The Maillard reaction (reaction between amino acid and reducing sugars that give browned food a distinctive flavour; distinct from caramelisation) is also sped up with respect to traditional water immersion heating (Siewe et al., 2020). The physical effects caused by ultrasound can convert sound energy into heat energy, thus improves the rate of heat transfer (Bhargava et al., 2021). Processing conditions must be optimised because high-power single-frequency ultrasounds may damage muscle structure (Bian et al., 2022). It is worth noting that creating ultrasonic waves has the disadvantage of high-power consumption and shows instability in practical applications (Bian et al., 2022). For cooking applications, the fish products could be packaged or not (depending on the specific process and the subsequent operations).

The application of ultrasound for seafood cooking is an emerging technology that has been scarcely studied during the last 20 years and, to the authors' knowledge, remains at research or pilot scale. Thus, its full industrialisation has not been completed.

After some studies highlighted the potential of ultrasound-assisted heating, more research is needed to reduce the power consumption and the instability of ultrasound systems (Bian et al., 2022). Furthermore, different food materials have different inherent characteristics, and the ultrasound parameters of different food products should also be optimised to enhance the process as well as improve food preservation properties (Bhargava et al., 2021). Finally, ultrasound should be treated cautiously, because it may be harmful to human health and safety when working with this technique (adverse tissue injury, electrical shock, and burns and indirect damage) (Bhargava et al., 2021).

The potential use of ultrasound at industrial scale is relatively simple because conventional equipment used in seafood post-harvest chains can be adapted easily (Cichoski et al., 2015). Among others, it is necessary to elucidate if the energy cost of ultrasound assisted

[67] Mass transfer phenomena is the net movement of mass from one location, usually meaning stream, phase, fraction, or component, to another.

cooking is lower than conventional heating processes. Furthermore, the technology has potential for continuous processing methods and scale up (Cichoski et al., 2015). Because no information is available about the possible generation of toxic substances after the ultrasound processing, further investigations must be carried out before the industrial scale-up of the process (Cichoski et al., 2015).

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11 FREEZING - CONVENTIONAL TECHNOLOGIES

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☒ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna

☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Main types of conventional freezing technologies

- Blast freezing
- Contact/plate freezing
- Cryonic freezing
- Immersion freezing

Blast freezing

Brief description

Blast freezing is a simple and effective way to freeze an assortment of fish products (Hall, 2011). It takes a fish product stored at ambient or chilled temperature and rapidly freezes the product for further storage.

(Air) blast freezing uses fans to create convection over the products which increases the surface heat transfer coefficient, which helps cooling the product (Dempsey & Bansal, 2012). The fans create a uniform air temperature throughout the freezer. Because air is used as a cooling medium, it is essential to ensure that this air distribution remains uniform throughout the freezer and must be considered during the loading the freezing system as an incorrectly loaded freezing system may reduce the efficiency of the blast freezing process (Kolbe & Kramer, 2007). Several loading systems exist for air blast freezers (Dempsey & Bansal, 2012; Hall, 2011):

- **Sharp freezers:** these basic air flow freezers make use of natural convention and have lower air movement created by the evaporator fans. Because it makes use of the natural convention in the freezer, the process is slow. This method is often used for freezing bulk products, and not processed food.
- **Tunnel freezers:** large fans are used to circulate the air throughout the freezer. These fans create a cross flow or counter flow to cool products in the freezer. With the dependency on the air flow circulation, loading needs to be planned properly to ensure sufficient airflow throughout the freezer. Different loading methods exist for tunnel freezers:
  - ***Batch freezers:*** products are loaded (with pallets or hooks) into the freezer. The batch is loaded into the freezer until it’s frozen, after which it is emptied out in order to load in a new batch of products.
  - ***Mechanised Freezers:*** systems (such as racks on wheels and trolleys) mechanically push the product throughout a tunnel. These push-through tunnels reduce labour costs and ensure that the air flow is maintained throughout.
  - ***Belt freezers:*** conveyer belt systems continuously load product into the freezer and make use of vertical air flows to freeze the products. These vertical flows efficiently freeze products on top of the conveyer belt. Several types exist which create this vertical airflow, those are a multi-tier belt freezer and a spiral belt freezer, which differ in the vertical transport method. The vertical airflow design allows the freezer to take up less operational space.
- **Spiral freezers:** spiral freezers make use of a moving belt that move the fish product throughout the freezer. In the freezer, air will be directed horizontally/vertically or from both directions over the product. This process is very

controllable because parameters such as belt speed, product loading, air speed and air flow direction can be adjusted and optimised easily.

- **Fluidized-bed freezers:** fluidized-bed freezers make use of vertical air flows on perforated conveyer belts. This creates "bubbles" which tumble and float the product on the conveyer belt to uniformly freeze products at the contact surface. This method is often used for processing shrimp and prawn products at high rates.
- **Impingement jet freezers:** product is moved alongside a conveyer belt where they are exposed to high intensity cold air streams (from one or two directions). These jets result in high heat-transfer ratios which rapidly cool the products.

During freezing process, water vapour from the fish products will evaporate and accumulate on the refrigerant evaporators of the freezers (Hall, 2011), and this will reduce the freezing efficiency of the freezer. This water vapour release can be reduced by packaging the product before freezing. To further ensure the efficiency of the freezer remains optimal, freezers need to be defrosted periodically.

Trends in technological evolution of blast freezing since 2002

Blast freezing has been in use since 1950 and is described as an easy and efficient freezing method. Throughout the years, the above-mentioned blast freezing variations have been put in place on operational sites around the globe. In the last two decades, the technology further evolved to improve the refrigeration efficiency of the process. Each improvement is made in relation to specific operational conditions, and include improvements such as (Dempsey & Bansal, 2012):

- Optimising the refrigerant pump system running in the freezer, by reducing the discharge pressure set points and raising the suction pressure set points
- Optimise air flow in freezer by utilising Variable Speed Drives (VSD's) for the fans
- Improve freezer insulation
- Optimise defrosting schedule
- Refrigerant selection

Additional industrial management strategies can further optimise the performance of the freezer (Dempsey & Bansal, 2012):

- Make use of off-peak electricity (e.g. during the night) to reduce the costs of the process. This is one of the most common used strategies.
- Replace outdated (e.g. 10-year-old) equipment
- Air flow and product loading management to properly directly airflow within the freezer
- Adjust product cycle to run freezers at lower air flow velocities, but longer periods
- During intermediate periods in-between loading products, lower freezer temperature to proper storage conditions and/or allow for coil defrosting in intermediate period.

In conclusion, improvements of blast freezing technologies focus on increasing process fine-tuning and efficiency by improving technology and management, thus both directly and indirectly improving GHG emissions.

Future of blast freezing

Future optimisation of blast freezing improves the previously mentioned optimisation strategies for specific operational sites. Each site, product, value chain has specific requirements and must be optimized locally. With climate change being an additional factor that will need to be considered in the optimisation of this process. See also the technological sheets of refrigerants and insulation.

Contact/plate freezing

Brief description

The freezing process is depended on the efficiency of the heat-transfer between the products and the environment. Air is the most common used medium for freezing products, but plate freezing has a higher heat transfer coefficient because of the direct contact with the product and is therefore more efficient (Ozogul, 2019).

Plate freezing systems are often used for freezing fish products with regular shapes (e.g. fillets and surimi). Freezing efficiency of the system is depended on the loading of the plate and the general management of the freezer. The moveable plates have been designed with internal channels to speed up the freezing process (Hall, 2011). These channels move refrigerants alongside the products, which extracts product heath through conduction and freezes the fish product (James & James, 2014).

Water vapour is released during the freezing process, so the system needs periodical defrosting. Water vapour can be reduced through proper product packaging.

Two types of plate freezers exist based on the orientation of the plates: horizontal plate freezers and vertical plate freezers. The latter is often used for on-board processing of fish (Hall, 2011).

The post-harvest chains using this technology often notes that the fish products are often deformed due to the mechanical pressure of the process, and represents one of the disadvantageous of this technology.

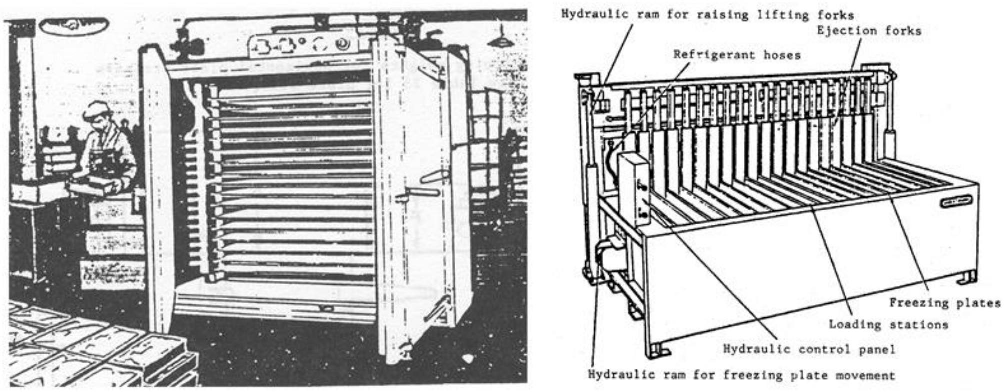

Figure 4: Overview of a horizontal plate freezer on the left, and on the right a vertical freezer(taken from FAO: Planning and Engineering Data 3. Fish Freezing - 3. Processes and Equipment, n.d.) .

Trends in technological evolution of contact/plate freezing since 2002

Since the Montreal Protocol, ozone depleting refrigerants which harm the protective ozone layer have been targeted to be phased out. Synthetic refrigerants, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) are banned or planned to be restricted due to their global warming potential (Fernández-Seara et al., 2012). For more explanation see the technological sheet about refrigerants.

In line with these regulation changes, alternative freezing agents have been investigated for their sustainability and effectivity. This has resulted in first a shift from R22 (chlorodifluoromethane) to ammonia (NH_3) (Zanoni et al., 2020), which helped removing harmful substances from the post-harvest chains using this technology. Furthermore, freezers have also been shifting away from ammonia systems towards CO_2, which has a lower freezing temperature and helps decreasing the time needed for the freezing process (Ozogul, 2019).

Different refrigerants have also been investigated as a cascading system, where two systems using different refrigerants are connected within a freezing system. This uses both the CO_2 and NH_3 freezing systems and links them by using a heat exchangers (Fernández-Seara et al., 2012). This creates a low temperature (CO_2) and a high temperature (NH_3) environment, and showed potential as a viable alternative in experimental design.

Future of contact/plate freezing

Future strategies to further optimise the freezing process, make use of the above discussed strategies and the optimisation of the individual steps of each freezing process related to specific products. Such optimisation can consist of among others optimising space management, freezing temperature, refrigerant use, dehumidification/defrosting.

Cryonic freezing

Brief description

Cryogenic freezing methods uses liquid nitrogen (N_2, at -195.8°C) or liquid carbon dioxide (CO_2, at -78.5°C) directly on the seafood product to rapidly freeze the product (Svendsen et al., 2022). The system uses sublimation, where the refrigerants directly transform from the liquid to the gas phase. The contact time of the refrigerant on the product is controllable, because it is sprayed on the product which moves through the freezer using conveyor belts (Hall, 2011).

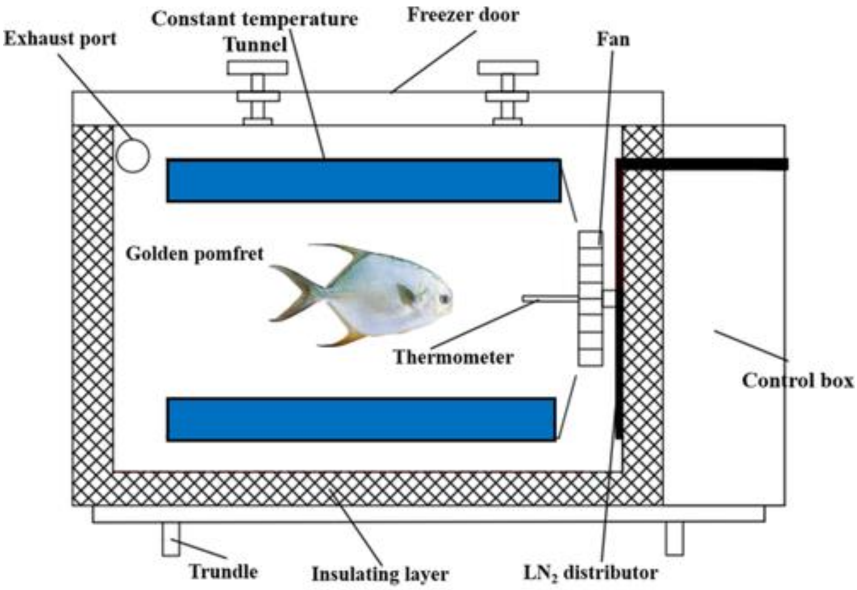

Figure 5: Schematic overview of cryogenic food freezer, which runs at - 196 ~ 30°C. As taken from Zhao et al., 2019.

The whole process has a high heat transfer coefficient, because the refrigerants evaporate directly on the seafood product surface, product heat disperses rapidly into the environment and the freezing process is very fast (Ozogul, 2019). With the rapid freezing process, moisture loss is minimised by reducing dehydration and drip loss, and texture is maintained (Truonghuynh & Li, 2019).

However, the freezing technique can also negatively impact the product quality. Fish quality can deteriorate due to cell wall ruptures (Sampels, 2014), thaw loss and an increase in lysosomal enzymatic activities due to cell stress during the freezing process (Truonghuynh & Li, 2019).

The major disadvantage of this technique is the higher production costs which are a consequence of keeping both liquid nitrogen and liquid CO_2 at very low temperatures. An additional disadvantage of the usage of CO_2 is the working hazards associated with the process. To use CO_2 as a liquid cryogenic freezing agent it must be ensured that the concentrations of air CO_2 do not exceed lethal levels (Ozogul, 2019). This effect can however by reduced by precooling the product or reducing the temperature differences between the product and refrigerant (Svendsen et al., 2022).

Trends in technological evolution of Cryogenic freezing since 2002

Technological innovations for cryogenic freezing have been focussed on improving the quality of the final frozen product. Methods such as edible films and coating, and combinations with other freezing (e.g. radiofrequency assisted freezing) have been used to increase the product quality (Truonghuynh & Li, 2019).

Future of Cryogenic freezing

Future improvements of cryogenic freezing and the product quality will combine different freezing methods to improve the product quality. Additionally, detailed mathematical modelling of the products deterioration can further help improving the product quality.

In most recent years, companies (such as Air Product) have been working on improving the sustainability of their cryogenic freezing equipment. In 2021, they unveiled their next generation Freshline® High Performance batch freezer which is build for higher efficiency. This equipment package is designed for higher freezing rates (due to an increase in capacity), more homogenous freezing and usage of lower amounts of liquid nitrogen and improved cleaning operations (*Cryogenic Freezing | Cryogenic Freezer | Air Products*, n.d.; *Food Industry News: AIR PRODUCTS HAILS ITS LATEST CRYOGENIC FOOD FREEZERS*, n.d.)

Immersion freezing

Brief description

Immersion freezing uses close contact of the refrigerant and the product, and sprays the freezing agent directly onto the product or makes use of immersion baths to freeze the seafood product (Hall, 2011). As for the freezing medium, an array of products can be used; brine/salt solutions which often contain sodium chloride (NaCl) and Calcium Chloride ($CaCl_2$), ethylene glycol or propylene glycol (Kolbe & Kramer, 2007; Sampels, 2014). With the freezing medium engulfing the product, the working temperature can be higher compared to (air) blast freezing: for brine mixtures such as NaCl the working temperature is around -18°C, for $CaCl_2$ it is -20°C and for water/propylene mixtures it is also around -18°C (Hall, 2011).

Because of the direct contact between the freezing medium and the fish product, heat transfer efficiency is very high. Even with the high heat transfer efficiency, freezing rates are still dependent on the product size and geometry, volume ratios of product and brine, general temperature control, brine temperature and brine velocity over the product (Ozogul, 2019).

The limiting factor for the working temperature is the viscosity of the freezing agent, and this can influence the sustainability of the process. Improper temperature settings can increase the viscosity of the refrigerant. This may lead to increased pumping requirements, ice formation in the heat exchangers and a less efficient heat transfer process, which reduces the sustainability of the product (Hall, 2011; Svendsen et al., 2022). Other operational difficulties with the process besides the viscosity issues, include keeping the medium at constant concentrations and free of microbial contaminants (Fikiin, 2009).

Intrusion of salt from brine solutions into muscle tissue of the fish product is another negative consequence of the process (Svendsen et al., 2022). This salt intrusion can cause increased product deterioration and lowers the quality for the consumer of the fish product. This can be countered by correct product packaging (Svendsen et al., 2022).

Trends in technological evolution of Immersion freezing since 2002

Recent advancements in heat and mass transfer, physical chemistry and fluid dynamics helped solving problems concerning salt uptake of the fish products and operational issues of the immersion fluids (Fikiin, 2009). This resulted in the development of the advanced immersion Individual Quick Freezing (IQF) systems (Fikiin, 2009).

Other special immersion freezing techniques[68] such as ultrasound, high pressure freezing, or electrostatic field assisted immersion freezing have been further developed to avoid salt uptake issues (Choi et al., 2016; Jia et al., 2017; Qian et al., 2018). Additionally, vacuum packaging before freezing also avoids direct contact with the freezing medium and avoids salt intake (Qian et al., 2018).

Future of Immersion freezing

Future technology improvements can aim to reduce the freezing point of the freezing medium (Yang et al., 2020). One possibility is adjusting the individual components and their mixture ratios within the freezing medium to ensure viscosity is optimal which helps optimising the heat transfer efficiency during the freezing process.

Further optimisation of the immersion freezing processes can be achieved by combing this method with other freezing technologies. By combining different freezing processes, the optimal approach can be identified and applied in order to maintain the quality of the product and to reach a maximum optimisation of the process (Ozogul, 2019).

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12 FREEZING - EMERGING TECHNOLOGIES

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☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☒ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Main emerging freezing technologies

- Superfreezing technology
    - Pressure shift freezing
    - Impingement freezing
    - CAS freezing
- Superchilling
- Ultrasound assisted freezing

Superfreezing technology

Brief description

Recent developments in the freezing sector are looking into alternative freezing methods. These alternatives are mainly in the exploration phase and no commercial implementation has taken place, with long-term implementation being for example depended on financial feasibility (Boziaris, 2013). The financial aspect of the implementation is especially relevant because specialised and adapted equipment is necessary for these freezing strategy.

Super freezing, which aims to rapidly freeze fish products to -60°C, is one approach aimed to increase product quality (Boziaris, 2013). This can be achieved by making use of freezing methods such as:

- **Pressure shift freezing:** a high-pressure vessel puts the seafood product under the desired pressure, after which the product is frozen to a temperature of -20°C (You et al., 2016). The pressure shift ensures that the water within the product remains liquid and once the pressure is released, freezing occurs rapidly and uniformly throughout the product (You et al., 2016). This rapid freezing creates small, uniform ice crystals throughout the product and has been shown to maintain the product quality of the fish product over time (Fikiin, 2009; Hall, 2010).
- **Impingement freezing:** this freezing method makes use of air jets and has been briefly discussed in the technology sheet on air blast freezing systems. A conveyor belt is blasted from one or two directions with high intensity jet streams, these create a turbulent environment around the product and boost the heat exchange (Boziaris, 2013). For thin fillets, these jet blasts result in a heat exchange rate similar to the ones using liquid nitrogen (Boziaris, 2013).
- **CAS freezing:** Cell Alive Freezing systems use a magnetic field that osculate over the product. This spins the water molecules in the seafood product and lowers the freezing point of water to -7°C (Boziaris, 2013). The magnetic field is turned off once the temperature of -7°C is reached, which results in an instantaneous freezing of the products' interior (Boziaris, 2013). CAS Freezing has been developed and commercially implemented in the tuna industry of Japan and is investigated for further use in Europe (Boziaris, 2013)

These super freezing techniques aim at increasing the efficiency of the freezing process, by making sure that nucleation (the start of a freezing event) occurs rapidly and uniformly throughout the product. The main advantage of these approaches is the lower amount of cell deterioration due to small ice crystal formation, which results in higher product quality (Boziaris, 2013; Hall, 2010). Indirect environmental gain for these freezing processes can result from the higher product quality (which can increase shelf life and reduce waste) or by decreasing the time (and required energy) of the freezing cycle.

Future of super freezing

These techniques are still under development and other gains (environmental or efficiency) are not always clear as of yet in these mainly academic oriented studies and applications. If they prove to be commercially interesting for several products, further implementation can occur.

Superchilling

Brief description

Partial freezing lowers the temperature down to 1-2°C below the initial freezing point of the seafood product (Wu et al., 2014), where the product is kept in a stage between chilling and freezing. At the temperature of the initial freezing point, the first ice crystals are formed on the surface of the product. Over time, the heat distribution within the seafood product finds a temperature equilibrium and a predefined ice distribution is reached throughout the product (Magnussen et al., 2008). This results in the freezing of the exterior of the fish product, while the interior is frozen for 5-30%. (Ozogul, 2019)

The initial freezing point varies for different types of seafood products, with more freezing point variation resulting from differences in catch season, product freshness, species, and individual water content (Wu et al., 2014). The origin of the seafood further influences the initial freezing temperature, with differences existing between for example pelagic or demersal fish and seawater or freshwater fish (Wu et al., 2014).

