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 Maritime and Fisheries Fund (EMFF)

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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

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Table of Contents

List of Tables

List of figures

LIST OF ABBREVIATIONS

Term	Description
AER	Annual Economic Report
AIPCE	European Union Fish Processors and Traders Association
BMSY	Biomass that enables a fish stock to deliver the maximum sustainable yield
CEP	European Federation of National Organisations of Importers and Exporters of Fish
CFP	Common Fisheries Policy
CINEA	European Climate, Infrastructure and Environment Executive Agency
CMO	Common Market Organisation Regulation
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CPL	Consortium Project Leader
CPUE	Catch Per Unit Effort
CS	Case study
DCF	Data Collection Framework
EASME	Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
EMFF	European Maritime and Fisheries Fund
EU	European Union
EUMOFA	European Market Observatory for Fisheries and Aquaculture products
FAO	Food and Agriculture Organization of the United Nations
FAP	Fisheries and aquaculture products
FDI	Fisheries Dependent Information
FMSY	Limit reference point for fishing mortality
FPI	Fish Processing Industry
GFCM	General Fisheries Commission for the Mediterranean
GHG	Greenhouse Gas
GVA	Gross Value Added
GWP	Global Warming Potential
HORECA	Hotel, Restaurant, Catering
IAS	Invasive Alien Species
ICES	International Council for the Exploration of the Sea
IMTA	Integrated Multi-Tropic Aquaculture
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessments
LED	Light Emitting Diode
MAP	Modified Atmosphere Packaging
MS	Member States
MSY	Maximum Sustainable Yield
NIS	Non-Indigenous Species
PH	Postharvest
RAS	Recirculating Aquaculture Systems
RFMO	Regional Fisheries Management Organisation
SDG	Sustainable Developments Goals
STECF	Scientific, Technical and Economic Committee for Fisheries
TAC	Total Allowable Catch

ABSTRACT

Climate change events are impacting EU Postharvest (PH) value chains, resulting in rising costs and unpredictable supply flows of raw materials. Despite this, direct economic costs (e.g. fuel, transport) are the top priority for producers to mitigate, with less emphasis on how future changes in climate will impact businesses.

New species may be added to the PH industry, while further development of wild caught fisheries and technological advancements may further the array of species available for the PH industry. Currently, EU PH value chains mitigate climate change effects through activities such as decreasing local production volumes, importing from third countries and diversifying to other species.

Processing activities associated with PH value chains utilise a substantial amount of fossil fuel and water resources, producing high levels of Greenhouse Gas (GHG) emissions. Furthermore, high reliance on natural resources reduces the industry's inherent resilience to climate change. Hotspots in PH GHG emissions are apparent in the development of packaging material, high-emission transport methods, long-term frozen storage and thermal treatments (i.e. cooking).

Structural improvements to optimise PH value chains include enhanced access to information after landing/auctions, while new technologies are continually being implemented in EU PH value chains.

RÉSUMÉ

Les événements liés au changement climatique ont un impact sur les chaînes de valeur post-capture au sein de l'UE, entraînant une hausse des coûts et des incertitudes quant aux flux d'approvisionnement en matières premières. Pourtant, les coûts économiques directs (par ex. le carburant, le transport) constituent la priorité absolue des producteurs pour en atténuer les effets, tandis que l'on accorde moins d'importance à l'impact des changements climatiques futurs sur l'activité économique.

De nouvelles espèces peuvent être ajoutées au secteur post-capture, tandis que le développement des pêcheries de poissons sauvages et les progrès technologiques peuvent élargir l'éventail des espèces disponibles pour le secteur. Actuellement, les chaînes de valeur post-capture de l'UE atténuent les effets du changement climatique au moyen d'activités telles que la diminution des volumes de production locale, l'importation de pays tiers et la diversification vers d'autres espèces.

Les activités de transformation associées aux chaînes de valeur du secteur post-capture utilisent une quantité importante de combustibles fossiles et de ressources hydriques, produisant des niveaux élevés d'émissions de gaz à effet de serre (GES). En outre, la forte dépendance aux ressources naturelles réduit la résilience du secteur face aux changements climatiques. Les principaux points d'émission de GES du secteur sont le développement des matériaux d'emballage, les méthodes de transport à fortes émissions, le stockage à long terme des produits congelés et les traitements thermiques (cuisson, par exemple).

Les améliorations structurelles visant à optimiser les chaînes de valeur post-capture englobent un meilleur accès aux informations après le débarquement/les criées, alors que de nouvelles technologies sont toujours introduites dans ces chaînes de valeur.

EXECUTIVE SUMMARY

This specific contract focused on providing a synopsis of fisheries and aquaculture postharvest (PH) value chains within the European Union. The study describes the issues associated to these kinds of value chains in terms of the markets they provide to, the processing undertaken within the value chain and how climate change may impact their activities. Within this, a descriptive summary of the different sectors (segments) that comprise PH value chains is presented. These descriptions highlight the diversity of pathways undertaken between PH value chains and the strong coupling between the processor, retailer or foodservice and customer. The factors that enhance or reduce these value chains' financial and physical resilience in relation to climate change is provided. This project then investigates how the structure of PH value chains impacts GHG emissions across the sector role and includes a description of the potential hotspots of GHG emission development. To aid in reducing these hotspots and GHG emissions overall, structural improvements made within PH value chains within the EU – and globally (detailed in peer review literature) – are summarised. This project also reviews trends in technological evolutions and industrial strategies implemented since 2002 aimed at improving energy efficiency and reducing GHG emissions within PH value chains. These evolutions and strategies were identified due to their effects in reducing GHG emissions, and a synopsis of these technologies is provided. Lastly, this work identifies emerging technologies aimed at providing further gains in reducing GHG emissions within PH value chains, including discussing how best to future-proof PH value chains within the EU.

Major impacts of climate change in the seafood PH sector

There is a paucity of information in the peer reviewed literature on the effects of the changing climate on PH value chains. The majority of literature focuses on impacts to fish harvests, within both the wild capture and aquaculture industries. In this respect, the major impact associated with the changing climate on EU PH value chains is the endangerment of access to raw materials, both for human consumption and the development of feed for aquaculture. This detail was also found in stakeholder engagement, which showed that the effects of climate change are being experienced by PH value chains within the EU. These are mainly associated with changes in the availability of fish products for processing within the PH value chain resulting from shifts (usually reductions) in the regional and seasonal abundance of stocks and, therefore, availability for processing. These effects at sea, or in aquaculture facilities, often lead to inflation of costs (i.e. reduced landing volumes, which enhance first sales prices and transport costs and cause the waste of perishable fish); for aquaculture, the loss (