Mechanical, cryogenic or impingement freezers can be used to achieve the initial freezing of the products exterior (Kaale et al., 2011).

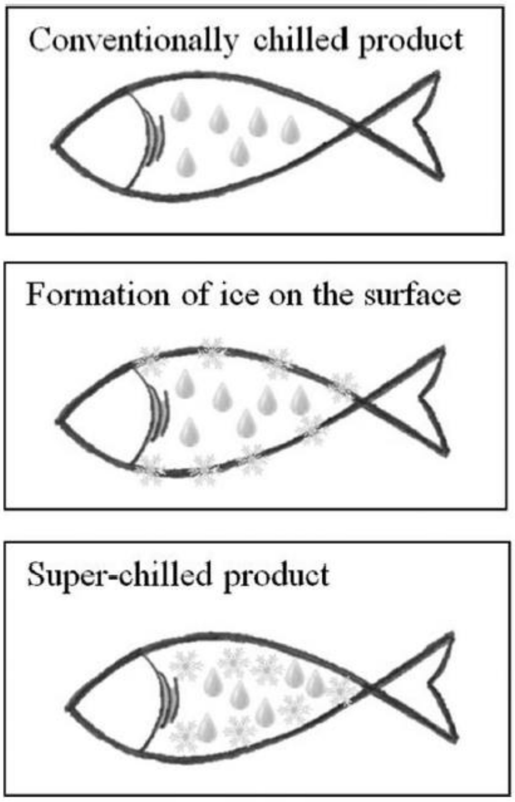

Figure 6: Overview of the super-chilling

Partial freezing has proven to be an efficient method to prolong the fish product's shelf life, increases sustainability of the refrigeration process, and decreases tissue damage due to ice crystals (Hall, 2011). Product quality and shelf life is increased because the internal temperature reduces the ongoing chemical and enzymatic activities that result and product quality loss (Magnussen et al., 2008). The sustainability of the (transporting) process increases because less ice is required and this due to the product itself being cooled internally (Wu et al., 2014). Transportation costs are further reduced due to the lower ice needs, because lower weights need to be transported and fish can be packaged more efficiently (Ozogul, 2019).

However, several challenges remain present for this freezing technique, with the most severe challenge being related to the variability in specific freezing conditions of the product (Wu et al., 2014). With an initial freezing point that is depended on properties of the seafood products, the chilling process should be optimised for each specific product. This requires calculations of the superchilling times and internal heat distribution of the seafood products (Magnussen et al., 2008). Computational fluid dynamics (CFD) is a simulation tool which is often used in combination with experimental data for the product specific calculations (Wu et al., 2014). The properties of the superchilling process needs to be adjusted further to achieve the required processing quality, efficiency, and shelf-life market requirements (Magnussen et al., 2008).

A last challenge for the implementation of the superchilling process can be found in the transition from traditional freezing technologies towards this new process. For an efficient superchilling process, data streams related to individual seafood products need to be available during the production of the final superchilled product (Magnussen et al., 2008). This will require transitioning to an adapted, data rich cold chain, with specific operational designs, packaging, and cooling techniques specific for each seafood product (Ozogul, 2019).

Trends in technological evolution of Partial Freezing (Superchilling) since 2002

By the development of the "SuperChiller" the efficiency of the cooling technique has improved over the years. This approach makes use of cooling the fish after filleting and before/after the trimming process (Wu et al., 2014). It precools the filets through a transportation with a cooled conveyor belt (at -8°C to - 6°C) and simultaneous air cooling (Wu et al., 2014). Because the process is adjustable, cooling efficiencies can be achieved for specific product needs.

Through experiments and modelling with CFD, preservation of different seafood products and the initial freezing points have been determined (Ozogul, 2019; Wu et al., 2014). This further helps optimise the efficiency of the superchilling process.

Future of Partial Freezing (Superchilling)

In the future, further implementation of the CFD and experimental data will work towards optimising the equipment efficiency to continue lowering the costs and increase the sustainability of the process (Wu et al., 2014). Furthermore, it is necessary to develop improved insights into the quality monitoring, especially related to ice formation and fish product quality, which will for increased market implementation (Wu et al., 2014).

If sufficient fundamental information is gathered, the cold chain can transition away from the traditional techniques towards superchilling. With the large potential of superchilling to deliver high quality products through a more efficient process, this transition has the potential to be a worthwhile investment.

Ultrasound assisted freezing

Brief description

Ultrasonic or ultrasound-assisted freezing techniques aim to produce fine ice crystals within the seafood product and aim to increase the efficiency of the freezing process (Cheng et al., 2015). Fast freezing produces fine extra- and intracellular crystals that cause minimal damage to the texture (cells) of the seafood product, while slow freezing can damage the product due to large sharp ice crystals penetrating cell membranes. Increasing freezing rates is an effective method to reduce ice crystal size and muscle tissue damage (Sun et al., 2019).

Ultrasound, with low frequencies and high intensity soundwaves (20-100 kHz, with 10-1000 W/cm²), are considered effective to reduce of freezing times (Zhang et al., 2018). This increase in freezing efficiency is the result from cavitation bubbles and microsteaming (Islam et al., 2014). Cavitation bubbles are created when the rarefaction force exceeds the attractive force among molecules in a medium (Cheng et al., 2015). The bubbles increase the nucleation (site where ice crystal starts to form) and ice formation (Cheng et al., 2015). Furthermore, a stable stream of the cavitation bubbles result in microsteaming, which creates strong eddy currents that promote heat and mass transfer during the freezing process (Cheng et al., 2015).

By combining ultrasonics with immersion freezing, samples had smaller ice crystals, better protein thermal stability and physicochemical properties in the muscles compared to immersion freezing and air freezing techniques (Zhang et al., 2018).

Trends in technological evolution of Ultrasonics since 2002

The effects of this freezing technique have been studied for a range of products, and all these studies focussed on the effect of different ultrasound parameters (James et al., 2015). All the studies were performed on a small scale and have been under review since 2005 (James et al., 2015).

Future of Ultrasonics

Studies on ultrasonic assisted freezing still have data gaps that need to be resolved. For example, information on the influence of freezing conditions on the freezing properties or a comparison between different products during the same freezing conditions have not yet been investigated (James et al., 2015).

No commercially used freezing machine makes use of this freezing technique (James et al., 2015). Future laboratory research and development can further develop this novel technique and enable a commercial implementation on the long term.

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13 COLD STORAGE, DEHUMIDIFIER

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
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☒ CS 21 Albacore tuna
☐ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Brief description

The accumulation of moisture and condensation in the cold temperature environment of cold storage warehouses and coolers can lead to a multitude of practical problems. Directly reducing the product quality (e.g. packaging damaged by condensation or ice, and contamination), cause safety issues (e.g. slippery floors, reduced visibility and ice deposit falls), reducing the product handling efficiency (e.g. ice and/or humidity on bar codes on products, pallets and packages, errors in transport, and stacking and logistics), causing a poor working environment (e.g. difficult to close doors due to ice, and an uncomfortable working environment), wasting man-hours and reduced productivity (e.g. time used to remove ice and condensation, and slower movement) and increase energy consumption and bills (e.g. defrosting cycles, inefficient working of evaporators when iced up, and heating to avoid icing) (COTES, 2022).

Although a proper control of the doors (e.g., high-speed automatic doors, door seals and strip curtains) can reduce the infiltration of warm air and its humidity they cannot stop it completely. Cold storage/freezer dehumidifiers help to reduce the humidity of the air in freezing/refrigeration systems, which enters via the cold storage entrances, reduce energy consumption, increase safety and sustainability. Dehumidifiers tend to work by creating dry, low dew point air by forcing most air to pass through a revolving desiccant wheel. The dry air is subsequently pumped into the freezer or cold storage unit (e.g., Munters, 2022, Condair, 2022, Bry-air and AirWaterGreen, 2022). With the latest developments these units can bring the humidity level down to a minimum at temperatures as low as -30°C (Condair, 2022).

This increases the refrigeration systems efficiency as it allows the cooling coils to run as intended by the manufacturer, increasing the interval between defrosting, and reducing energy losses caused by improper door sealing due to ice accumulation. Together, all these reduce avoidable energy expenditure and unnecessary wear of the refrigeration system which is directly correlated to the reduction of GHG emissions, while the reduction/avoidance of other efficiency problems linked to humidity in cold storages will indirectly reduce the GHG emitted per kilo of product produced.

Figure 7: AIRWATERGREEN dehumidifiers unit

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14 COLD STORAGE, INSULATION SYSTEMS

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
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Types of insulation systems

- Strip curtains
- High speed doors
- Air curtains
- Conditioned air vestibule (air lock)

The thermal insulation of cold storage units is responsible for maintaining cold temperatures through time, by minimizing the heat transfer between the cold storage and its surroundings. Each time a door opens, a warmer and more humid air from outside is introduced into the systems while cold air leaves it. This represents an important source of energy waste, while also creates several problems (e.g., ice accumulation, wet floors) caused by the increasing humidity.

Good insulation materials should have very low thermal conductivity, hence slowing the flow of heat transfer. This will reduce the direct energy consumption of the cold storage plant by reducing the energy needed to maintain the cold temperatures and the GHG emissions derived from non-renewable energy sources, such as by preventing the waste of perishable products, exposed to non-optimal conditions, and cooling equipment breakdown.

Insulation accounts for 20-35% of the total heat load of a cold storage plant, meaning that choosing the appropriate insulation material will have significant impact on the plant's energetic consumption (Gao 2018) and in the GHGs emissions associated with it.

Strip curtains

PVC strip curtains are widely used in cold storage facilities as they efficiently prevent cold air from escaping the room when the door is open, allow an easy access to personal and machinery, provide a relatively good visibility between the two environments and are very cheap. Nonetheless, they have important disadvantages: as product is carried in with forklifts it encounters the strips compromising its hygiene, they reduce the visibility and speed of machinery, the alignment of the strips is quickly shifted due to the passage of people, forklifts and products leading to loss of cold air, and they will quickly require maintenance and needed to be changed when used frequently.

High speed doors

High speed doors are designed free of rigid parts allowing a fast opening and closure without representing a safety hazard for people and vehicles. As manually controlled doors are not time efficient, automated systems are used, which reduce the opening time, hence cold air loss and saving energy. Nonetheless while the door is open there is nothing blocking the heat exchange between the two environments, and when the usage is too frequent the door will remain open relatively long. Also, maintenance, wear and damage costs tend to be high.

Air curtains

Air curtains consist of a constant downward laminar air flow creating an effective barrier between two different environments. These benefit the cold storage operations by greatly reducing energy losses as it reduces temperature variation by 90% down to less than one degree. In addition, they increase the productivity of the cold storage by allowing to leave the door open and letting vehicles and personnel pass freely and efficiently between the two environments, reduce work hazards caused by the accumulation of ice or water, but increase visibility by removing plastic strips and/or door. Finally, air curtains optimizing the product quality and hygiene by the reduction of hot posts near the entrance where cold chains can be compromised. Compared to strips and high-speed doors, air curtains are very effective in high transport frequency environments but require a relatively larger investment.

Air curtains for temperature-controlled road transport have also been developed, providing an automatic vertical air curtain separating the air inside the trailer from the temperature outside the vehicles. This has proven to reduce heat infiltration between 30-45% (e.g., Blue Seal Air Curtains by Brightec, **Error! Reference source not found.**).

Conditioned air vestibule

All previous options allow somehow the infiltration of warm external air and loss of internal cold air. A solution which neutralizes this almost completely is the installation of conditioned air vestibule on the entrance of the cold storage and trap the air between two doors. The air between the two doors can then be more efficiently (smaller volume) controlled, lowering its costs, and contributing to the general energy savings. Vestibules systems can be combined with the other above presented options to provide an even more effective temperature control. However, its closed infrastructure will inevitably reduce the workflow speed and its efficiency. Trade-offs must be analysed in detail when specific choices are made for the different options presented here.

Trends in technological evolution of insulation systems since 2002

Currently, two types of insulation materials are mostly used and commonly available for cold storage warehouses installation, those are polyurethane and polystyrene (EPS and XPS). Although some other insulation materials are also efficient in reducing heat exchanges between the environment and the cold unit, some of them are very sensitive to humidity (e.g., mineral wool), reducing their performance and requiring time and financial investments for their maintenance and replacement. Such options are therefore unlikely to be used for cold-storage applications.

Current contact insulation materials

Polyurethane

Polyurethane is among the best-performing insulation materials, with an insulation capacity 700% better than bricks and 50% better than fiberglass. Its insulation capacity is due to its structure of small cells in combination with the composition of the gas in these, also called “blowing agent”. Years ago, the blowing agents used for polyurethane foam used to be chlorofluorocarbons (CFCs) refrigerants (i.e., CFC-11 or CFC-12, infamous for their ozone depletion and greenhouse gas effect) but have now been changed to newer and more sustainable alternative refrigerants, such as hydrofluoroolefins (HFO) and hydrocarbons (HC). Nonetheless, the usage of these newer and sustainable blowing agent alternatives may imply efficiency, durability, or economic trade-offs (Wagman 2018). While HFOs provide better thermal performance than HFCs, and are non-flammable, they would be needed in larger quantities, hence increasing costs. The HC are on the other hand less cost demanding but offer a lower thermal efficiency and are highly flammable. Finally, synthetic alternatives such as Ecomate (FoamSupplies) have been developed to offer excellent thermal properties, while maintaining lower cost and reduced flammability risks (Kolbe et al. 2006, Wagman 2018).

Polyurethane foam can be applied by spraying it onto surfaces with a gun or ready in place in panels (e.g., sandwich panels, Figure 1). Although it will not burn with a small flame (e.g., match), chemical additives must be added to limit its flammability when uncoated or unlined (Kolbe et al. 2006).

Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS)

Expanded polystyrene (EPS) or also known as "styrene" is a lightweight white foam, used in the walls and roofs of cold storage facilities with insulation properties constant over time (Kolbe et al. 2006, EPS Industry Alliance 2022). It adheres to different materials, such as metal, wood, or drywall, thus giving panels reasonable strength in construction and works in a temperature range from 20°C to -100°C. Similarly, to polyurethane, EPS is expanded using a blowing agent (e.g., Pentane). Its closed-cell structure reduces the water absorption and vapor permeability to minimum values, enabling it to maintain its performance even in humid environments. Although EPS are also flammable, flame retardants significantly minimize the ignitability of the foam and the spread of flames. The EPS is 100% recyclable into new packaging/insulation products or durable goods, however, might be difficult to collect due to its very light weight (large volume). Its production does not involve any ozone-layer depleting CFCs and HCFCs and does not lead to the generation of residual solid waste.

Extruded polystyrene (XPS) is manufactured through an extrusion process with polystyrene, a blowing agent, and other materials. Unlike other forms of insulation, such as EPS, XPS doesn't have any tiny voids or spacing between the cells. This decreases heat transfer while also making it very resistant to water absorption and water vapour transmission, allowing it to retain low thermal conductivity even when there is a lot of water present. The moisture-resistant qualities of XPS foam are especially relevant for cold storage applications because the interior areas of cold storage warehouses tend to have more moisture and condensation.

Both, polystyrene, and polyurethane can be used for the building of cold storage warehouses using sandwich panels. These panels are usually constructed with an insulating core (EPS or polyurethane), joined by two metallic or non-metallic (steel or aluminium) layers. These panels are especially efficient in warehouses located near harsh environments (e.g., coast, industrial areas), by making them more resistant to corrosion (due to coatings). The thickness of the panels installed in industrial refrigeration chambers ranges from 100 to 125 mm (at above zero temperatures) and between 175 and 200 mm (at sub-zero temperatures) (Mecalux 2022). In addition to their very high thermal insulation, these panels are fast and easy to install, budget friendly, aesthetic, resistant to fire and allow an almost unlimited modularity for specific applications and environments. Together, this enhances the efficiency of the warehouse, hence leading to a more efficient usage of resources and minimizing GHG emission per product produced.

Future of contact insulation materials

Although the previously presented materials do help to reduce GHG emission indirectly by reducing energy consumption linked to temperature fluctuations, heat exchange, refrigerant consumption, refrigeration wear and product waste, both insulation materials are petroleum derived, and their production is still responsible for GHG emissions. Furthermore, once the insulation material is no longer usable the foams do not break down and can stay in the environment for 1000 years. Both academic research and the industrial sector have already developed and are currently developing efficient alternatives which in addition to reduce heat loss in cold storage facilities will be produced with very low to no GHG emission. The following section presents the advantages and disadvantages of these new technologies

Aerogel

Aerogel is a new type of insulation material, with excellent thermal insulation performance compared to conventional insulation materials. It is produced from silica, silicon dioxide, and up to 99.8% air. It is light weight but strong and durable; half a kilogram of aerogel can support approximately half a ton. Thanks to its very high performance, thinner thermal insulation layers can reach the same insulation values of currently used insulation materials. Aerogel is also very physically resistant, that is resistant to internal stress during construction and resistant to deformation even after long-term use, while also chemically stable, with no release of harmful substances and no decomposition during its usage. Its production process does not involve harmful gases, while the solid wastes generated and the insulation material itself can be recycled once no longer in use (Silica Aerogel Insulation 2022).

Aerogel preparation involves expensive precursor raw materials, chemicals, and needs to dry (the key step in the production process), making the production relatively more expensive compared to the current conventional building insulations.

Corn-based Polylactic acid + Cellulose fibres

Polylactic acid, also known as biodegradable hydrolysable aliphatic semicrystalline polyester, is a "prototype" insulation foam which was developed mixing corn-based polylactic acid with cellulose fibres using carbon dioxide. This foam is safer than conventional insulation foams, but also compostable and efficient (UNT 2020). It is 90% biodegradable within 50 days but performs like conventional insulation with similar efficiency. As this insulation material is still in an innovation and prototype stage, currently information on this insulation material is very limited.

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15 COLD STORAGE, REFRIGERANTS

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☒ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☐ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Brief description

Refrigerants are widely used for industrial, commercial, domestic and transport refrigeration in the seafood post-harvest value chain. These are substance that absorb the heat in the refrigeration unit. High pressurised warm refrigerant is traditionally cooled and liquefied through air heat exchangers. When this cool liquid evaporates, it removes heat from the air creating low temperatures in the refrigeration unit. Subsequently, the cold gas is pressurised and condensed at higher temperatures before being send again to the air heat exchanger.

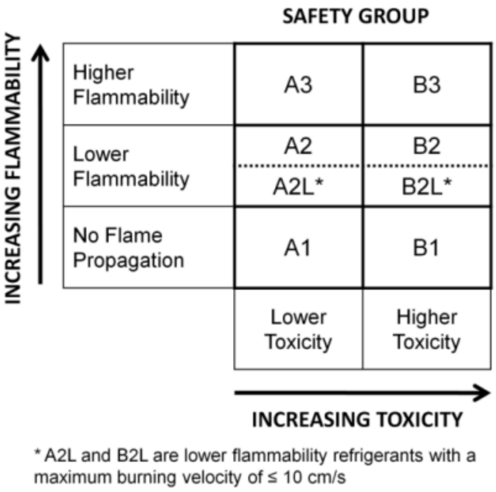

Figure 8: Safety group diagram for refrigerants based on the ASHRAE standard 34-2013.

Although most chillers using refrigerants follow this process, the selection of the "ideal" refrigerant is not straightforward and depends on the design of both the chiller and the refrigeration unit, expected performance, safety, reliability, cost, and environmental sustainability (Maina and Huan 2015). For refrigerants, safety is commonly grouped in safety categories defined by the ASHRAE standard 34-2013, based on their flammability and toxicity (Figure 8) (Goetzler *et al.* 2014). From 1987 onwards, environmental concerns on the usage of refrigerants became a key driving factor in the selection, phase-out, and development of new and more sustainable refrigerants Savitha *et al.* 2021). The Global Warming Potential (GWP), Total Equivalent Warming Impact (TEWI), and Ozone Depletion Potential (ODP) indices were used to compare sustainability across refrigerants (e.g., Wu *et al.* 2013). The GWP compares the global warming impact of the emission of greenhouse gas in comparison to the emission of carbon dioxide (CO_2) in each time frame (e.g., 100 years). The TEWI goes further than the GWP, which considers only direct emissions (e.g., leakage of the refrigerant to the atmosphere), by also including indirect emissions because of the energy consumption of the refrigeration system. Finally, the ODP refers to the amount of ozone destroyed by emissions of vapour over its entire atmospheric lifetime relative to that caused by the emission of the refrigerant CFC-11.

Although all aim to maintain cold temperatures, refrigerant types are also very dependent on the characteristics of the refrigeration unit. One refrigerant will be unlikely to fit the demands and expectations of all refrigeration steps in the seafood post-harvest cold chain. For example, the size of the condensing unit and refrigerator itself will vary tremendously between industrial (e.g., cold warehouses, processing), commercial (e.g., retail outlets), transport (e.g., refrigerated trucks), static and mobile air conditioning, and domestic refrigeration units. In addition, refrigeration systems may use intermediary steps to increase the stability and the efficiency of the chiller using a specific refrigerant, for example a glycol heat exchange step can greatly reduce temperature peaks therefore stabilizing the performance of the chiller and by extension the refrigerant. Moreover, by stabilizing the performance of the chiller unit, the risk for critical failures and maintenance time and cost reduces. Of key importance is finding the correct combination of refrigerant, chiller unit, and intermediary cooling steps to create the most performance and cost-efficient set-up.

Trends in refrigerant evolution and currently used refrigerants

The following section includes information on all past and present commonly used refrigerants, including the description of refrigerants developed and/or phased-out before 2002. Although beyond the timeframe of the project (2002), this information is relevant to understand the continuous dynamics in refrigerant selection and use.

Refrigerants phased-out or in the process of being phased-out

<u>CFC (e.g., CFC-11, CFC-12)</u>

Chlorofluorocarbons (CFC) were phased-out in January 1996 under the Montreal protocol, due to the liberation of chlorine once they break down in the upper layers of the atmosphere and the subsequent destruction of the ozone layer (high ODP).

<u>HCFC (HCFC-22, HCFC-123, HCFC-502)</u>

Hydrochlorofluorocarbons (HCFC) have both high ODP and GWP, nonetheless lower than CFCs due to their shorter atmospheric life. Their complete phasing-out was scheduled for 2020 under the Montreal protocol. Developing countries started their phase out process in 2013 and a stepwise reduction is in place until their complete phase-out by 2030.

<u>HFC (HFC-134a, HFC-245fa, HFC-125, HFC-32)</u>

Hydrofluorocarbons were developed and introduced to the refrigeration market to help phase out CFCs and HCFCs. Their ODP is equal or very close to zero, as they do not contain chlorine, however some of them possess high GWPs (12-14000). The HFC phase-out started in 2019 and the use of HFCs is planned to be reduced by 85% in 2036 and by 80% in 2045, for developed and developing countries respectively.

Refrigerants for the future

As detailed in the previous section, since the 90’s high GWP and ODP refrigerants have been phased-out or are currently being phased-out. As a result, the refrigeration industry is developing low-GWP and zero ODP alternatives. Although sustainability is now key in the development of alternatives, these should also aim to be non-toxic, non-flammable, have acceptable operating pressures and an appropriate volumetric capacity to the application. Older and phased-out refrigerants were not toxic and not flammable, but as described before not sustainable either. In contrast, newer natural and synthetic alternatives are zero-ODP and have low GDP, but tend to be more flammable, toxic, or have lower volumetric capacity than HFC, limiting their usage to specific applications or requiring further technological development to be implemented (Goetzler *et al.* 2014).

Several synthetic and natural molecules have been identified or developed as suitable sustainable refrigerants and have been identified as low GWP alternatives to replace HFCs. Importantly, most refrigerants are suitable for only one or a few specific steps of the cold chain. For instance, refrigerants suitable for industrial refrigeration in seafood processing facilities are unlikely to suit smaller refrigeration units used in transport refrigeration or in supermarkets (Goetzler *et al.* 2014). Details on each type of refrigerant, possible replacement applications, safety, and efficiency characteristics, are presented in the following section.

Synthetic alternatives

Low-GWP HFCs (HFC-32 and HFC-152a)

The refrigerants HFC-32 and HFC-152a have been identified as viable replacements due to their lower GWP while maintaining comparable efficiencies compared to other HFCs. Although classified as A2L and A2 (low flammability and toxicity) respectively, both refrigerants remain on the higher end of the GWP scale in comparison to more sustainable alternatives. Refrigerant HFC-32 is considered suitable for air conditioning and heat pump applications, while HFC-152 has been found to be a viable replacement in commercial refrigeration application, chillers, and industrial refrigeration.

HFO (HFO-1234yf, HFO-1234ze)

Hydrofluoroolefins (HFO) are some of the most viable alternative refrigerants, with very low GWP as they have been designed to degrade quickly in the atmosphere (Majurin *et al.* 2015). The industry has developed several HFO blends for specific applications, from which HFO-1234yf and HFO-1234ze stand out, due to their GWP lower than 1 and A2L (low flammability and toxicity) safety classification.

Refrigerant HFO 1234yf has been found to be an effective replacement of the HFC-134a and is already being used for Mobile Vehicle Air Conditioning (MVAC) and is promising in chillers and commercial refrigeration applications. In addition, HFO-1234ze is easier to produce, hence cheaper, and could be used for large chillers requiring large quantities of refrigerants. Other HFO blends have been designed to offer higher volumetric capacities, with trade-offs in either GWP or flammability. Although their GWP values are higher, they are still much lower than the HFCs they would replace. However, their production implies multiple processes and is costly. In addition, the efficiency of HFO refrigeration systems has been found to be directly proportional to their GWP, meaning that sustainability or efficiency will be compromised (Goetzler et al. 2014). In case of fire, HFOs such as HFO-1234yf, will decompose and release very toxic molecules (i.e., hydrogen fluoride and carbonyl fluoride), while leaked HFOs can break down in the atmosphere and lead to increasing ecosystem acidity (Savitha et al. 2021).

Natural alternatives

Hydrocarbons

Propane, isobutane, and propylene have been identified as promising alternatives with similar efficiency to HFC. They have GWP values of less than three and are significantly cheaper to produce (by-products from the petrochemical industry) than synthetic alternatives but are classified as A3 refrigerants due to their high flammability. Despite this risk, hydrocarbons are suitable for small to medium-sized refrigeration, chillers, and air conditioning systems, and could be considered (i.e., propane) for larger residential and commercial air conditioning and chiller units (Goetzler et al. 2014). The cost of using hydrocarbons for small domestic and light commercial applications is like using HFCs, but significantly higher for larger commercial and industrial refrigeration systems due to safety measures (explosion-proof enclosures) (DANFOS, 2022).

Ammonia

Ammonia is of comparable efficiency to HFCs, environmentally safe (GWP = 0 and ODP = 0) but toxic (class B), making it unsafe for air conditioning units. Ammonia is, nonetheless, applicable for industrial and heavy commercial applications, such as large freezing and refrigeration plants without compromising safety. Although inexpensive and abundantly available refrigerant, ammonia refrigeration systems are relatively expensive due to the requirement for steel tubing, semi-hermetic compressors, and the installation of several safety devices, such as gas detectors (DANFOS, 2022), which may reduce the incentive to shift from HFC to ammonia refrigeration units.

Although, Ammonia is already being used in industrial refrigeration units, accelerating the shift toward this natural refrigerant will require the investment of money and effort to develop new products and materials specifically for small-capacity, low-charge ammonia systems for light industrial and heavy commercial applications. A few promising new technologies are gaining wider acceptance in recent years (e.g., Microchannel heat exchangers, DX ammonia evaporators and distributed systems, and Ammonia/CO2 cascade systems) (Collins 2016).

Carbon dioxide

Carbon dioxide (CO_2) is non-flammable and sustainable (GWP = 1 and ODP = 0) and has been found as a viable replacement for applications such as commercial refrigerated vending machines, supermarket refrigeration, secondary expansion systems, and industrial and transport refrigeration systems. However, because of CO_2's inherent toxicity, it is unlikely to be beneficial for air conditioning purposes. A CO_2 refrigerant has a far lower theoretical cycle efficiency than the HFCs it would replace, and consequently reducing the total system efficiency. Nonetheless, the development of CO_2 systems, allow it to be used in various refrigeration applications such as supermarkets and vending machines.

Although a by-product of many industries, hence relatively cheap and available, the high pressures needed for CO_2 systems to work increases its price and represents safety hazards that need to be considered for its operation. This slows down the shift from HFCs to CO_2 based systems as it would require a full system redesign to adapt to the high pressure.

Sustainable synthetic and natural refrigerants have been developed to replace the HFCs with higher GWP. Nonetheless, the shift to these new options is not straight forward and implies investment, structural changes, and trade-offs. Furthermore, these new alternatives may not be suitable for all stakeholders involved in cold-chain post-harvest processes. Some of the most promising alternatives are synthetic HFO blends and natural ammonia and CO_2.

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16 PACKAGING

Fish Post-harvest European value chains using this process

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Brief description

Proper food packaging ensures that seafood products remain fresh throughout the entire processing chain (Almeida et al., 2021). The main functions of product packaging can be summarised as followed: (1) Protect the food product; by protecting it from external environments and by creating the optimal storage environment in the package itself, (2) Communicate outwards in the form of marketing and product information towards consumers, (3) Provide a convenient product for the consumers, and (4) Contain food products within its packaging (Walsh & Kerry, 2012).

When looking at the environmental impact of seafood product packaging, several things must be considered. The first consideration includes the type of environmental impacts for each product. These impacts can be subdivided into direct and indirect environmental impacts. Direct impacts are related to the fabrication, transport, and handling of waste from producing the packaging (Lindh et al., 2016). In contrast, indirect environmental impacts are related to the environmental consequences of food loss and associated waste streams (Molina-Besch et al., 2019).

Furthermore, when considering the environmental impact of packaging, different types or levels need to be included in the assessment. These levels are depended on the amount of contact the packaging has with the product and the specific needs within the value chain, with (1) primary packaging being in direct contact with the product (e.g. the wrapping or cans), (2) secondary packaging containing several layers of primary packaging products (e.g. cardboard boxes that batch several products together) and (3) tertiary packaging which is mainly used for transport between different facilities of the value chain (e.g. transport boxes, pallets) (ISO, 2016). In life-cycle assessments (LCA's) not all the packaging levels are considered in the assessments of environmental impacts and solutions or improvements for each packaging type, or at least the results of such detailed analyses are not commonly given in papers (Almeida et al., 2021).

All these factors influence the environmental impact of packaging types and need to be included in assessments of the most sustainable products. The following paragraphs will describe in greater detail the direct and indirect environmental impacts of the fish packaging, and what technologies and methods have been used to reduce the environmental impacts.

Direct environmental impacts of packaging

In a review from 2021, the direct environmental impact of fish packaging was analysed for different operational post-harvest supply chains and packaging products (Almeida et al., 2021). The review considered 32 life-cycle assessments executed over different fish products and reported the environmental impact of a wide array of packaging types.

In the review, it was noted that enormous differences in impact of primary packaging occurred between canned products and other fish products (Almeida et al., 2021). The impact range of canned products varied between 6-89% (for tinplate) and 10-83% (for aluminium) (Almeida et al., 2021), and resulted from the energy requirements for the life cycle of these materials (Vázquez-Rowe et al., 2014). The high variation in environmental impact was determined to be result of (1) variability in packaging weight compared to product weight (which identifies the amount of packaging used), (2) variation in the fish product processing, and (3) operational differences and associated data differences (data detail level) used for estimating the environmental impact (Almeida et al., 2021).

In contrast, the environmental impact of packaging for fish products that need energy intensive processing steps (e.g., freezing, chilling, and drying) takes up a smaller quantity of the product's environmental footprint. The contribution of packaging for these fish products varied around values of 5% of the total climate change impacts (Almeida et al., 2021).

Due to the differences in relative contribution to the environmental impact of the fish products, sustainable solutions need to be focussed on distinct aspects of the product. For canned products, substitutions in packaging could influence the environmental impact significantly; with a shift from tinplate to aluminium in canned tuna reducing the impact with 63% (Avadí et al., 2015) and 56% for sardines (Almeida et al., 2015). A different study reported that the switch from tinplate to plastic resulted in the greatest decrease in impact (Laso et al., 2018). This change however will also change the product presentation towards to consumer and may need large equipment changes, which can make it a financially less sound decision (Almeida et al., 2021). In contrast, with the low environmental impact of packaging in the frozen and chilled products, it is better to focus the packaging efforts on the reduction of food waste instead of finding material with lower environmental impacts (Almeida et al., 2021).

Lastly, recycling and reusing of packaging materials has great potential to further reduce the GHG emissions due to the end-of-life practices for these materials. If properly reused and recycled, packaging material can be choses over new packaging materials even if the energy requirements of specific recycling may be higher, because the longevity of the product will have an overall positive effect compared to processing of new packaging materials with a shorter lifespan (Almeida et al., 2021). However, if recycling capacity is insufficient, large amounts of used materials will still be processed in less environmentally efficient methods (e.g., by exporting used materials to other countries) which can counter the overall positive environmental effect (Almeida et al., 2021).

Indirect environmental impacts of packaging and packaging solutions

The impact of the food waste is the main subject, when considering the indirect impact of fish product packaging. This environmental impact related to food waste makes up a substantial part of the climate impact of the food supply chain, with estimates of up to 15-16% of the food chain impact (Scherhaufer et al., 2018). As fish product deteriorates very quickly, efforts on improving packaging have mostly focussed on increasing the shelf life and product quality, as well as monitoring the quality throughout its storage time.

Packaging technology

Modified atmosphere packaging

One of the main functions of the fish product packaging is acting as a protective barrier for the external environment. Internally creating the optimal environmental conditions for prolonging the shelf-life, such as modified atmosphere packaging (MAP), specifically focusses on this aspect. The MAP packaging lowers the product respiration and ethylene production rates which slow deterioration processes down, as well as avoid the formation of bacterial growth and reduce possible chemical reactions of the product (Tsironi & Taoukis, 2018). Gasses such as oxygen, CO_2, and N_2 are widely used to create the modified atmosphere. Importantly, the concentration of the gasses within the package is depended on the specific food product (Kirtil et al., 2016).

In combination with MAP, active and smart packaging helps prolonging the shelf life of the fish product. Active packaging responds actively to (internal or external) environmental changes and aims to prolong shelf life by adapting packaging conditions accordingly (Tsironi & Taoukis, 2018). Intelligent packaging monitors (internal or external) conditions, and if product deterioration is measured it communicates findings to consumers (Fellows, 2009).

Active packaging

Three main active packaging types exists, those are gas control, moisture control, and antimicrobials and/or antioxidants (Tsironi & Taoukis, 2018). Gas controlled active packaging absorbs substances that are associated with product deterioration or emits gasses to control or decrease the deterioration rate of the product. Lowering the oxygen level lowers muscle tissue deterioration, which happens through iron oxidation, unsaturated fatty acids and ascorbic acid, and photosensitive dye oxidation (Tsironi & Taoukis, 2018). Gas, such as CO_2 has proven to be hindering bacterial growth, and a variation of technologies can be used for this gas control (Tsironi & Taoukis, 2018).

Moisture control can be achieved by using absorbing materials such as pads, sheets, blankets (Biji et al., 2015) or by making use of desiccants (Sängerlaub et al., 2013). Furthermore, several companies have developed active moisture regulators that make use of polypropylene (PP) or polyethylene terephthalate (PET) to further manage the moisture content in the packaging (Tsironi & Taoukis, 2018).

Active packaging can lastly release antimicrobial and antioxidants as a response to product deterioration. By detecting compounds released during product deterioration, a controlled release of bioactive compounds or volatile antimicrobials can hinder the development of microbes in the fish product (Tsironi & Taoukis, 2018).

Intelligent packaging

Smart packaging makes use of indicators to detect and communicate the presence of deterioration. Indicators exists for freshness, packaging integrity and time and temperature (Tsironi & Taoukis, 2018).

Freshness indicators indicate the presence of microbial metabolites and change the colour accordingly. These indicators can be used to communicate the remaining shelf-life or if a product is still appropriate for consumption by the consumer (Tsironi & Taoukis, 2018). Similarly, packaging can leak indicators that can be used to communicate the structural integrity of the packaging material, which can be especially important for MAP (Tsironi & Taoukis, 2018). Through pH indicators, smart labels for CO_2 and O_2, and optical sensors, the freshness of the product can be measured and communicated. Lastly, time and temperature smart sensors can inform shelf-life changes as a result from temperature changes and handling times and can provide information on how many times the product was handled and if the product was handled correctly (Tsironi & Taoukis, 2018). This is especially important for fish products, as these are heavily depended on storage/handling. These indicators are not only useful to report on the product quality/shelf-life but may also be an indicator of the packaging integrity itself.

Edible coating and films

Lastly, additional coating and film can be used to add more protection to the fish products. These layers can be added directly onto the products' surface (coatings) or can be prepared separately and added later onto the product (films). They work as an extra protective layer around the fish product and control leakage (such as gasses, moisture, and solutes) while allowing exchange of gasses (such as O_2, CO_2, and Ethylene) (Tsironi & Taoukis, 2018).

The environmental impact of packaging is a complex matter. Depending on the packaging level and impact type, the environmental consequences can differ greatly. Reported LCA's have often only focussed on parts of the package life cycle, thus making the overall environmental impact not always clear. However, thanks to recent review papers, some deeper insights were gathered.

For direct impacts, there is a significant difference between canned and pre-processed fish products. For the canning industry, large parts of the environmental footprint are related to the life cycle of the canned material and changes in packaging material can drastically reduce the environmental impact. For processed fish products that use freezing, chilling, and other intermediary storage steps, the contribution of packaging is relatively low. Here efforts are better focussed on the indirect impacts of the packaging.

Indirect impacts, food spoilage and waste generation, can further be controlled and maintained through several packaging innovations. The most relevant innovations include MAP, and active and smart packaging materials, which all aim at prolonging the shelf life of the fish product.

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17 INDUSTRIAL MANAGEMENT STRATEGIES, ENERGY

Fish Post-harvest European value chains using this process

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Types of industrial strategies related to energy

- Heat recovery
- Insulate the retort and other heating equipment
- Automation and robotics for improving energy and resource efficiency
- Renewable sources of energy

Heat recovery

Heat recovery is a good strategy to reduce GHG emissions. It has been estimated that for many food processing facilities, process heat alone accounts for about 60-70% of total energy needs (Ladha-Sabur et al., 2019; Sovacool et al., 2021). Heat recovery is the reuse of heat produced in specific operations for other operations carried out in the same factory. For example, using residual heat of condensed steam from sterilisation to heat water for cleaning or for another operation such as boiling. It can be even used for preheating the incoming air in the ambient heating systems of the production plant. From a general perspective, heat recovery can reduce energy needs by 10% (Sovacool et al., 2021).

Many companies, especially those which use heat intensively like canning factories, did internal diagnoses (or with the help of an external company) to determine where action can be taken for heat recovery to reduce economic costs and, at the same time, to reduce GHG emissions.

Although techniques like pasteurization are currently energy efficient (95% of heat in pasteurizers is recovered), the potential for waste heat recovery in other processes is substantial (Sovacool et al., 2021). Heat recovery will continue to be a useful strategy to improve the competitiveness of seafood companies, helping to reduce GHG emissions, without strong investment.

Insulate the retort and other heating machines

Cleaner production strategies based on the improvement of insulation of the retorts (autoclave; sealed pressure chamber for heat treatments) and other heating machines for reducing energy consumption (COWI). Typically, the energy consumption is 200-240 kWh per tonne of canned product. The energy consumption is a major environmental issue, as it causes resource depletion and air pollution. Insulation of the retort can save 1.4 kg of fuel per tonne of canned product.

Improving insulation of retorts is currently a standard practice for the equipment suppliers R&D operations. This strategy is also very common in companies when implementing cleaner production. These initiatives must be viewed considering a general commitment to continuously develop products and processes.

Although an insulation strategy has been around for some time, there are a lot of small and/or traditional companies in Europe that are still using retorts and similar machines that are poorly insulated. These old machines are or will be at the end of their useful life in the following years, so it can be expected that these companies will substitute the current units for other more modern and better insulated units. Furthermore, the insulation materials are improving continuously, so there is still room for improvement.

Automation and robotics for improving energy and resource efficiency

The incorporation of automation and robotics in food production for better control of production systems is one of the cornerstones of the Fourth Industrial Revolution in which the industrial sector is immersed. It has been highlighted as an essential strategy not only to reduce the cost of production, but also to improve energy and resource efficiency and reduce GHG emissions (Simpson et al., 2013; Sovacool et al., 2021).

During the past 20 years automation of processes and the use of robotic solutions have gained increasing attention. In fact, automation and robotics is probably one of the most important sources of innovation in the development of new machinery for the seafood sector. This includes standard automated cutting and forming machines, ovens, mixers, blending machines, sorting equipment, filling equipment, and packaging and wrapping equipment (Sovacool et al., 2021). These initiatives must be viewed considering a general commitment to continuously develop more efficient products and processes and reduce related costs. Some subsectors, such as seafood canning, raw material handling and packaging, are currently almost entirely automated (Sovacool et al., 2021).

Automation and robotics will play a main role in the seafood sector over the next 20 years. As in other sectors, the required levels of quality control, speed of production, labour shortages and overall profitability will need to be addressed (Sovacool et al., 2021). Automation will allow to change production methods, "lights-out manufacturing", and "24:7 manufacturing" will be possible, enhancing productivity yields and lowering energy consumption (Thomas et al., 2018).

Renewable sources of energy

Substituting fossil fuels by renewable energy sources can strongly reduce the GHG emissions. It is a key strategy of the 2030 Climate Target Plan of the European Union. It has been estimated that the 60% of existing heat demands in the food sector can be provided by renewable energy, especially those needing low to medium temperatures (IRENA, 2015). The renewable energy sources that show the most potential are biomass energy sources, solar thermal heating, and geothermal heat pumps (Sovacool et al., 2021). Factories located in southern Europe, where there are many sun days, can integrate solar panels on their roofs to reduce their external energy consumption. However, placing solar panels on roofs may proof challenging as many factory buildings are not structurally calculated to place the weight of solar panels on their roofs. Targeted and constructive investigations and funding will be necessary in the future.

The use of renewable sources of energy has been increased a lot in the past two decades. Many fish processing companies, especially those which use heat intensively like canning factories, did internal diagnoses (or with the help of an external company) to determine potential strategies and applying those strategies to increase energy efficiency and increase the employment of renewable energy sources. Companies have tried to reduce the use of traditional solid-liquid fuels by modifying their processes and adopting new processing technologies that demand electricity, which can be supplied by renewable energy sources directly (e.g., solar panels at the factory) or indirectly (e.g., the electricity supplier).

The use of renewable energy sources will be the cornerstone of the adaptions of the European seafood sector to reach the objectives of the 2030 Climate Target Plan. To adapt their systems to the legal requirements, companies will have to modify their processes and adopt new processing technologies that, for example, demand electricity, which may be provided directly (e.g., solar panels at the factory) or indirectly (e.g., the electricity supplier). If maximum technological modernisation takes place, there will be a significant transfer of energy use from natural gas to electricity, resulting in an overall increase in energy use and costs, but with a significant reduction in CO_2 emissions (in the UK this could represent a cumulative CO_2 reduction between 2014 and 2050 of 70 million tonnes) (Sovacool et al., 2021). The magnitude of the cost increase will depend on costs from adopting the fuel or processes to changing factories' infrastructures.

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18 INDUSTRIAL MANAGEMENT STRATEGIES, GENERAL

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☒ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of general industrial strategies

- Automation and Data collection
- Cleaner production strategies
- Promoting short food supply chains
- Industrial strategies (incentive and methods for change)

Automation and Data collection

Although data monitoring and automation technologies are two distinct types of strategic developments, they are presented together in this technological sheet because they complement each other and are very likely (or should be) to be integrated together into cold storage facilities. This does not rule out the possibility of implementing them separately, as they do not necessarily depend on each other to function.

Data monitoring has become relevant for many industrial and commercial sectors, as it allows companies to track their efficiency throughout their value chain, to identify issues and to adjust in “real time”. The combination of process automation and data monitoring allows to reach higher production rates, higher efficiency of material and energy use, lower energy consumption, better product quality and consistent standards, increased work safety and reduced working hours. Furthermore, data monitoring and its analyses can also help to justify investments by providing accurate payback calculations, to enhance troubleshooting and diagnosis of issues.

The automation of processes in cold storages/warehouses is advantageous as facilities can be built vertically, rather than horizontally, reducing its footprint, hence reducing the price of the property and associated taxes, and reducing the heat gained through the roof area

(Kolbe et al. 2006, Caldwell, 2013). Thus, vertically built cold storage/warehouses will reduce the energy needed to maintain the cold temperatures in the storage unit, reduce equipment wear due to unnecessary/excessive use, and reduce quality and product loss due to hotspots and temperature fluctuation. Similarly, automation allows a more efficient door management and reduces cold loss through them.

In cold storage facilities, the cooling systems are responsible for 70-80% of the energy consumption (bills) (Evans et al. 2013). Technological developments and industrial management changes have enabled the cold chain industry to increase their energy efficiency, reduce operational costs and increase its environmental sustainability throughout their processes. Nonetheless, over time most refrigeration systems do not continue to operate as effectively as the manufactures planned and might be functioning far from optimal due to poor maintenance, failed components, lack of technical knowledge among the site managers to understand the impact of operational changes or time to undertake meaningful plant performance evaluations (FFT, 2019). To tackle these issues, automated data monitoring, modelling and accessibility through newly developed data monitoring technologies and platforms have been developed to provide specific, precise, and clearly explained insights/recommendations to optimize the plants performance and maximise its efficiency, therefore reducing energy consumption and the GHGs emissions and costs associated with those specific issues.

In the following section the main technological developments in cold storage automation and data monitoring, and their advantages and disadvantages are presented.

Technological development in Cold storage automation

Technological development in the automation of the cold storage units is mostly linked to the pallet storage and its management. In traditional human-managed cold storage units up to 60% of the space available must be used for gangways for forklifts and personnel to move and manage the stored products (Refrigers.com, 2011; Cadwell, 2013). In contrast, in automated systems, pallets are now reached by cranes and shuttle systems, hence heavily reducing, or removing the need for gangways, allowing more pallets to be stored in the same storage space, thus using less energy per kg of product. Furthermore, cranes allow storage space to be built up vertically rather than horizontally (e.g., Viastore.com 2022; Logiqs, 2022), reducing its footprint. This represents a critical factor for energy savings as most heat gains in cold warehouses occurs through the roof (Cadwell, 2013).

Automated facilities tend to have smaller and better (automatically) controlled doors, as they do not need to be used anymore by humans and forklifts to carry pallets in and out of the facilities, thus reducing cold air loss. One crane can work at a faster rate compared to a man-operated forklift, handling up to 50 pallets per hour hence maximising efficiency (Cadwell, 2013). Altogether, these changes represent a significant energy consumption reduction, first directly as refrigeration units must work less to maintain the low temperatures and second, indirectly because of the increased efficiency, reduced quality and product loss, reduced time loss due to safety hazards and accidents, and reduced waste production (Viastore.com 2022; Logiqs, 2022, Central Florida Freezer & Warehousing, 2019).

Semi-automatic pallet shuttles do need the presence of a forklift and its operator, to place the pallet on the channel where the where the automated transport will occur by means of a Wi-Fi-connected tablet, which operates and instructs the system to execute determined movements (**Error! Reference source not found.**). In contrast, in a fully a utomated pallet shuttle system, the shuttle is guide by software that consists of warehouse management systems, which coordinates all operations in the most efficient way, while forklifts are replaced by automated transfer cars and stacker cranes (**Error! Reference source not found.**). The choice between these two alternatives will depend on specific workflows, investments, warehouse capacity, safety, and logistics. Nonetheless, both alternatives optimize the movement of manual systems, minimize the error probability (products ending up in the wrong transport chain) and provide significant advantages to enhance the workflow's efficiency.

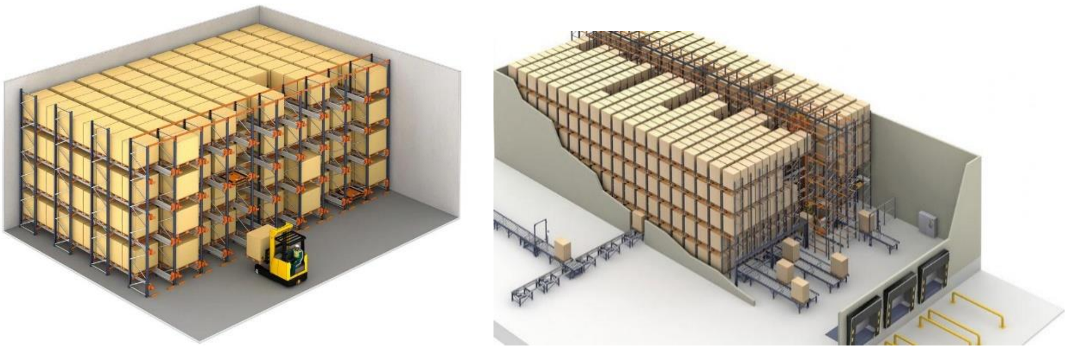

Figure 9: Semi-automated (left) and fully automated (right) pallet shuttle system. Source: Mecalux.com, 2022

Although they still represent a significant investment, automated technologies have become affordable for the industry in the last decades (FFT, 2019) and investment cost linked to its installation can soon be paid-back by the increased efficiency of the storage unit and the reduction of the costs described before.

Technological development in data monitoring and analysis

Monitoring data during cold storage (and transport) is crucial in assuring that product quality is maintained throughout the cold chain, but also can help to detect and reduce system malfunctions, and suboptimal settings, and therefore increase the systems efficiency, decrease energy consumption and costs. Although data monitoring in cold storage facilities has already been used for several decades, a multitude of solutions have recently been developed to also provide continuous and automatic plant performance data, the analyses of this data and concrete solutions/recommendation made available to specific/relevant personnel in an appropriated language (e.g., Zanoni and Marchi, 2020).

For cold storage applications, wireless temperature loggers may be the most common implemented system. These allow to, in real time and remotely, detect hotspots and temperature fluctuations to reduce damage and financial losses associated with inappropriate cold chain supply systems. Nonetheless, more advanced applications may include the monitoring of specific machinery and their energy consumption, to detect malfunctions and/or un-optimal settings, as the aim is to increase the efficiency of the system. For the latter it is crucial, that the data analyses and derived conclusions/recommendations are made available to the correct personnel and in an adequate language. For example, an engineer may not have a full understanding of the performance indicators for specific equipment but would still be able to optimize the plants performance if recommendations are provided in an understandable way. It is worth mentioning that a multitude of data monitoring and analyses systems have been developed by now, allowing these to be equipped in basically all cold storage plants, regardless of their age, size, and type of system (i.e., refrigerant used, temperature ranges).

Cleaner production strategies

Unlike traditional management, where pollution control is an after-the-event, 'react and treat' approach, Cleaner Production is defined as the continuous application of an integrated, preventive, environmental strategy applied to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment (Baas et al., 1992).

Although it has most commonly been applied to production processes, bringing about the conservation of resources, the elimination of toxic raw materials, and the reduction of wastes and emissions, it can also be applied throughout the life cycle of a product, from the initial design phase, through to the consumption and disposal phase.

The other important feature of Cleaner Production is that by preventing inefficient use of resources and avoiding unnecessary generation of waste, an organisation can benefit from reduced operating costs, reduced waste treatment and disposal costs, and reduced liability. Investing in Cleaner Production to prevent pollution and reduce resource consumption is more cost effective than relying on increasingly expensive 'end-of-pipe' solutions. There have been many examples that demonstrate the financial benefits of the Cleaner Production approach as well as the environmental benefits.

It is often claimed that Cleaner Production techniques do not yet exist or that, if they do, they are already patented and can be obtained only through expensive licences. Neither statement is true, and this belief wrongly associates Cleaner Production with 'clean technology'. Firstly, Cleaner Production depends only partly on new or alternative technologies. It can also be achieved through improved management techniques, different work practices and many other 'soft' approaches. Cleaner Production is as much about attitudes, approaches, and management as it is about technology. Secondly, Cleaner Production approaches are widely and readily available, and methodologies exist for its application. While it is true that Cleaner Production technologies do not yet exist for all industrial processes and products, it is estimated that 70% of all current wastes and emissions from industrial processes can be prevented at its source using technically sound and economically profitable procedures.

Promoting short food supply chains

Short food supply chains could be defined as co-operative systems that include very few intermediaries, increasing sustainability, transparency, social relations and fairer prices for food producers and consumers. Such supply chains usually involve local producers working together to promote local food which, in many cases, only travels a short distance, so producers and consumers can communicate with each other. This strategy is related to the concept of "decentralisation" as opposed to the concept of "centralisation" that normally governs the conventional large chain. Producing food closer to its point of consumption not only minimises the energy needed for transport and delivery but could also diminish food storage and refrigeration needs and, consequently, reducing the GHG emissions (Sovacool et al., 2021). From a technological perspective, one innovative idea is for "central kitchens" where fresh foods like fish products can be prepared very close to their place of consumption (Sovacool et al., 2021).

Trends in technological evolution of short food supply chains since 2002

In the last two decades, short food supply initiatives and networks have flourished across Europe and North America (Cicatiello, et al., 2015). Due to the COVID-19 pandemic, their importance has increased. Although it has been established that short food supply chains are better from an environmental perspective, the main driver for the increasing popularity in Europe is to ensure a fair price for small producers.

Short food supply chains are expected to grow strongly over the next 20 years, based not only on their proven benefits for small-scale producers, but also because of the change in lifestyle that has taken place due to the COVID-19 pandemic. However, there is a need to assess whether the increase in short food supply chains is really related to a decrease in GHG emissions.

Industrial strategies (incentive and methods for change)

To effectively transition a sector towards more sustainable practices, it is important to look at motivators for change and distinct sector areas with a high potential for change. This approach aims to identify actions with the most impact whilst keeping the sector on-board for the change.

Academic literature investigates this potential for change through two distinct strategies: by identifying and focussing on processes with high environmental impacts and by specifically investigating the motivators for change. Most of the academic efforts have been reported as life-cycle assessments of the industry, with less effort aimed at the incentive for change of the sector. Furthermore, efforts to incentivise focussed on consumer awareness and demands of the industry, while the processing practices remain less understood (Illes, 2007).

When specifically focussing on the development of strategies, two levels can be identified, that is sector level (high-level industrial strategies) and local businesses level (low-level industrial strategies).

High-level industrial strategies

High level industrial strategies look at an incentive to change covering a whole sector. Regarding the incentive for change, companies themselves work towards sustainability for four distinct reasons: 1. Regulations, 2. Community relations, 3. Cost and revenue imperatives, and 4. Societal obligations (Epstein et al., 2017).

For the fish processing equipment (FPE) producing companies specifically, a study on the incentive in small companies within Europe was executed to determine the drivers for change (enablers and obstacles) of green innovation (E. S. Bar, 2015). The interviewed companies in the studies were all working on innovation, but innovations were never environmentally driven (E. S. Bar, 2015). Environmental impacts and requirements were never actively added into the FPE producing business mainly due to limited financial and staff capital, and a lack of in-house knowledge and tools (E. S. Bar, 2015). Because PFE producing businesses need to meet very specific customer needs, there is no financial margin or need to go beyond the environmental requirements (E. S. Bar, 2015). The lack of in-house knowledge and costumer demands focussed on environmental impacts results in the prioritisation of other design qualities (such as efficiency and cost) (E. S. Bar, 2015). Furthermore, because FPE companies provide equipment in a larger supply chain, their impact is often overlooked and/or overshadowed. Because environmental hotspots (such as feed production, refrigeration, fuel use and transport) (Winther et al., 2020) receive most of the attention, sustainable improvements in the processing equipment chain receive less attention (E. S. Bar, 2011).

This paper concludes that investments into the innovation for the FPE producing companies are mainly financially driven, with the intention of the investment aimed at stricter regulations and decreasing production costs (by increasing efficiency and/or decreasing the need for manual labour (E. S. Bar, 2015). The sector itself sees stricter regulations and policy as an effective method of moving towards more sustainable practices (E. S. Bar, 2015), and this is in line with findings from other sectors (Epstein et al., 2017).

Low-level industrial strategies

Supply chain management at a business level requires decision making within the company and cooperation with other stakeholders, for example through the collaboration of a transport business and seafood producer. A few review papers delved into improved environmental practices specifically for the seafood sector and summarized in (Denham et al., 2015).

In this review paper, topics such as transport, packaging, storage, and retail are briefly discussed. Supply chain improvements are described through five categories: (1) Good housekeeping, (2) Input substitution, (3) Technological modification, (4) Product modification, (5) Recycling waste (UNEP, 2002). This paper contained a list of cleaner production cycle strategies that can be applied in both the seafood sector production as well as the post-harvest chains (Denham et al., 2015).

Transport

The environmental impact of transportation is a complex matter. It can drastically influence the environmental footprint of a product (Coley et al., 2011), but is depended on the preceding processing steps and associated costs (Tlusty & Lagueux, 2009). Fish product processing influences freshness and shelf life and make different transport methods available, for example fresh fish needs to be transported quicker compared to frozen seafood products to avoid quality loss. Transportation through ship freight is the least impactful transportation method for frozen product, followed by road and air freight respectively (Vázquez-Rowe et al., 2012). Because of the rapid quality deterioration of fresh products, it became clear that transport of fresh products with lorries and air freight is more impactful compared to frozen transport (Andersen, 2002).

Pre-processing methods such as among others, freezing, drying, and smoking, therefore need to be considered for transport over longer distances, because these allow longer transport times without quality loss (Andersen, 2002). Above-mentioned processing steps reduce the need for energy intensive refrigeration during product transport and allow the usage of energy-efficient transport alternatives (Andersen, 2002). Further improvements can be achieved by monitoring and creating awareness with the consumer of the distance travelled per product. This can be achieved by monitoring and communicating travelled distances towards consumers, whilst further improving transport efficiency (Kissinger, 2012).

Packaging

The overall impact of the packaging and processing is something that needs to be considered in the context of the product’s supply chain. If more energy intense processing and packaging methods need to be used but it helps to improve the quality and shelf-life of the product, it can be justified in the processing steps (Williams & Wikström, 2011).

For packaging of a product with shelf-life requirements of less than 30 days, Modified Atmosphere Packaging (MAP) is seen as the least energy, heat, and power intensive in comparison to methods such as high-pressure processing and thermal pasteurisation (Pardo & Zufía, 2012).

Processing

The environmental footprint of processing activities is optimisable by making use of monitoring, quality checks and subsequent good housekeeping rules (Denham et al., 2015). Process monitoring allows for identification of supply chain issues and helps with the implementation of follow-up actions. Such actions can for example be achieved by adapting defrosting and maintenance cycles, detecting, and eliminating wasteful process streams (Bezama et al., 2012). Supply chain optimisation and good housekeeping as such will not only increase efficiency of the process, but also help reducing climate impact by lowering the energy and water needs (Thrane et al., 2009).

Monitoring and optimisation of the processing supply chain further helps reducing the environmental impacts by delivering more products of the highest quality. In turn, avoiding the production of waste products optimises resource usage and reduces waste generation, which further lower the process footprint (Zugarramurdi et al., 2007). Other activities that help to reduce waste generation such as dynamic expiration dates, freezing of products to prolong their freshness and alternative usage of waste products can further help lowering the impact of the processing chain (Denham et al., 2015).

Furthermore, waste process streams and their environmental impacts can be further reduced by combining different businesses through symbiotic relationships (circular economy). It has been shown that collaboration between different industrial stakeholders can increase efficient resource usage, reduce greenhouse gas emissions, waste production and eutrophication (Martin & Harris, 2018).

Retail

Good housekeeping practices can reduce the environmental footprint of retail activities. This can be achieved by ensuring the (energy) waste process streams are reduced, by for example installing air curtains to reduce temperature loss in retail fridges (Laguerre et al., 2012). Increasing retail packaging efficiency and demanding higher sustainability requirements from their suppliers is another example (Denham et al., 2015).

Both high- and low-level industrial strategies aim at improving the resource efficiency. High level industrial strategies are mainly aimed at improving the use of financial capital, by decreasing costs or increasing the productivity. Low level industrial strategies work on the level of increasing efficient resource usage, and this can be achieved through sustainability monitoring and reporting as well as proper implementation of corrective actions and good housekeeping.

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19 INDUSTRIAL MANAGEMENT STRATEGIES, WATER

Fish Post-harvest European value chains using this process

☒ CS 1 Sprat & Herring
☒ CS 2 Blue whiting, Boar fish
☒ CS 3 Herring & Mackerel
☒ CS 4 Chub & horse mackerel, sardine
☒ CS 5 Mackerel, Herring, Horse Mackerel
☒ CS 6 Salmon aquaculture
☒ CS 7 Red mullet, gurnard (& squid)
☒ CS 8 Whitefish (& crustaceans)
☒ CS 9 Seabass & Seabream
☒ CS 10 Cod & Bream
☒ CS 11 Carp
☒ CS 12 Sole & plaice
☒ CS 13 Invasive species (lionfish, rabbitfish)
☒ CS 14 Mussels & Oysters
☒ CS 15 Mussels
☒ CS 16 Shrimp (Pandalus)
☒ CS 17 Nephrops
☒ CS 18 Imported shrimp
☒ CS 19 Imported shrimp
☒ CS 20 Tuna Bay of Biscay & imported tuna
☒ CS 21 Albacore tuna
☒ CS 22 Improved processing technology
☒ CS 23 Common Cuttlefish

Types of industrial strategies related to water

- Reusing retort water for cooling or cleaning (water recovery)
- Water storage tank in retort

Reusing retort water for cooling or cleaning

Cleaner production strategies based on the reuse of the water in the retort (autoclave) for cooling or cleaning (COWI). Typically, the energy consumption is 200–240 kWh per tonne of canned product (COWI). The energy consumption is a major environmental issue, as it causes resource depletion and air pollution. Instead of discharging the water, the water can be directed to a cooling tower and reused for heating. The number of times water can be reused depends on maintaining the reused water clean. The water can become contaminated with broken cans and residues from the surface of the cans. Damaged cans should be removed before placed into the retort to avoid contamination of the water. When the water can no longer be recirculated, it could be used to clean the sealed cans and for other cleaning activities. The investment required for installation of the necessary pipes and pumps is low, and about 85% of the water can be reused.

Reuse of the retort water for cooling or cleaning is currently very common in the companies when implementing cleaner production strategies. These initiatives must be viewed considering a general commitment to continuously develop products and processes.

Although this strategy is old, there are a lot of small and/or traditional companies in Europe that are still directly eliminating water of retort, so there is still room for improvement.

Water storage tank in retort

Environmentally cleaner production strategies based on the improvement of insulating retorts and other heating machines to reduce energy consumption (COWI) have been made. Typically, the energy consumption is 200-240 kWh per tonne of canned product (COWI). The energy consumption is a major environmental issue, as it causes resource depletion and air pollution. Water-filled retorts without water storage facilities use approximately 75% more energy than retorts with water storage facilities (COWI). Therefore, the installation of a storage tank should be considered if not already in place. The required capital investment is low, and both energy and water savings are very substantial: approximately 173 kWh and 5-6 m^3 of water per tonne (COWI).

The installation of a storage tank in retorts is currently a standard part of the equipment. This strategy is also very common in companies when implementing cleaner production because the required capital investment is low, and savings are very substantial. These initiatives must be viewed considering a general commitment to continuously develop products and processes.

Although this strategy is old, there are a lot of small and/or traditional companies in Europe that do not have water storage tanks for their retorts. These old machines are or will be at the end of their useful life in the following years, so it can be expected that these companies will substitute the current units for other more modern with water storage tanks.

References

COWI https://wedocs.unep.org/bitstream/handle/20.500.11822/9559/-Cleaner%20Production%20Assessment%20in%20Fish%20Processing-2000320.pdf?sequence=3&amp%3BisAllowed=

ANNEX 5. SUMMARY OF GHG EMISSIONS AND COST IMPACTS OF TECHNOLOGIES AND INDUSTRIAL STRATEGIES ON THE PH VALUE CHAIN

This Annex summarizes technologies and industrial strategies used in the EU Post-Harvest value chains.

Overview of technologies used in the PH value chains

Pre-processing – Thawing

Current **conventional thawing technologies** consist of water immersion-spray thawing, air thawing and microwave assisted thawing. Although both **air as immersion/spray** thawing technologies have disadvantages, such as the use of intermediate medium, longer processing times and potential microbial contamination, they are still in use due to their simplicity, their low cost and high capacity (Lee et al., 2021). The unique property of **microwaves** to penetrate and produce heat in the interior of food materials (volumetric heating) allows to accelerate thawing and tempering (Li & Sun, 2002). A heat transfer medium like water or air is not necessary when using this technology, which is an important advantage with respect to conventional water immersion or air thawing. Microwave assisted thawing needs a smaller space for processing, and reduces also drip loss and chemical deterioration (Li & Sun, 2002). However, this technique lacks uniform heating (James et al., 2017) and proper temperature control (Li et al., 2020). Improving the conventional thawing technologies comes with each their own specific challenges. For immersion-spray thawing, process efficiency and energy efficiency can be boosted and wastewater can be reduced. For air thawing the most important improvement can be made in reducing the slow thawing rates, while for microwave assisted thawing, the microwave conditions have to be improved in order to increase the heating uniformity within the seafood product during thawing.

Emerging technologies are ohmic thawing, high hydrostatic pressure thawing, radiofrequency assisted thawing and ultrasound assisted thawing.

The rapid and relatively uniform heating of **ohmic** thawing is achieved by the direct passage of electric current through the product (Liu et al., 2017). Advantages of this technique compared to conventional thawing are a higher heating rate, higher energy conversion efficiency and reduced processing time (Li & Sun, 2002). As the heating is produced directly within the food product (direct heating), no intermediary medium (e.g., air or water) has to be used which improves efficiency and reduces the amount of wastewater (Seyhun et al., 2014). Due to the higher energy conversion efficiency, this technology could allow the reduction of energy consumption of thawing/tempering and, indirectly, reducing the GHG emissions (Liu et al., 2017; Miao et al., 2007; Seyhun et al., 2014). Currently, this technology is not applied in the industry and remains experimental.

High hydrostatic pressure (HHP; also called high pressure processing) is an emerging food processing technology that pressurises food up to 800 MPa (standard industrial devices up to 600-650 MPa) for up to several minutes (Puértolas & Lavilla, 2020). Previous research has shown that the application of HHP improves the thawing process of fresh fish, reducing drip loss and maintaining a good product quality if the treatment is optimised (Cartagena et al., 2021; Puértolas & Lavilla, 2020). Although HHP is used especially for prepared meals (Puértolas & Lavilla, 2020), this technology is not yet industrialised. HPP faces technical challenges such as scale up and/or high costs related to the specialised equipment necessary to generate and maintain the high pressures during thawing process, (Cartagena et al., 2021). Despite of already existing research on this technology, HPP will be most likely applied on high-value products where the reduction of drip loss could amortise the cost of the treatment.

The unique property of radiofrequency electromagnetic radiation is to penetrate and produce heat in the interior of food materials (volumetric heating) allowing to accelerate thawing and tempering. **Radiofrequency assisted thawing** requires shorter thawing time (minutes) and less space for processing, reduces drip loss and chemical deterioration. However, it lacks uniform heating (James et al., 2017) and proper temperature control resulting in overheating is an issue (Li et al., 2020; Li & Sun, 2002) similar to microwave treatments. In the last five years the first industrial units have been sold to the general food industry, and for the seafood industry (STALAM[69]).

Ultrasound thawing involves the application of ultrasound during water immersion thawing/tempering, improving thawing uniformity and saving time with respect to traditional water immersion thawing (Bhargava et al. 2021; Li et al., 2020). The advantage of this technology lies in improving the heat transfer (Bian et al., 2022; Qiu et al. 2020; Li et al., 2020), thus facilitating the thawing process and significantly improving the efficiency of thawing (Bian et al., 2022; Qiu et al., 2020). For example, cod blocks required about 71% less time to thaw through ultrasound-assisted immersion in water when ultrasound at 1500 Hz frequency and power of 60 W was applied, as compared to conventional water immersion (Bhargava et al. 2021). Processing conditions must be optimised because high-power single-frequency ultrasound may damage the muscle structure of the product (Bian et al., 2022; Qiu et al. 2020). It is worth noting that ultrasonic waves have the disadvantages of high energy consumption and instability in practical applications (Bian et al., 2022). Ultrasounds should be treated cautiously, because it may be harmful to human health as it entails work safety hazards (adverse tissue injury, electrical shock, and burns and indirect damage) (Qiu et al., 2020). Ultrasound assisted thawing is currently in a research stage. Large efforts will have to be made for to allow this technology to work as large-scale industrial applications.

Processing

Control of water activity - drying

Drying of foodstuffs is an ancient practice and the technologies used for drying have mostly been around from previous century, thus **all** these technologies can be called **conventional**. Drying technologies are sun drying, solar drying and microwave drying, airless drying, freeze-drying, heat pump drying, hybrid heat pump drying and osmotic dehydration.

Sun drying is the most widespread and the cheapest method for drying fish (Boziaris, 2014). The process happens at low temperatures (even below 10°C; cold and fresh weather), while ambient humidity and time play key roles. Because sun drying does not need an external energy source, this drying process is probably one of the most environmentally friendly processing techniques with possibly the lowest impact in terms of energy and GHG emissions. However, the most important challenges during sun drying are the loss of quality due to contamination with dust and excreta from birds and animals, and difficulties related to controlling the process and the drying parameters (Boziaris, 2014).

Solar drying is an evolution of traditional sun drying. It differs from sun drying because the solar dryer is an enclosed structure that traps heat inside the dryer and uses it

[69] STALAM is a leading supplier of radio frequency (RF) equipment for the drying and thermal processing of raw materials and semi-finished and finished industrial products

efficiently (Immaculate et al., 2012). Solar drying also saves time, occupies a smaller drying area, improves the quality of the final products, and makes the process more efficient as well as protecting the environment (Boziaris, 2014; Catorze et al., 2022). In comparison to other drying techniques that employ hot air or heat pumps, solar drying saves energy and can potentially reduce GHG emissions (Catorze et al., 2022). Normally the (passive) process is still slow compared with other drying technologies such as heat pump drying (active drying). Trying to increase the processing speed, some solar dryers use electricity to support and maintain the process if there is no sun (Catorze et al., 2022). Although it can be expected that in coming years these difficult to control 'natural' drying processes will be replaced by specific, process efficient active drying technologies, the low energy demands and low climate impact of these traditional techniques may financially win from more energy demanding quick active technologies

Microwave heating has multiple applications in different heating technologies because it can heat the product without a heat transfer medium like water or air (see also conventional thawing processes) (Viji et al., 2022). In general, microwave processing is time saving, energy efficient and yields good quality fish products with high nutritional value (Darvishi et al., 2013; Viji et al., 2022). The faster and more focussed heat transfer results in a reduced energy waste, thus reducing the GHG-emissions. However, the application of this technology for drying seafood products still has a lot of room for improvement and, to the best of knowledge of the authors, its industrial application is very scarce. A major disadvantage of microwave drying is overheating of the product (Viji et al., 2022). A combination of microwave drying with other technologies can overcome these drawbacks of microwave drying. For example, vacuum assisted microwave drying or hot air microwave drying are successful developments, aimed to improve the product quality (Duan et al., 2011; Viji et al., 2022).

Airless drying happens in an airless dryer (Stubbing, 1993) and consists of a semi-closed rotary-dryer system that uses superheated water steam as drying medium. This technology is not so much suited for seafood drying but is applied in the aquatic feed production processes. In contrast to air dryers that have to vent hot air as waste, some benefits of airless drying system are reduction of energy usage as dryer exhaust (water vapour) can be condensed for energy recovery or used as an efficient heat source somewhere else in the plant. In addition, as this drying process creates an oxygen free environment, it presents a minimum risk for fire in the dryer and feed oxidation rate decreases.

Freeze-drying, also called lyophilization is a drying process that uses the sublimation of ice as its main drying mechanism (Boziaris, 2014; Waghmare et al., 2021). Freeze-drying provides dried products with a porous structure, small or negligible shrinkage, superior flavour and aroma retention, and improved rehydration capacity compared to products dried with other methods (Boziaris, 2014). However, freeze-drying has a high capital and operating costs due to long processing times and high energy consumption (Boziaris, 2014). Thus, it is mainly used on high-value products. Research has demonstrated that freeze-drying coupled with other processing technologies such as infrared, microwaves, ultrasound, and pulsed electric field reduces the drying time, increasing the drying rate, and saves energy (Waghmare et al., 2021). For example, the use of ultrasound shortens the drying time and, and therefore can save up to 70% of the total energy required by the conventional process (Merone et al., 2020).

A **heat pump dryer** is based on the use of hot and dry air of controlled temperature and relative humidity. The system involves a heat pump and a drying chamber. The humid air of the drying chamber passes through the evaporator, where the moisture is condensed into water. After the evaporator, the dried air is heated in the condenser and goes to the drying chamber again. The heat pump presents an efficient and environmentally friendly technology due to its low energy consumption (Boziaris, 2014), its robust performance and the high thermal efficiency of a correctly designed dryer. Some research efforts have significantly increased the energy efficiency of heat pumps. For example, by 35% through multi-staging and by 20% through the integration of heat-driven ejectors into the heat pump (ejector augmentation) (Chua et al., 2010). Additionally, the development of better compressor technology has reduced the energy consumption of heat pump systems (potentially up to 80% of savings) (Chua et al., 2010).

Hybrid heat pump dryers are efficient and environmentally friendly due to their low energy consumption (reduction of up to 60%), and their easy use in combination with a renewable energy source (solar, geothermal or biomass energy) (Hamdani et al., 2018; Singh and Gaur, 2021). Hybrid heat pump dryers for food-based applications are currently a focus of research and developed, especially in Asian countries (Hamdani et al., 2018; Singh and Gaur, 2021). According to different studies, hybrid dryers are profitable because they improve the energy efficiency of the process (reviewed in Hamdani et al., 2018). For example, the solar biomass hybrid dryer operates with biomass energy when there is no sun, so it can potentially operate year-round on renewable energy sources.

Osmotic dehydration is carried out by immersing the seafood in concentrated osmotic solutions (hypertonic solutions) of salt, sugar, or other low molecular weight compounds (water in the product diffuses to the osmotic solution), and is a common step in salting, smoking, and marinating (Boziaris, 2014). Osmotic dehydration reduces food damage created by heat and decreases the energy costs in comparison to other drying techniques (Boziaris, 2014). However, it is a slow process, and it is not possible to obtain food with the same low water content as with other more aggressive drying techniques that apply heat. To reduce waste and improve the overall efficiency of this process, different approaches for reusing the hypertonic solution are nowadays applied (e.g., membrane filters, recirculation, UV decontamination, etc.). Research has been demonstrated that osmotic dehydration coupled with other processing technologies such as ultrasound and pulsed electric field reduces the drying time, increases the drying rate, and saves energy (Boziaris, 2014; Semenoglou et al., 2020).

<u>Control of water activity – salting</u>

Salting is one of the oldest ways of fish preservation (Boziaris, 2014), with dry, pickle or brine salting and injection salting being **conventional** techniques. It is centred on the diffusion of salt into the fish muscle and the removal of water from the fish muscle, lowering water activity (Rui Costa, 2010). Nowadays, the fish is piled with alternating layers of salt into a plastic tub with a hole in the bottom for draining the liquid extracted from the fish (Boziaris, 2014). In pickle salting the liquid extracted while the salt is penetrating the fish muscle is not drained and the fillets are gradually immersed in saturated brine. However, the ratio of brine to fish is much lower than the ratios that are usually used in brine salting. Brine salting is performed by immersing fish directly into brine. Dry, pickle and brine salting are normally applied at low temperatures to avoid microbial grow, so its impact in terms of energy consumption and GHG emissions is lower than that of other fish PH technologies used to control product water activity that need to heat the product.

Over the last decades, salting by **automatic brine injection** into the fish flesh by multi-needle systems has become common practice (Boziaris, 2014). The process accelerates the salting, homogenously distribute the salt within the seafood tissue and increase yield (Boziaris, 2014). As the brine is injected directly into the fish muscle, injection salting also reduces the amount of brine required compared to conventional brine salting (immersion). However, this salting method can increase risk of cross contamination with microorganisms and metal from the needles and, if brine is injected at high pressure, it can damage the fish muscle. Injection salting is normally used at low temperature to avoid microbial grow, so its impact in terms of energy consumption and GHG emissions is lower than for other fish PH technologies used to control product water activity that need to heat the product.

In order to reduce waste and improve the global efficiency, different approaches for reusing of the brine are nowadays applied (e.g., recirculation, UV decontamination, filtration, and others). Conventional salting, especially dry salting, is a slow process. To decrease the processing time and improve the diffusion of salt, the combined application of other food processing technologies that may enhance mass transfer phenomena during subsequent salting process may be applied, like pulsed electric fields, ultrasounds, or laser micro perforation (Cropotova et al., 2021; Olivares et al., 2021). Research has demonstrated that a pre-treatment of other processing technologies such as pulsed electric field, ultrasounds, or laser micro perforation reduces the processing time and increase the salt concentration in the fish (Cropotova et al., 2021; Olivares et al., 2021). However, according to the authors' knowledge, these combined processes are not applied at industrial level today.

An **emerging** technology is **vacuum impregnation salting** which could be used as a method to reduce processing time and promote a more homogeneous distribution of the salt in the product (Tomac et al., 2020). Vacuum impregnation is the application of a partial vacuum pressure that allows the removal of native liquid and gases trapped in food tissues, and the further impregnation with a solution in which food are immersed when atmospheric pressure is restored (Tomac et al., 2020). The process can be also used at in a pulsed way, called **pulsed-vacuum impregnation** (Martins et al., 2019). For example, the use of vacuum impregnation for mild salting of hake can reduce processing time by 75% (Tomac et al., 2020). Studies on vacuum impregnation applied in fish products are scarce (Martins et al., 2019; Tomac et al., 2020) and therefore this technology remains in research and development stage.

<u>Control of water activity – smoking</u>

Smoking is a preservation technique that also allows flavour and taste ingredients to be introduced into the fish muscle by exposing it to smoke (Boziaris, 2014; Venugopal, 2006). Nowadays, the main purpose of smoking is to enhance the sensory quality. In **hot smoking** the temperature is maintained above 30°C (normally between 70°C and 80°C) (Boziaris, 2014; Venugopal, 2006). In **cold smoking**, the temperature is maintained below 30°C (Venugopal, 2006). Compared to hot smoking, cold smoking is a slower process but increased retention of the original textural properties of the products (Boziaris, 2014). A combination of hot and cold smoking is also often used (Boziaris, 2014). Traditional smoking techniques consists of suspending the fish above slowly burning wood chips (normally hardwood). In **mechanical smoking**, the smoke is produced from smoke condensates (solid or liquid form). Hot and cold smoking implicates the slow burning of wood and other combustion substances, directly or indirectly, so the impact on GHG emissions could be high if the system is not well controlled. Furthermore, undesirable compounds (e.g., polycyclic aromatic hydrocarbons, PAHs) can be generated and pass to the fish products.

In **liquid smoking**, the fish product is introduced in a liquid in which smoke concentrate is dissolved (Boziaris, 2014; Nithin et al. 2020). The liquid concentrate transfers the aroma and flavour of smoke into the fish muscle. Liquid smoking is faster compared to previously mentioned methods, produces a more homogeneous smoking and reduces the risk of the presence of (known) toxic compounds derived from combustion processes (e.g., polycyclic aromatic hydrocarbons, PAHs) (Boziaris, 2014; Nithin et al., 2020). In addition, liquid smoking has lower operation costs, less environmental pollution and is less time consuming than other smoking methods (Boziaris, 2014; Simon et al., 2005).

To reduce waste and improve the overall efficiency, different approaches are used in trying to minimise the use of smoke and increase the smoking speed by improving the control of the process variables. Both, technological suppliers, and processors, are also optimizing the smoking techniques to reduce the generation of undesirable compounds (e.g., PAHs). In the last decades, the traditional hot and cold smoking is being gradually substituted by liquid smoking (Simon et al., 2005). The use of liquid smoke (and smoke flavourings) in food industry is gaining importance due to its ease of use and because this technique avoids contaminating seafood products with PAHs, without compromising the flavour and preservative properties of smoke (Nithin et al., 2020). In any case, artisans and small smoked fish producers will likely continue to use traditional methods.

As an **emerging** technology, **electrostatic smoking** is an evolution of traditional hot and cold smoking based on electrostatic precipitation (Baron et al., 2008). In this process, fish are treated with smoke in an electrical field (Boziaris, 2014). The electrical field acts on the ionised smoke particles, accelerating the smoking process, thereby shortening the smoking period. Electrostatic smoking is fully mechanized. Therefore, it could lower labour and production costs compared to traditional hot and cold smoking while maintaining high-quality final products (Boziaris, 2014). Although the technology has been known since the 1950s, it is not widespread at industrial level, and can still be considered a new technology which holds some promise (Baron et al., 2008). It can be expected that the evolution of the technology will indeed focus on increasing process efficiency and product quality.

Control of water activity – marinating

Another old processing technology of seafood is **marinating**, and in the meantime also **injection marinating** has been established as a **conventional** marinating technology. Traditionally, marinating involves immersing seafood into a marinade solution containing salt, sugar spices and/or other substances, which is allowed to penetrate through diffusion over time in order to modify the sensory properties and increase shelf life of the product (Boziaris, 2014). Cold marinating (at refrigeration temperature) is the most used method, representing about 92% of the market in Europe (Boziaris, 2014), and takes hours, days or weeks of time. In cooked, fried, and pasteurized marinated seafood products, marinating occurs at the same time of the heating processes, reducing the processing time. Thus the latter method reduces the energy and economic costs and the corresponding environmental impact.

Over the last decades, marinating by automatic marinade **injection** into the seafood flesh by multi-needle systems has become common practice (Boziaris, 2014). This method reduces marinating time, increases automation, homogenously distribute the solutes within the seafood tissue and improves processing yields (Boziaris, 2014). In addition, injection marinating also reduces the amount of marinade required compared to conventional immersion marinating. However, this marinating method can increase risk of cross contamination with microorganisms and metal from the needles and, if marinade is injected at high pressure, it can damage the fish muscle (the final product). Injection marinating is normally applied at low temperatures to avoid microbial grow, so its impact in terms of energy consumption and GHG emissions is lower than for other fish PH technologies used to control product water activity that need to heat the product.

The application of **vacuum impregnation** during marinating process could reduce processing time and promote a more homogeneous distribution of the solutes in the product (Figueroa et al., 2020), but remains an emerging technology. The process can be also used in a pulsed way, called **pulsed-vacuum impregnation** (Martins et al., 2019). Advantages compared to injection marinating processes is that the seafood tissue itself remains untouched, reducing the chances of cross-contamination, thus increasing hygiene, while also decreasing the chance of damaged seafood products, thus retaining a high product quality. However, studies on vacuum impregnation applied to seafood products are uncommon (Figueroa et al., 2020; Martins et al., 2019; Tomac et al., 2020).

To reduce waste and improve the overall process efficiency of the marinating technologies, different approaches to reuse the marinade presently exist (e.g., recirculation, UV decontamination, filtration, and others). Research has demonstrated that a pre-treatment of other processing technologies such as pulsed electric field, high pressure processing, ultrasounds, or laser micro perforation reduces the processing time (enhance mass transfer phenomena) and improve the marinating process of meat and fish (Figueroa et al., 2020). However, these pre-treatment technologies remain in research and development and no economic and environmental impact studies to elucidate the suitability of such combined systems exist.

Heating – pasteurisation, sterilisation and canning

The canning and sterilisation of seafood products is a traditional practice in seafood PH-chains, which allows to manufacture products that are stable at room temperature and have a long shelf life (Hall, 1997). To apply the necessary sterilisation temperatures (around 121°C), different retort (autoclave; sealed pressure chamber for heat treatments) configurations are used in the sector (Venugopal, 2006). They are batch systems, but there are also semi-continuous configurations which improve the plant capacity and save time (Hall, 1997). **Conventional** sterilisation and pasteurisation technologies are steam and air retorts, saturated steam retorts, water immersion retorts, water spray retorts, steam pasteurisers and microwave pasteurisers.

Retorts (autoclaves) are normally based on the utilisation of steam (Hall, 1997). The simplest and oldest one is the **saturated steam** retort. During sterilisation it employs direct steam heating at atmospheric pressure, thus there is no overpressure (Allpax)[70]. Its main advantage is the low capital investment (Allpax). However, it employs a lot of steam and uses a lot of energy, so the technology is no longer efficient (Allpax). The key difference between **water spray** retort and the conventional saturated steam retort is that the first one employs overpressure, generated by introducing air or steam into the vessel during sterilization (Allpax). To overcome the insulating effects of the air, spray nozzles introduce the steam and mix it with the air (Allpax). The steam and air retort are an overpressure process, like water immersion or water spray retorts. Overpressure is reached by pressurised air that enters the retort with the steam (Allpax). To prevent cold areas in the autoclave and improve the efficiency of the process, fan systems are used to mix the steam with the air (Allpax). In **water immersion** retorts, the products are submerged in water and treated at above atmospheric pressure (Allpax). Overpressure is created by introducing air, steam, or a mix on top of the water (Allpax). The heated air agitates the water as it flows to the surface and serves to pressurize the processed load. The retorts mentioned here can have rotating configurations for maximised efficiency (heat distribution, and processing time). Steam and air retorts consume similar amounts of energy and produces similar GHG emissions compared to conventional saturated steam retorts. Compared to the rest of conventional retorting technologies, this configuration consumes the lowest amount of water (Hall, 1997), except when a water header tank is used (see below).

Some of the limitations of saturated steam retorts (high energy and steam consumption) seem impossible to overcome because they are an inherent part of this technology. An advantage of water spray and water immersion retorts is the presence of a water header tank that catches the hot water after the sterilisation process. The hot captured processed

[70] Allpax https://www.retorts.com/white-papers/retort-sterilization-process/

water after sterilization can be used for the next cycle. Specifically, to reduce the energy consumption and GHG emissions, and to improve process efficiency, water spray retorts can use a heat exchanger and a pump to recirculate both sterilizing water and cooling water during the process. This increases the machines' price, but it also drastically reduces the needed energy and, therefore, the processing cost. In the future more optimisation effort from technology companies will be made, especially regarding the control of the process and the energy consumptions (optimisation of capacity, more amount of product treated with similar energy consumption, better insulation, etc.). For water spray retorts improving the control of the air flow (vertical air flow, reversible up or down airflow), hygienic design, cleaning (including clean in place (CIP) sanitation systems), temperature control (sensors, software for control applications), humidity control, vapour injection (nozzles), insulation materials, and others. All these improvements are focused on reducing processing time and/or reducing processing costs and, indirectly, reducing energy consumption (usually electricity).

The use of **steam** is currently a standard in fish PH value chains for pasteurising seafood products. The main difference between cooking and pasteurisation systems is that the product is already packaged or in a container, normally in glass jars or plastic pouches. The pasteurisation systems combine steam and forced air to improve the heat transfer and reduce processing time (Orlando et al., 2020; Venugopal, 2006).

Microwaves can inactivate microorganisms, including spores, so it can be used for pasteurising or sterilising food (Viji et al., 2022; Xue et al., 2021). As in any PH application, pasteurisation or sterilisation with microwaves lacks uniform heating (Viji et al., 2022) and proper temperature control (Li et al., 2020), so not much equipment using microwaves exists. In pasteurisation, and especially in sterilisation, very high temperatures must be reached in the product (>120°C) so the problems concerning lack of uniform heating are more relevant than for other applications. In general however, microwave processing is time saving, energy efficient and yields good quality fish products with high nutritional value (Viji et al., 2022).

Although steam pasteurisation is generally well optimised, increased efforts to optimize the control of the process and the energy will have to be made. Similar efforts will have to be made for microwave pasteurisation. A combination of microwave heating and conventional heating or other emerging technologies, such as ohmic heating has vast potential to alleviate certain drawbacks (Viji et al., 2022). The lack of knowledge on the actual temperature profile during microwave pasteurisation is a major challenge for the commercial application of this technology (Viji et al., 2022). This hiatus in knowledge necessitates focused research towards a reliable and real time record of temperature distribution in food products (Viji et al., 2022). Additionally, as dielectric properties of seafood products vary with its composition, a specific microwave frequency must be chosen for each individual product for better results (Viji et al., 2022). Development of packaging materials also needs special attention as packaging can help to enhance uniform penetration and heat generation within the product (Viji et al., 2022).

Although an already impressive range of conventional technologies exist for sterilisation and pasteurisation, also an array of **emerging** technologies exists. Those are pressure assisted thermal processing, microwave assisted thermal sterilisation, high hydrostatic pressure pasteurisation, ultrasound assisted pasteurisation, cold plasma decontamination, pulsed light decontamination and ultraviolet decontamination.

Pressure assisted thermal processing (PATP) involves the application of high pressures (up to 600 MPa) combined with mid-high temperatures (typically 60-120°C). Main advantages compared to conventional thermal treatments are microbial sterilization, modification of physical properties, enzyme inactivation and reducing allergens in different food products (Puértolas et al., 2022; Svenich et al., 2015). Although this technology shows promise, research into seafood specific applications is scarce (Puértolas et al., 2022). The adiabatic heating (internal heating of the system due to changes in the environment), raising the temperature (up to 25°C) due to increased pressure, is crucial for the reduction of the heating cost (Svenich et al., 2015). However, it is currently not clear whether economically and environmentally PATP is a better solution than classical heat treatments and may explain why this technology is not fully industrialised. One of the key disadvantageous is the non-uniform temperature distribution in the treatment chamber, which can vary for industrial units in range of ~10°C (Svenich et al., 2015).

As stated above, pasteurisation using **microwaves** still has certain challenges to overcome. One emerging technology is microwave assisted thermal sterilization (MATS) (Barbosa-Cánovas et al., 2014). It is based on the use of water as a heating medium in combination with direct exposure of the food to microwaves (Barbosa-Cánovas et al., 2014). By using water as an intermediate medium, non-uniform heating and edge effects (overheating surfaces) can be minimised (Barbosa-Cánovas et al., 2014). They can operate as batch and continuous systems, reducing processing times from 1/4 to up to 1/10 of time required for conventional thermal methods (Barbosa-Cánovas et al., 2014). Some of the advantages of this innovative technology in contrast to conventional sterilization (retorting) include higher production rates and less operational costs (Barbosa-Cánovas et al., 2014). Using microwaves for heating (electricity; heat generated inside the product and water), MATS has potential to reduce the environmental impact of sterilization and diminish GHG emissions. Interestingly, the MATS system is currently being commercialized and was installed in two US companies in 2014 (Barbosa-Cánovas et al., 2014). However, further detailed studies are needed to elucidate whether this innovation is economically cost-effective and has a positive environmental impact.

High hydrostatic pressure (HHP) has been discussed in section 0 for thawing. The same technology can be used for pasteurisation and has specifically the advantage here that HHP is considered as a non-thermal process because the treatment temperature can be maintained below room temperature, avoiding heat mediated modifications of food properties and improving food quality with respect to conventional thermal pasteurisation (Puértolas & Lavilla, 2020). Although HHP is more expensive than thermal pasteurisation, this technology has a lower environmental impact in almost all impact categories (Cacace et al., 2020). A possible explanation for this outcome is that while HHP makes use of more electricity than thermal processing, the latter makes use of steam, as a direct or indirect heating media, leading to significant energy inefficiencies in some cases (Cacace et al., 2020; Pardo & Zufia, 2012). High cost of the equipment, installation and maintenance is the main challenge for this technology to become widespread. Yet this may be alleviated by tolling services[71] which are growing within the industry, and which allow producers an easier access to this industrial equipment without the need of high investments (Puértolas & Lavilla, 2020).

Ultrasound assisted pasteurisation (see section 0 for thawing) involves the application of ultrasounds during water immersion heating, accelerating the heat and mass transfer and, therefore, reducing processing times (Bhargava et al., 2021; Cichoski et al., 2015). If this technology would be industrialised, processing conditions will have to be optimised for each seafood product because high-power single-frequency ultrasounds may damage food muscle structure (Bhargava et al., 2021; Bian et al., 2022). It is worth noting that ultrasonic waves have the disadvantages of high-power consumption in practical applications (Bian et al., 2022). More research is needed to reduce the power consumption and the instability of ultrasound systems (Bian et al., 2022) and if the power can indeed be reduced to such an extent that it uses less power compared to conventional

[71] Tolling services are often defined as a simple arrangement, where one company processes raw material or near-finished goods for another in return for a "toll" or fee

pasteurisation methods. Although, the potential use of ultrasound at industrial scale is relatively simple because conventional pasteurisation equipment be adapted (Cichoski et al., 2015), ultrasound technology should be treated cautiously, because it may be harmful to human health (adverse tissue injury, electrical shock, and burns and indirect damage) (Bhargava et al., 2021).

Cold plasma decontamination is an emerging non-thermal technology in research and development stage that has been proposed for decontamination of food surfaces and food contact surfaces. Excitation of any gas (combined or individual) with an external source of energy exceeding the ionisation potential of the gas will change its state to the ionised form called plasma (Olatunde et al., 2021). During this process, various species such as negative and positive ions, radicals, neutral and excited molecules, electrons, and quanta of electromagnetic radiation (e.g., visible, and ultraviolet light) are produced, provoking the inactivation of the microorganisms that are present in the treated surfaces. Specific further research to investigate if this technology has a positive or negative GHG emissions impact is still necessary.

Ultraviolet light (specifically Ultraviolet C, 200-280 nm) is an emerging non-thermal technology that has been proposed for decontamination of food surfaces and food contact surfaces (Pedrós-Garrido et al., 2018). Ultraviolet light C doses of up to 0.79 J/cm^2 improved the safety and extended the shelf life of refrigerated fish up to six days (Monteiro et al., 2021). **Pulsed light** is generates high-energy light pulses of short duration of a broad and intense spectrum (200-1100 nm) (Pedrós-Garrido et al., 2018).

Ultraviolet based technology is well known and relatively easy to produce cost-effectively. As a result, this technology has received more interest from the food industry than other non-thermal decontamination technologies such as cold plasma or pulsed light. In fact, there are some applications of ultraviolet light in seafood processing, specifically for the decontamination of surfaces in contact with foods, like conveyor belts or packaging. Pulsed light is more complex than ultraviolet technology. Although there are industrial solutions for surface decontamination of packaging by pulsed light in other sectors (dairy, drinks), there are currently no applications in the seafood PH chain. As cold plasma, ultraviolet light and pulsed light can trigger or accelerate oxidation reactions (e.g., lipid oxidation) and cause negative effects on food quality, their development and industrialisation have been limited (Mahendran et al., 2019; Monteiro et al., 2021). As these technologies use electricity, it has been noted they have potential positive environmental impacts (Olatunde et al., 2021; Pedrós-Garrido et al., 2018), especially when the energy sources to generate the electricity are environmentally friendly.

<u>Heating – cooking and frying</u>

Cooking and frying food is an important social and culinary activity for humanity. Not surprisingly a specific set of important **conventional** technologies exist. Those technologies are, water immersion cooking, steam-oven cooking, sous-vide cooking, deep frying (oil immersion), air frying and grilling.

Cooking/boiling in water is the conventional practice in the seafood PH value chains, especially when production flow and/or the added value of the product are low, meaning that the production cost must be as low as possible. Furthermore, it is a traditional culinary. The process involves the immersion of the product in heated water (up to 100°C) (Feng et al., 2017; Venugopal, 2006). The water is continuously heated during the process to maintain the temperature of the system. Conventional water-immersion technologies have disadvantages of long processing times, potential of cross-contamination (reduced hygiene), prolonged exposure of the external surfaces to warm temperatures, use of large amounts of water, and generation of the possible large amounts of wastewater (Venugopal, 2006). In addition, energy cost can be high when having to bring large volumes of water to the boiling point and maintaining those high temperatures. Despite these disadvantages, this technology is still in use due to its simplicity, its low cost and high capacity (Venugopal, 2006).

At industrial level some technological improvements have been made to increase the efficiency of the processes. Examples of these improvements are water heating technology efficiency, better controlling of water temperature, reducing the use of water, including technologies for cleaning, and reusing the water, reducing heat losses by improving insulation materials of the kettles. During the last 20 years, older boiling systems are being replacing by convection ovens/cookers that use vapour and forced hot air flows.

Steam or steam-air oven-cookers are currently a standard for cooking seafood products. They combine steam and force hot air flows to improve the heat transfer and reduce processing time. Steam has a higher thermal conductivity than hot air used in conventional ovens with the potential to induce rapid heating with minimal side effects (Orlando et al., 2020; Venugopal, 2006).

At industrial and HORECA level, efforts have been made to improve the performance of the ovens and cookers. For example, improving the control of the air flow (vertical air flow, reversible up or down airflow), hygienic design, cleaning (including Clean in Place (CIP) sanitation system), temperature control (sensors, controlling software), humidity control, vapour injection (nozzles), and insulation materials. All these improvements are focused on reducing processing time and/or reducing the processing cost, and indirectly reducing the energy consumption (normally electricity) (Orlando et al., 2020). Efforts to further reduce the energy consumption of steam ovens are underway. For example, advances made in other heating technologies, such as microwaves or ohmic heating, could improve the implementation of combined processes to reduce energy losses.

Sous-vide cooking has gained popularity because of its mild cooking conditions on meat and fish preparations. It is applied in the HORECA sector or in households. Sous-vide is a French term meaning "under vacuum". Thus, the fish is packed in heat-stable vacuumised pouches and then cooked in water using low temperatures (60-95°C) for up to 48 hours (Ismail et al., 2022; Redfern et al., 2021). Using vacuum sealing in sous-vide provides an efficient and consistent transfer of heat from water to food products and increases the shelf life of products due to the absence of oxygen in the vacuum sealed pouch. Although the process needs lower temperatures than conventional boiling, the processing times are higher (hours) and thus the energy consumption may be higher (depending on the process) compared to conventional boiling and cooking. Specifically for restaurants, sous-vide units were developed to optimise the temperature control.

Traditional frying (oil immersion) or deep fat frying is a complex process during which foods are cooked, lose water, and absorb oil/fat (Fang et al., 2021). The high heat of frying, usually 180-200°C, generates distinct aromas called flavours, that gives fried food a rich taste (Fang et al., 2021; Venugopal, 2006). Usually bleached and refined vegetable oils are used for frying (Venugopal, 2006). Frying is most frequently used in coated products (Venugopal, 2006). A major disadvantage or deep frying is waste generation, and is indeed an important disadvantage related to other frying alternatives (Fang et al., 2021). Several new techniques such air frying, electrostatic frying and vacuum frying have been designed that use low quantities of oil/fat while retaining the good flavour and texture which would be obtained with traditional deep-fat frying (Fang et al., 2021).

Air frying is an alternative technique to dehydrate food products with hot air and oil droplets in the frying chamber, typically achieving fried food with a crust and very low-fat contents (Fang et al., 2021; Yu et al., 2020). Air frying uses hot air circulation instead of hot surfaces, offering shorter processing times comparing to the conventional air drying, but a longer frying time than conventional frying (Fan et al., 2007; Fang et al., 2021). The products resulting from this technique exerts great benefits to consumers health, because it aims at reducing the use of oil mainly for health reasons (improving food quality) rather than to reduce food waste (oil waste). In addition, air frying also has environmental advantages, such as lowering oil consumption and achieving the zero effluent discharge (Yu et al., 2020).

Industrial units and household appliances of both deep and air frying have undergone technological improvements to increase the process efficiency. Examples of such improvements are improved oil heating technology efficiency, improved control of oil temperature, reduced the usage of oil, cleaning and reusing the oil, reduced heat loss, and improved insulation materials of the kettles. Systems will become progressively more efficient, being a standard frying technique. Although the improvements to be made over conventional frying are clear, it is necessary to compare technologies with alternative frying technologies (e.g., vacuum frying) to determine which is best suited per individual application and food product.

Grilling or broiling involves the application of dry heat to the surface of food, commonly from above or below, cooking the food and generating a caramelisation process in the surface (grill marks are attractive for the consumer) (Venugopal, 2006). In a roasting or grilling operation high temperatures are needed. Conductive and convective heat transfer are mainly used (Matsuda et al., 2013). Conventionally, industrial and HORECA systems are based on an electric resistance or gas heaters. In household, the traditional grillers involve the use of charcoal briquettes and lumps (Jelonek et al., 2020), because it gives to the food special sensory properties that are difficult to imitate with other heat sources. For a high-quality grilled product, it is important to optimize the temperature parameters during the grilling process for each individual product (Venugopal, 2006).

At industrial level improvement effort for grilling are focused on reducing the processing time and/or reducing the processing cost and, indirectly, reducing energy consumption (normally electric energy). For example, infrared lamps have been implemented in industrial and HORECA grillers to improve the process efficiency. Even though many studies have been conducted to assess air pollution and human health risks arising from exposure to charcoal-based grilling, limited standards and policies have been implemented internationally to assure grilling fuel quality (Jelonek et al., 2020). Especially charcoal based grilling produces important GHG emissions and substances that negatively impact human health (e.g., PAHs). The development of solid fuels with the lowest GHG emission and reduced amounts of harmful substances could mitigate these problems, but not solve it. Although this practice could become more limited, supported by European awareness of climate change and by the development of new appliances that allow similar results using heat sources that potentially have a lower environmental impact, a 'barbeque' retains an important social factor.

As conventional technologies that determine such an important aspect of human lives face challenges related to environmental impacts, cooking technologies have also innovated into some **emerging** technologies. Those are microwave cooking, ohmic heating, ultrasound assisted heating, electrostatic frying and vacuum frying.

Although **microwave cooking** has been successfully applied at home, in restaurants and in some food industries for 50 years, it still faces certain critical challenges on the seafood industrial level, therefore retaining its emerging technology status. After the first industrial level attempts, some companies that started to use microwave cooking finally stopped because this technique lacked uniform heating and because products (fish) of different sizes are hard to cook uniformly at the same time (Thrane et al., 2009). Focused research ensuring reliable mapping of the temperature at different places inside the product is necessary for improving the process and try to reduce hotspots (Viji et al., 2022). In addition, microwave cooking cannot be used with metal packaging (Li et al., 2020).

Nonetheless, microwave processing is time saving, energy efficient and yields good quality fish products with high nutritional value (Viji et al., 2022).

Ohmic heating has also been described in section 0. It is an interesting new technology due to its ability to heat food quickly (with minimal destruction) and to provide higher energy conversion efficiencies, more uniform heating and/or reduced processing time than conventional thermal processing (Jin et al., 2020; Li & Sun, 2002). Due to the higher energy conversion efficiency, this technology could reduce the energy consumption of heating and, indirectly, reducing the GHG emissions. Another advantage is the absence of water usage and thus avoids generating wastewater (Seyhun et al., 2014). Despite of its potential, the application of this technology for fish has been limited (Jin et al., 2020). In the limited food industry research, more attention has been paid to this application for aseptic processing and pasteurisation of particulate foods (Li & Sun, 2002). Currently, this technology is not applied in the industry.

Ultrasound assisted cooking is very similar to what was described in section 0. This technique reduces the loss of nutrients, development of off-flavours and deterioration of functional properties of foods that take place in thermal processing, such as structural damage due to cell bursting (Bhargava et al., 2021). The application of ultrasound for seafood cooking remains at research and development stage and is therefore not industrialised. On important reason for further research on ultrasound assisted cooking is because no information is available about the possible generation of toxic substances during processing (Cichoski et al., 2015).

In comparison to conventional deep frying, **electrostatic frying** uses a discharge plate equipped on the bottom of the fryer. This technology is commercialised for the HORECA by a Japanese company (Denba, Tokyo, Japan), however, their basic principles are not well explained (Fang et al., 2021). In theory, it reduces frying time, acrylamide levels and oil uptake compared to traditional frying, although Fang et al. (2021) did not see any difference between traditional frying and electrostatic frying. It is not known whether it is being applied by any company.

Vacuum frying is defined as frying under pressures below atmospheric levels, preferably below 6.65 kPa (Andrés-Bello et al., 2010). Due to the low pressure, the boiling point of the water in the food product is lowered. This reduces the processing temperature and the Miallard reaction or browning reaction during processing (Andrés-Bello et al., 2010; Fang et al., 2021). Thus, vacuum frying offers some advantages, including the reduction of the oil content in the fried product, and the preservation of natural colour and flavours of the products (Andrés-Bello et al., 2010). In addition, as the adverse effects on oil quality are reduced (Andrés-Bello et al., 2010), the same oil can be used during multiple treatment cycles, and thus the generation of waste oil is potentially lower than in conventional deep frying. Vacuum frying is not applied at industrial level, or it is applied only in several very specific cases. However, it is a technology that it is used in the HORECA, especially in “haute cuisine” restaurants, using household appliances designed for vacuum impregnation, like Gastrovac® (Andrés-Bello et al., 2010). Studies on vacuum-fried products have been focussed on fruits and vegetables, while the use on seafood products has not been researched (Andrés-Bello et al., 2010).

Storage

Freezing

Today freezing is one of the major strategies to store seafood products and therefore **conventional** technologies such as blast (air) freezing, contact/plate freezing, cryogenic freezing and immersion freezing exist.

Blast freezing, around since 1950, is a simple and effective way to freeze an assortment of seafood products (Hall, 2011), taking a product stored at ambient or chilled temperature and rapidly freezing the product for subsequent storage. As (air) blast freezers use air as a cooling medium within the freezer, care must be taken while loading the freezer so that the cold air distribution remains uniform. Consequently, as an incorrectly loaded freezing system may reduce the efficiency of the blast freezing process (Kolbe & Kramer, 2007). Several loading systems exist for air blast freezers (Dempsey & Bansal, 2012; Hall, 2011), such as sharp freezers, tunnel freezers (batch, mechanised and belt freezers), spiral freezers, fluidized-bed freezers and impingement jet freezers. During freezing process, water vapour from the fish products will evaporate and accumulate on the refrigerant evaporators of the freezers (Hall, 2011), and this will reduce the freezing efficiency of the freezer. This an example of a common disadvantage of blast freezers and need to be well monitored. Thus, to ensure the efficiency of the freezer remains optimal, freezers need to be defrosted periodically.

Although, air is the most common used medium for freezing products, **plate freezing** has a higher heat transfer coefficient because of the direct contact with the product and is therefore more efficient (Ozogul, 2019). This technology is often used for freezing fish products with regular shapes (e.g., fillets and surimi). Freezing efficiency of the system is depended on the loading of the plate and the general management of the freezer (Hall, 2011). Also, for this technology water vapour is released during the freezing process, and thus the system needs periodical defrosting. The PH value chains using this technology often notes that the fish products are often deformed due to the mechanical pressure of the process, and represents one of the disadvantageous of this technology.

Both of the above freezing systems use refrigerant gases, which have been a major GHG emission issue in the past. Since the Montreal Protocol[72], ozone depleting refrigerants which harm the protective ozone layer have been targeted to be phased out. Synthetic refrigerants, are banned or restricted due to their global warming potential (Fernández-Seara et al., 2012). In line with these regulation changes, alternative freezing agents have been investigated for their sustainability and efficacy (Zanoni et al., 2020). Different refrigerants have also been investigated as a cascading system, where two systems using different refrigerants are connected within a freezing system (Fernández-Seara et al., 2012). Further improvements of both freezing technologies focus on increasing process fine-section-tuning and efficiency by improving technology and management, thus both directly and indirectly improving GHG emissions. As each site, product and PH value chain has specific requirements, the freezing process must be locally optimized. In the future (coming years) this will entail optimisation of among others space management, freezing temperature, dehumidification and defrosting, and also looking at environmentally friendly energy sources, refrigerants and insulation.

Cryogenic freezing methods uses liquid nitrogen (N_2, at -195.8°C) or liquid carbon dioxide (CO_2, at -78.5°C) directly on the seafood product to rapidly freeze those products (Svendsen et al., 2022). The whole process has a high heat transfer coefficient, therefore making the freezing process very fast (Ozogul, 2019). With the rapid freezing process, moisture loss is minimised by reducing dehydration and drip loss, and texture is maintained (Truonghuynh & Li, 2019). The major disadvantage of this technique is the higher production costs which are a consequence of keeping both liquid nitrogen and liquid CO_2 at very low temperatures. An additional disadvantage of the usage of CO_2 is the working hazards associated with the process. To use CO_2 as a liquid cryogenic freezing agent it must be ensured that the concentrations of air CO_2 do not exceed lethal levels in the working environment (Ozogul, 2019). This effect can however by reduced by precooling the product or reducing the temperature differences between the product and

[72] 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, 1522 UNTS 3, 26 ILM 1541, 1550 (1987)

refrigerant (Svendsen et al., 2022). Technological innovations for cryogenic freezing have been focussed on improving the quality of the final frozen product by for example testing combinations with other freezing (e.g. radiofrequency assisted freezing) methods (Truonghuynh & Li, 2019). In most recent years, companies (such as Air Product[73]) have been working on improving the sustainability of their cryogenic freezing equipment. In 2021, they unveiled their next generation Freshline® High Performance batch freezer which is built for higher efficiency. This equipment package is designed for higher freezing rates (due to an increase in capacity), more homogenous freezing and usage of lower amounts of liquid nitrogen and improved cleaning operations.

Immersion freezing uses close contact of the refrigerant and the product, and sprays the freezing agent directly onto the product or makes use of immersion baths to freeze the seafood product (Hall, 2011). As for the freezing medium, an array of products can be used; brine/salt solutions which often contain sodium chloride (NaCl) and Calcium Chloride (CaCl2), ethylene glycol or propylene glycol (Kolbe & Kramer, 2007; Sampels, 2014). With the freezing medium engulfing the product, the working temperature can be higher compared to (air) blast freezing: for brine mixtures such as NaCl the working temperature is around -18°C, for $CaCl_2$ it is -20°C and for water/propylene mixtures it is also around -18°C (Hall, 2011). The limiting factor for the working temperature is the viscosity of the freezing agent, and this can influence the sustainability of the process. Improper temperature settings can increase the viscosity of the refrigerant. This may lead to increased pumping requirements, ice formation in the heat exchangers and a less efficient heat transfer process, which reduces the sustainability of the process (Hall, 2011; Svendsen et al., 2022). Future technology improvements can aim to reduce the freezing point of the freezing medium (Yang et al., 2020). One possibility is adjusting the individual components and their mixture ratios within the freezing medium to ensure viscosity is optimal. Also, special immersion freezing techniques such as ultrasound, high pressure freezing, or electrostatic field assisted immersion freezing have been developed to improve process efficiency (Choi et al., 2016; Jia et al., 2017; Ozogul, 2019; Qian et al., 2018).

Recent developments in the freezing sector are looking into alternative freezing methods. These alternatives are mainly in the exploration phase and no commercial implementation has taken place, with long-term implementation being for example depended on financial feasibility (Boziaris, 2013). The financial aspect of the implementation is especially relevant because specialised and adapted equipment is necessary for these **emerging** freezing strategies, such as superchilling, superfreezing and ultrasound assisted freezing.

Superchilling, or partial freezing, lowers the temperature down to 1-2°C below the initial freezing point of the seafood product (Wu et al., 2014), where the product is kept in a stage between chilling and freezing. Mechanical, cryogenic or impingement freezers can be used to achieve the initial freezing of the products exterior (Kaale et al., 2011). Partial freezing has proven to be an efficient method to prolong the fish product's shelf life, increases sustainability of the refrigeration process, and decreases tissue damage due to ice crystals (Hall, 2011). This because fast freezing produces fine extra- and intracellular crystals that cause minimal damage to the texture (cells) of the seafood product, while slow freezing can damage the product due to large sharp ice crystals penetrating cell membranes (Sun et al., 2019). The sustainability of the (transporting) process increases because less ice is required and this due to the product itself being cooled internally (Wu et al., 2014). Transportation costs are further reduced due to the lower ice needs, because lower weights need to be transported and fish can be packaged more efficiently (Ozogul, 2019). However, the major challenge remains the variability in specific freezing conditions of each product (Wu et al., 2014). With an initial freezing point that is depended on

[73] Cryogenic Freezing | Cryogenic Freezer | Air Products, n.d.; Food Industry News: AIR PRODUCTS HAILS ITS LATEST CRYOGENIC FOOD FREEZERS, n.d.

properties of the seafood products, the chilling process should be optimised for each specific product (Magnussen et al., 2008 The properties of the superchilling process needs to be adjusted further to achieve the required processing quality, efficiency, and shelf-life market requirements (Magnussen et al., 2008). To implement superchilling it will require transitioning to an adapted, data rich cold chain, with specific operational designs, packaging, and cooling techniques specific for each seafood product (Ozogul, 2019), which present major challenges of their own.

Super freezing, which aims to rapidly freeze fish products to -60°C, is an approach aimed to increase product quality (Boziaris, 2013; Hall, 2010). Furthermore, this technology aims to increase the efficiency of the freezing process, by making sure that nucleation (the start of a freezing event) occurs rapidly and uniformly throughout the product. This can be achieved by making use of several specific freezing methods such as, pressure shift freezing, impingement freezing and Cell Alive Freezing (CAS) freezing. Indirect environmental gains for these freezing processes can result from the higher product quality (which can increase shelf life and reduce waste) or by decreasing the time (and required energy) of the freezing cycle. However, these technologies are still under research and development and other gains (environmental or efficiency) are not always clear as of yet.

Ultrasonic or ultrasound-assisted freezing technology aims to produce fine ice crystals within the seafood product and aims to increase the efficiency of the freezing process (Cheng et al., 2015). Ultrasound, with low frequencies and high intensity soundwaves (20-100 kHz, with 10-1000 W/cm²), are considered effective to reduce of freezing times (Zhang et al., 2018). By combining ultrasonics with immersion freezing, samples had smaller ice crystals, better protein thermal stability and physicochemical properties in the muscles compared to immersion freezing and air freezing techniques (Zhang et al., 2018). Studies on ultrasonic assisted freezing still need to increase information on the influence of freezing conditions on the freezing properties and a comparison between different products during the same freezing conditions still need to be made (James et al., 2015). Note that ultrasound technology is returning in different processes (thawing, heating, freezing).

<u>Cold storage – insulation</u>

The thermal **insulation** of cold storage units is responsible for maintaining cold temperatures through time, by minimizing the heat transfer between the cold storage and its surroundings. Each time a door opens, warmer and more humid air from outside is introduced into the systems while cold air leaves it. This represents an important source of energy waste, while also creates several problems (e.g., ice accumulation, wet floors) caused by the increasing humidity. Good insulation materials should have very low thermal conductivity, hence slowing the flow of heat transfer. This will reduce the direct energy consumption of the cold storage plant by reducing the energy needed to maintain the cold temperatures and the GHG emissions derived from non-renewable energy sources, such as by preventing the waste of perishable products, exposed to non-optimal conditions, and cooling equipment breakdown. Insulation accounts for 20-35% of the total heat load of a cold storage plant, meaning that choosing the appropriate insulation material will have significant impact on the plant's energetic consumption (Gao, 2018) and in the GHG emissions associated with it. In order to achieve correct cold storage of seafood product, several **conventional** technologies, such as strip curtains, high speed doors and air curtains, as well as conventional insulation materials are used.

Polyvinylchloride (PVC) **strip curtains** are widely used in cold storage facilities as they efficiently prevent cold air from escaping the room when the door is open, allow an easy access to personal and machinery, provide a relatively good visibility between the two environments and are very cheap. Nonetheless, they have important disadvantages. As product is carried in with forklifts it encounters the strips compromising its hygiene, they reduce the visibility and speed of machinery, the alignment of the strips is quickly shifted due to the passage of people, forklifts and products leading to loss of cold air, and they will quickly require maintenance and needed to be changed when used frequently.

High speed doors are designed free of rigid parts allowing a fast opening and closure without representing a safety hazard for people and vehicles. As manually controlled doors are not time efficient, automated systems are used, which reduce the opening time, hence cold air loss and saving energy. Nonetheless while the door is open there is nothing blocking the heat exchange between the two environments, and when the usage is too frequent the door will remain open relatively long. Also, maintenance, wear and damage costs tend to be high.

Air curtains consist of a constant downward laminar air flow creating an effective barrier between two different environments. These benefit the cold storage operations by greatly reducing energy losses as it reduces temperature variation by 90% down to less than one degree. Air curtains optimizing the product quality and hygiene by the reduction of hot posts near the entrance where cold chains can be compromised. Compared to strips and high-speed doors, air curtains are very effective in high transport frequency environments but require a relatively larger investment. Air curtains for temperature-controlled road transport have also been developed, providing an automatic vertical air curtain separating the air inside the trailer from the temperature outside the vehicles. This has proven to reduce heat infiltration between 30-45%.

All previous options allow somehow the infiltration of warm external air and loss of internal cold air. A solution which neutralizes this almost completely is the installation of **conditioned air vestibules** (air locks) on the entrance of the cold storage and trap the air between two doors. The air between the two doors can then be more efficiently (smaller volume) controlled, lowering its costs, and contributing to the general energy savings. Vestibule systems can be combined with the other above presented options to provide an even more effective temperature control. However, its closed infrastructure will inevitably reduce the workflow speed and its efficiency. Trade-offs must be analysed in detail when specific choices are made for the different options presented here.

Currently, two types of **conventional contact insulation** materials are mostly used and commonly available for cold storage warehouses installation, those are polyurethane and polystyrene (both Expanded PS, EPS and eXtruded PS, XPS). Although some other insulation materials are also efficient in reducing heat exchanges between the environment and the cold unit, some of them are very sensitive to humidity (e.g., mineral wool), reducing their performance and requiring time and financial investments for their maintenance and replacement. Such options are therefore unlikely to be used for cold-storage applications.

Polyurethane is among the best-performing insulation materials, with an insulation capacity 700% better than bricks and 50% better than fiberglass. Its insulation capacity is due to its structure of small cells in combination with the composition of the gas in these, also called "blowing agent". Years ago, the blowing agents used for polyurethane foam were chlorofluorocarbons (CFCs) refrigerants (i.e., CFC-11 or CFC-12, infamous for their ozone depletion and GHG effect) but have now been changed to newer and more sustainable alternative refrigerants, such as hydrofluoroolefins (HFO) and hydrocarbons (HC). Nonetheless, the usage of these newer and sustainable blowing agent alternatives may imply efficiency, durability, or economic trade-offs (Wagman 2018). While HFOs provide better thermal performance than HFCs, and are non-flammable, they would be needed in larger quantities, hence increasing costs. The HC are on the other hand less cost demanding but offer a lower thermal efficiency and are highly flammable. Finally, synthetic alternatives such as Ecomate (FoamSupplies) have been developed to offer excellent thermal properties, while maintaining lower cost and reduced flammability risks (Kolbe et al. 2006; Wagman 2018).

Expanded polystyrene (EPS) or also known as "styrene" is a lightweight white foam, used in the walls and roofs of cold storage facilities with insulation properties constant over time (Kolbe et al. 2006; EPS Industry Alliance 2022) working in a temperature range from 20°C to -100°C. Similarly, to polyurethane, EPS is expanded using a blowing agent (e.g., Pentane). The EPS is 100% recyclable into new packaging/insulation products or durable goods, however, may be difficult to collect due to its very light weight (large volume). Its production does not involve any ozone-layer depleting CFCs and HCFCs (hydrochlorofluorocarbons) and does not lead to the generation of residual solid waste.

Extruded polystyrene (XPS) is manufactured through an extrusion process with polystyrene, a blowing agent, and other materials. Unlike other forms of insulation, such as EPS, XPS lacks any tiny voids or spacing between the cells. This decreases heat transfer while also making it very resistant to water absorption and water vapour transmission, allowing it to retain low thermal conductivity even when there is a lot of water present. The moisture-resistant qualities of XPS foam are especially relevant for cold storage applications because the interior areas of cold storage warehouses tend to have more moisture and condensation.

Both, polystyrene, and polyurethane can be used for the building of cold storage warehouses using sandwich panels. The thickness of the panels installed in industrial refrigeration chambers ranges from 100 to 125 mm (at above zero temperatures) and between 175 and 200 mm (at sub-zero temperatures) (Mecalux, 2022). In addition to their very high thermal insulation, these panels are fast and easy to install, budget friendly, aesthetic, resistant to fire and allow an almost unlimited modularity for specific applications and environments. Together, this enhances the efficiency of the warehouse, hence leading to a more efficient usage of resources and minimizing GHG emission per product produced.

Although the previously presented materials do help to reduce GHG emission indirectly by reducing energy consumption linked to temperature fluctuations, heat exchange, refrigerant consumption, refrigeration wear and product waste, both insulation materials are petroleum derived, and their production is still responsible for GHG emissions. Furthermore, once the insulation material is no longer usable the foams do not break down and can stay in the environment for 1000 years. Both academic research and the industrial sector have already developed and are currently developing efficient alternatives which in addition to reduce heat loss in cold storage facilities will be produced with very low to no GHG emission. These **emerging** insulation materials are aerogels and corn-based polylactic acid/cellulose fibres foam.

Aerogel is a new type of insulation material, with excellent thermal insulation performance compared to conventional insulation materials. It is produced from silica, silicon dioxide, and up to 99.8% air. Thanks to its very high thermal performance, thinner insulation layers result in similar insulation values of currently used insulation materials. Its production process does not involve harmful gases, while the solid wastes generated and the insulation material itself can be recycled once no longer in use (Silica Aerogel Insulation 2022). Aerogel preparation involves expensive precursor raw materials, chemicals, and needs to dry (the key step in the production process), making the production relatively more expensive compared to the current conventional building insulations.

Polylactic acid, also known as biodegradable hydrolysable aliphatic semicrystalline polyester, is a "prototype" insulation foam which was developed mixing corn-based polylactic acid with cellulose fibres using carbon dioxide. This foam is safer than conventional insulation foams, but also compostable and efficient (UNT 2020). It is 90% biodegradable within 50 days but performs like conventional insulation with similar efficiency. As this insulation material is still in a research and development stage, information on this insulation material is very limited.

Cold storage – dehumidifier

The accumulation of moisture and condensation in the cold temperature environment of cold storage warehouses and coolers can lead to a multitude of practical problems. One of those important problems is an increase of energy consumption and bills (e.g. defrosting cycles, inefficient working of evaporators when iced up, and heating to avoid icing) (COTES, 2022). Although a proper control of the doors (e.g., high-speed automatic doors, door seals and strip curtains) can reduce the infiltration of warm humid air they cannot stop it completely. Cold storage/freezer **dehumidifiers** help to reduce the humidity of the air in freezing/refrigeration systems, which enters via the cold storage entrances, reduce energy consumption, increase safety and sustainability. Dehumidifiers tend to work by creating dry, low dew point air by forcing most air to pass through a revolving desiccant wheel. The dry air is subsequently pumped into the freezer or cold storage unit (e.g., Munters, 2022, Condair, 2022, Bry-air and AirWaterGreen, 2022). With the latest developments these units can bring the humidity level down to a minimum at temperatures as low as -30°C (Condair, 2022).

This increases the refrigeration systems efficiency as it allows the cooling coils to run as intended by the manufacturer, increasing the interval between defrosting, and reducing energy losses caused by improper door sealing due to ice accumulation. Together, a dehumidifier can reduce avoidable energy expenditure and unnecessary wear of the refrigeration system which is directly correlated to the reduction of GHG emissions, while the reduction/avoidance of other efficiency problems linked to humidity in cold storages will indirectly reduce the GHG emitted per kilo of product produced.

Cold storage – refrigerants

Modern day freezing technologies would not be possible without efficient **refrigerant** gases. Refrigerants are widely used for industrial, commercial, domestic and transport refrigeration in the seafood PH value chain. These are substance that absorb the heat in the refrigeration unit. High pressurised warm refrigerant is traditionally cooled and liquefied through air heat exchangers. When this cool liquid evaporates, it removes heat from the air creating low temperatures in the refrigeration unit. Subsequently, the cold gas is pressurised and condensed at higher temperatures before being send again to the air heat exchanger. Although most chillers using refrigerants follow this process, the selection of the "ideal" refrigerant is not straightforward and depends on the design of both the chiller and the refrigeration unit, expected performance, safety, reliability, cost, and environmental sustainability (Maina & Huan, 2015). In addition, refrigeration systems may use intermediary steps to increase the stability and the efficiency of the chiller using a specific refrigerant, for example a glycol heat exchange step can greatly reduce temperature peaks therefore stabilizing the performance of the chiller and by extension the refrigerant. Moreover, by stabilizing the performance of the chiller unit, the risk for critical failures and maintenance time and cost reduces. Of key importance is finding the correct combination of refrigerant, chiller unit, and intermediary cooling steps to create the most performance and cost-efficient set-up.

From 1987 onwards, environmental concerns on the usage of refrigerants became a key driving factor (see section 5.2.3.1) in the selection, phase-out, and development of new and more sustainable refrigerants (Savitha et al., 2021). The Global Warming Potential (GWP), Total Equivalent Warming Impact (TEWI), and Ozone Depletion Potential (ODP) indices were used to compare sustainability across refrigerants (e.g., Wu et al., 2013).

The GWP compares the global warming impact of the emission of GHG in comparison to the emission of carbon dioxide (CO_2) in each time frame (e.g., 100 years). The TEWI goes further than the GWP, which considers only direct emissions (e.g., leakage of the refrigerant to the atmosphere), by also including indirect emissions because of the energy consumption of the refrigeration system. Finally, the ODP refers to the amount of ozone destroyed by emissions of vapour over its entire atmospheric lifetime relative to that caused by the emission of the refrigerant CFC-11.

Conventional refrigerant gases that suffered from returning negative TEWI, GWP, and/or ODP values are very efficient and well performing refrigerants, which were in addition non-toxic and non-flammable. Examples of groups of these refrigerants are chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC). Although CFC haven been no longer in use since 1996, HCFC is still being phased-out and HFC only started to phase-out.

Since the 90's high GWP and ODP refrigerants have been phased-out or are currently being phased-out. As a result, the refrigeration industry is developing low-GWP and zero ODP alternatives. Although sustainability is now key in the development of alternatives, these should also aim to be non-toxic, non-flammable, have acceptable operating pressures and an appropriate volumetric capacity to the application. Newer natural and synthetic alternatives are zero-ODP and have low GDP, but tend to be more flammable, toxic, or have lower volumetric capacity than HFC, limiting their usage to specific applications or requiring further technological development to be implemented (Goetzler et al., 2014).

Several synthetic and natural molecules have been identified or developed as suitable sustainable **future refrigerants** and have been identified as low GWP alternatives to replace HFCs. Importantly, most refrigerants are suitable for only one or a few specific steps of the cold chain. For instance, refrigerants suitable for industrial refrigeration in seafood processing facilities are unlikely to suit smaller refrigeration units used in transport refrigeration or in supermarkets (Goetzler et al. 2014). Examples of newer synthetic alternatives are low-GWP hydrofluorocarbons and hydrofluoroolefins (HFO) (Goetzler et al., 2014; Majurin et al., 2015; Savitha et al., 2021). Examples of natural alternatives are hdyrocarbons such as propane, isobutene and propylene, ammonia and carbon dioxide (Collins, 2016; DANFOS, 2022; Goetzler et al., 2014).

Packaging

Proper food **packaging** ensures that seafood products remain fresh throughout the entire processing chain (Almeida et al., 2021). The main functions of product packaging can be summarised as followed, i) protecting the seafood product from external environments and by creating the optimal storage environment in the package itself, ii) communicate outwards in the form of marketing and product information towards to consumers, iii) provide a convenient product for the consumers, and iv) contain food products within its packaging (Walsh & Kerry, 2012).

When looking at the environmental impact of seafood product packaging, two large aspects must be considered. First the type of environmental impacts for each product must be considered. These impacts can be subdivided into direct and indirect environmental impacts. Direct impacts are related to the fabrication, transport, and handling of waste from producing the packaging (Lindh et al., 2016). In contrast, indirect environmental impacts are related to the environmental consequences of food loss and associated waste streams (Molina-Besch et al., 2019). Second, different levels need to be included in the assessment of the environmental impact of packaging. These levels are depended on the amount of contact the packaging has with the product and the specific needs within the value chain, with i) packaging being in direct contact with the product (e.g. the wrapping or cans), ii) packaging containing several layers of primary packaging products (e.g.

cardboard boxes that batch several products together), and iii) packaging which is mainly used for transport between different facilities of the value chain (e.g. transport boxes, pallets) (ISO, 2016). In life-cycle assessments (LCA's) not all the packaging levels are considered in the assessments of environmental impacts and solutions or improvements for each packaging type, or at least the results of such detailed analyses are not commonly given in papers (Almeida et al., 2021). The two large aspects influence the environmental impact of packaging types and should be included in any assessment aiming to identify the most sustainable packaged products.

Direct environmental impact of fish packaging was analysed for different operational PH supply chains and packaging products (Almeida et al., 2021). Specifically, Almeida et al. (2021) did 32 life-cycle assessments including different fish products and reported on the environmental impact of a wide array of packaging types. This study noted that enormous differences in impact of primary packaging occurred between canned products and other fish products (Almeida et al., 2021). The climate change impact range of canned products varied between 6-89% (for tinplate) and 10-83% (for aluminium) (Almeida et al., 2021), and resulted from the energy requirements for the life cycle of these materials (Vázquez-Rowe et al., 2014). The high variation in environmental impact was determined to be result of i) variability in packaging weight compared to product weight (which identifies the amount of packaging used), ii) variation in the fish product processing, and iii) operational differences and associated data differences (data detail level) used for estimating the environmental impact (Almeida et al., 2021). In contrast, the environmental impact of packaging for fish products that need energy intensive processing steps (e.g., freezing, chilling, and drying) takes up a smaller quantity of the product's environmental footprint. The contribution of packaging for these fish products varied around values of 5% of the total climate change impacts (Almeida et al., 2021).

Due to the differences in relative contribution to the environmental impact of the fish products, sustainable solutions need to be focussed on distinct aspects of the product. For canned products, substitutions in packaging could influence the environmental impact significantly, with a shift from tinplate to aluminium in canned tuna reducing the impact with 63% (Avadí et al., 2015) and 56% for sardines (Almeida et al., 2015). A different study reported that the switch from tinplate to plastic resulted in the greatest decrease in impact (Laso et al., 2018). This change however will also change the product presentation towards to consumer and may need large equipment changes, which can make it a financially less sound decision (Almeida et al., 2021). In contrast, with the low environmental impact of packaging in the frozen and chilled products, it is better to focus the packaging efforts on the reduction of food waste instead of finding material with lower environmental impacts (Almeida et al., 2021).

Recycling and reusing of packaging materials has great potential to further reduce the GHG emissions due to the end-of-life practices for these materials. If properly reused and recycled, packaging material can be choses over new packaging materials even if the energy requirements of specific recycling may be higher, because the longevity of the product will have an overall positive effect compared to processing of new packaging materials with a shorter lifespan (Almeida et al., 2021). However, if recycling capacity is insufficient, large amounts of used materials will still be processed in less environmentally efficient methods (e.g., by exporting used materials to other countries) which can counter the overall positive environmental effect (Almeida et al., 2021).

When considering the **indirect** impact of fish product packaging, the impact of the food waste is the main contributor. Food waste is a substantial part of the climate impact of the food supply chain, with estimates of up to 15-16% of the food chain impact (Scherhaufer et al., 2018). As fish product deteriorates very quickly, efforts on improving packaging have mostly focussed on increasing the shelf life and product quality, as well as monitoring the quality throughout its storage time.

Finding information on packaging may be less challenging as currently packaging, as it produces waste and is a source for research on recycling, is considered in many environmental impact assessment. However, making the distinction between conventional and emerging packaging technology is difficult. Therefore the packaging technology described in the current report is considered as part of a **continuous** technology development. Important packaging technologies are modified atmosphere packaging (MAP) (Kirtil et al., 2016; Tsironi & Taoukis, 2018), active packaging (Biji et al., 2015; Sängerlaub et al., 2013; Tsironi & Taoukis, 2018), intelligent packaging (Tsironi & Taoukis, 2018), and edible coating and films (Tsironi & Taoukis, 2018).

Overview of industrial strategies used in the PH value chains

General industrial strategies

Finding information on industrial management strategies was challenging as many of these strategies are not reported. Management strategies are a dynamic tool to make changes in the PH value chains, thus they cannot be easily considered as conventional or emerging but rather are a **continuous** development and improvement of existing industrial management strategies. However, industrial strategies that may lead in the future of management methods are considered here as emerging.

Unlike traditional management, where pollution control is an after-the-event, 'react and treat' approach, **cleaner production** is defined as the continuous application of an integrated, preventive, environmental strategy applied to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment (Baas et al., 1992). Cleaner production strategies should not be confused with 'clean' technology. First, cleaner production depends only partly on new or alternative technologies. It can also be achieved through improved management strategies, different work practices and many other 'soft' approaches. Cleaner production is as much about attitudes, approaches, and management as it is about technology. Second, cleaner production approaches are widely and readily available, and set methodologies exist for its application.

Although it has most commonly been applied to production processes focussing on the conservation of resources, the elimination of toxic raw materials, and the reduction of wastes and emissions, it can also be applied throughout the life cycle of a product, from the initial design phase, through to the consumption and disposal phase. As an example, it is estimated that 70% of all current waste and emissions from industrial processes can be prevented at its source using technically sound and economically profitable procedures based on cleaner production strategies.

The other important feature of cleaner production is that by preventing inefficient use of resources and avoiding unnecessary generation of waste, an organisation can benefit from reduced operating costs, reduced waste treatment and disposal costs, and reduced liability. Investing in cleaner production to prevent pollution and reduce resource consumption is more cost effective than relying on increasingly expensive 'end-of-pipe' solutions. There have been many examples that demonstrate the financial benefits of the cleaner production approach in addition to environmental benefits.

Short food supply chains could be defined as co-operative systems that include very few intermediaries, increasing sustainability, transparency, social relations and fairer prices for food producers and consumers. Such supply chains usually involve local producers working together to promote local food which, in many cases, only travels a short distance, so producers and consumers can communicate with each other. This strategy is related to the concept of "decentralisation" as opposed to the concept of "centralisation" that normally governs the conventional large chain. Producing food closer to its point of consumption not only minimises the energy needed for transport and delivery but could also diminish food storage and refrigeration needs and, consequently, reducing the GHG emissions (Sovacool et al., 2021). From a technological perspective, one innovative idea is for "central kitchens" where fresh foods like fish products can be prepared very close to their place of consumption (Sovacool et al., 2021). In the last two decades, short food supply initiatives and networks have flourished across Europe and North America (Cicatiello, et al., 2015). Due to the COVID-19 pandemic, their importance has increased. Although it has been established that short food supply chains are better from an environmental perspective, the main driver for the increasing popularity in Europe is to ensure a fair price for small producers. There remains a need to assess whether the increase in short food supply chains really does decrease GHG emissions.

An industrial strategy that can be considered and will potentially **revolutionise** some of the current industrial strategies is **automation and data collection/monitoring**. Although automation and data monitoring technologies are two distinct types of strategic developments, they complement each other (including the technologies involved in these strategies) and thus should be used as an integrated strategy. However, this does not rule out the possibility of implementing either automation or data collection/monitoring separately, as they do not necessarily depend on each other to function.

In cold storage facilities, the cooling systems are responsible for 70-80% of the energy consumption (bills) (Evans et al. 2013). Technological developments and industrial management changes have enabled the cold chain industry to increase their energy efficiency, reduce operational costs and increase its environmental sustainability throughout their processes. The **automation** of processes in for example cold storages/warehouses is advantageous as facilities can be built vertically, rather than horizontally, reducing its footprint, hence reducing the price of the property and associated taxes, and reducing the heat gained through the roof area (Kolbe et al., 2006; Caldwell, 2013). Moreover, vertically built cold storage/warehouses will reduce the energy needed to maintain the cold temperatures in the storage unit. Similarly, automation allows a more efficient door management and reduces cold loss through them.

Data monitoring has become relevant for many industrial and commercial sectors, as it allows companies to track their efficiency throughout their value chain, to identify issues and to adjust in "real time". The combination and integration of process automation and data monitoring allows to reach higher production rates, higher efficiency of material and energy use, lower energy consumption, better product quality and consistent standards, increased work safety and reduced working hours. Furthermore, data monitoring and its analyses can also help to justify investments by providing accurate payback calculations, to enhance troubleshooting and diagnosis of issues.

To use cold storage facilities as an example again, over time most refrigeration systems do not continue to operate as effectively as the manufactures planned and might be functioning far from optimal due to poor maintenance, failed components, lack of technical knowledge among the site managers to understand the impact of operational changes or time to undertake meaningful plant performance evaluations (FFT, 2019). To tackle these issues, automated data monitoring, modelling and accessibility through newly developed data monitoring technologies and platforms have been developed to provide specific, precise, and clearly explained insights/recommendations to optimize the plants performance and maximise its efficiency, therefore reducing energy consumption and the GHGs emissions and costs associated with those specific issues.

<u>General industrial strategies – high level</u>

To effectively transition a sector towards more sustainable practices, it is important to look at **motivators for change** and distinct sector areas with a high potential for change. This approach aims to identify actions with the most impact whilst keeping the sector on-board for the change.

In academic literature this potential for change is investigated through two distinct strategies, i) by identifying and focussing on processes with high environmental impacts, and ii) by specifically investigating the motivators for change. Most of the academic efforts have been reported as life-cycle assessments of the industry, with less effort aimed at the incentive for change of the sector. Furthermore, efforts to incentivise focussed on consumer awareness and demands of the industry, while the processing practices remain less understood (Illes, 2007).

When specifically focussing on the development of strategies, two levels can be identified, that is sector level (**high-level** industrial strategies) and local businesses level (**low-level** industrial strategies). Both high- and low-level industrial strategies aim at improving the resource efficiency. High level industrial strategies are mainly aimed at improving the use of financial capital, by decreasing costs or increasing the productivity. Low level industrial strategies work on the level of increasing efficient resource usage, and this can be achieved through sustainability monitoring and reporting as well as proper implementation of corrective actions and good housekeeping.

High level industrial strategies look at an incentive to change covering a whole sector. Regarding the incentive for change, companies themselves work towards sustainability for four distinct reasons, 1) regulations, 2). community relations, 3) cost and revenue imperatives, and 4) societal obligations (Epstein et al., 2017). Although, acting upon environmental impact by companies may be seen as a societal obligation, this aspect may very often be overlooked by the companies. As an example, a study on a fish processing equipment company concluded that investments into the innovation for the processing equipment producing companies are mainly financially driven, with the intention of the investment aimed at stricter regulations and decreasing production costs (by increasing efficiency and/or decreasing the need for manual labour (Bar, 2015). The sector itself sees stricter regulations and policy as an effective method of moving towards more sustainable practices (Bar, 2015), and this is in line with findings from other sectors (Epstein et al., 2017).

General industrial strategies – low level

Supply chain management at a business level requires decision making within the company and collaboration with other stakeholders, for example through the collaboration of a transport business and a seafood producer. Supply chain improvements are described through five categories, 1) good housekeeping, 2) input substitution, 3) technological modification, 4) product modification, 5) recycling waste (UNEP, 2002). Denham et al. (2015) also contained a list of cleaner production cycle strategies that can be applied in both the seafood sector production as well as the PH value chains.

The environmental impact of **transportation** is a complex matter. It can drastically influence the environmental footprint of a product (Coley et al., 2011), but is depended on the preceding processing steps and associated costs (Tlusty & Lagueux, 2009). Fish product processing influences freshness and shelf life and make different transport methods available, for example fresh fish needs to be transported quicker compared to frozen seafood products to avoid quality loss. Transportation through ship freight is the least impactful transportation method for frozen product, followed by road and air freight respectively (Vázquez-Rowe et al., 2012). Because of the rapid quality deterioration of fresh products, it became clear that transport of fresh products with lorries and air freight is more impactful compared to frozen transport (Andersen, 2002). Pre-processing methods such as among others, freezing, drying, and smoking, therefore need to be considered for transport over longer distances, because these allow longer transport times without quality loss (Andersen, 2002). Above-mentioned processing steps reduce the need for energy intensive refrigeration during product transport and allow the usage of energy-efficient transport alternatives (Andersen, 2002). Further improvements can be achieved by monitoring and creating awareness with the consumer of the distance travelled per product. This can be achieved by monitoring and communicating travelled distances towards consumers, whilst further improving transport efficiency (Kissinger, 2012).

The overall impact of the **packaging** and processing is something that needs to be considered in the context of the product's supply chain. If more energy intense processing and packaging methods need to be used but it helps to improve the quality and shelf-life of the product, it can be justified in the processing steps (Williams & Wikström, 2011). For example, packaged product with shelf-life requirements of less than 30 days Modified Atmosphere Packaging (MAP) was observed as the least energy, heat, and power intensive in comparison to other processing methods such as high-pressure processing and thermal pasteurisation (Pardo & Zufía, 2012).

The environmental footprint of **processing** activities is optimisable by making use of monitoring, quality checks and subsequent good housekeeping rules (Denham et al., 2015). Process monitoring allows for identification of supply chain issues and helps with the implementation of follow-up actions. Such actions can for example be achieved by adapting defrosting and maintenance cycles, and detecting and eliminating wasteful process streams (Bezama et al., 2012). Supply chain optimisation and good housekeeping as such will not only increase efficiency of the process, but also help reducing climate impacts by lowering the energy and water needs (Thrane et al., 2009). Avoiding the production of waste products optimises resource usage and reduces waste generation, which further lower the process footprint (Zugarramurdi et al., 2007). Other activities that help to reduce waste generation such as dynamic expiration dates, freezing of products to prolong their freshness can further help lowering the impact of the processing chain (Denham et al., 2015). Waste process streams and their environmental impacts can be further reduced by combining different businesses through synergistic relationships (circular economy). It has been shown that collaboration between different industrial stakeholders can increase efficient resource usage, reduce GHG emissions, waste production and eutrophication (Martin & Harris, 2018).

Good housekeeping practices can reduce the environmental footprint of **retail** activities. This can be achieved by ensuring the (energy) waste process streams are reduced, by for example installing air curtains to reduce temperature loss in retail fridges (Laguerre et al., 2012). Increasing retail packaging efficiency and demanding higher sustainability requirements from their suppliers is another example (Denham et al., 2015).

Industrial strategies – energy

Among energy reducing industrial strategies an easier subdivision between conventional and emerging strategies can be made. Examples of **conventional** strategies are replacing water boilers with steam boilers, heat recovery strategies, and insulating heating and cooling equipment.

Although **replacing water boilers with steam boilers** aims at improving the efficiency of the process, both by reducing energy and water consumption (Thrane et al., 2009), the example is placed here as there exist separate water recovery strategies (see *section 3.3.3.1.5*). Replacing conventional water heater boilers with steam oven-cookers started in the 1990s (Thrane et al., 2009) and currently is a standard in many operations in the fish sector. This strategy is very common in companies when they want to implement a more sustainable production strategy. Important to note is that the total financial and time investments related to this strategy are significant (Thrane et al., 2009).

Heat recovery is a good strategy to reduce GHG emissions. It has been estimated that for many food processing facilities, process heat alone accounts for about 60-70% of total energy needs (Ladha-Sabur et al., 2019; Sovacool et al., 2021). Heat recovery is the reuse of heat produced in specific operations for other operations carried out in the same factory. For example, using residual heat of condensed steam from sterilisation to heat water for cleaning or for another operation such as boiling. It can be even used for preheating the incoming air in the ambient heating systems of the production plant. From a general perspective, heat recovery can reduce energy needs by 10% (Sovacool et al., 2021). Many companies, especially those which use heat intensively, such as canning factories, did internal diagnoses (or with the help of an external company) to determine where actions could be taken for heat recovery strategies to reduce economic costs and, at the same time, to reduce GHG emissions. Although methods like pasteurization are currently energy efficient (95% of heat in pasteurizers is recovered), the potential for waste heat recovery in other processes is substantial (Sovacool et al., 2021).

Another impactful strategy is the **insulation** of the retorts and other heating equipment in order to reduce energy consumption (COWI). Typically, the energy consumption is 200-240 kWh per tonne of canned product. The energy consumption is a major environmental issue, as it causes resource depletion and air pollution. Insulation of the retort can save 1.4 kg of fuel per tonne of canned product. Improving insulation of retorts is currently a standard practice for the equipment suppliers R&D operations. This strategy is also very common in companies when implementing cleaner production. In addition, the insulation materials are improving continuously, thus improved gains in GHG reduction will be achieved in the future. In similar fashion cooling equipment can also be insulated but brings challenges like the ever present moister (condensation) in cooling systems.

Two **emerging** strategies to reduce energy consumption as an important source of GHG emission are automation and robotics and implementation of renewable energy sources.

The incorporation of **automation and robotics** in food production for better control of production systems is one of the cornerstones of the Fourth Industrial Revolution in which the industrial sector is immersed. It has been highlighted as an essential strategy not only to reduce the cost of production, but also to improve energy and resource efficiency and reduce GHG emissions (Simpson et al., 2013; Sovacool et al., 2021). In fact, automation and robotics is probably one of the most important sources of innovation in the development of new machinery for the seafood sector. This includes standard automated cutting and forming machines, ovens, mixers, blending machines, sorting equipment, filling equipment, and packaging and wrapping equipment (Sovacool et al., 2021). Some subsectors, such as seafood canning, raw material handling and packaging, are currently almost entirely automated (Sovacool et al., 2021). Automation and robotics will play a main role in the seafood sector over the next 20 years. As in other sectors, the required levels of quality control, speed of production, labour shortages and overall profitability will need to be addressed (Sovacool et al., 2021). Automation will allow to change production methods, "lights-out manufacturing", and "24:7 manufacturing" will be possible, enhancing productivity yields and lowering energy consumption (Thomas et al., 2018).

Substituting fossil fuels by **renewable energy sources** can strongly reduce the GHG emissions. It is a key strategy of the 2030 Climate Target Plan of the European Union[74] and will demand PH stakeholders to adapt their processing technologies. It has been estimated that the 60% of existing heat demands in the food sector can be provided by renewable energy, especially those needing low to medium temperatures (IRENA, 2015). The renewable energy sources that show the most potential are biomass energy sources, solar thermal heating, and geothermal heat pumps (Sovacool et al., 2021). Factories

[74] https://ec.europa.eu/clima/eu-action/european-green-deal/2030-climate-target-plan_en

located in southern Europe, where there are many sun days, can integrate solar panels on their roofs to reduce their external energy consumption. However, placing solar panels on roofs may proof challenging as many factory buildings are not structurally calculated to place the weight of solar panels on their roofs. Targeted and constructive investigations and funding will be necessary in the future. Many fish processing companies, especially those which use heat intensively like canning factories, apply strategies to increase energy efficiency and increase the employment of renewable energy sources. Companies have tried to reduce the use of traditional solid-liquid fuels by modifying their processes and adopting new processing technologies that demand electricity, which can be supplied by renewable energy sources directly (e.g., solar panels at the factory) or indirectly (e.g., the electricity supplier). If maximum technological modernisation takes place, there will be a significant transfer of energy use from natural gas to electricity, resulting in an overall increase in energy use and costs, but with a significant reduction in CO_2 emissions (in the UK this could represent a cumulative CO_2 reduction between 2014 and 2050 of 70 million tonnes) (Sovacool et al., 2021). The magnitude of the cost increase will depend on costs from adopting the fuel or processes to changing factories' infrastructures.

Industrial strategies – water

Industrial strategies to reduce water usage are considered **continuously** evolving strategies and consist of reusing water and storing water.

Water reusing strategies come in play with retort technology and is reused for cooling or cleaning (COWI). Instead of discharging, the used water can be directed to a cooling tower and reused for heating. The number of times water can be reused depends on maintaining the reused water clean. The water can become contaminated with broken cans and residues from the surface of the cans. Damaged cans should be removed before water is pumped into the retort to avoid contamination of the water. When the water can no longer be recirculated, it could be used to clean the sealed cans and for other cleaning activities. The investment required for installation of the necessary pipes and pumps is low, and about 85% of the water can be reused. Reuse of the retort water for cooling or cleaning is currently very common in the companies when implementing cleaner production strategies.

Water-filled retorts without **water storage** facilities use approximately 75% more energy compared to retorts with water storage facilities (COWI). Therefore, the installation of a storage tank should be considered if not already in place. The required capital investment is low, and both energy and water savings are very substantial, approximately 173 kWh and 5-6 m^3 of water per tonne (COWI). The installation of a storage tank in retorts is currently a standard part of the equipment. This strategy is also very common in companies when implementing cleaner production because the required capital investment is low, and savings are very substantial.

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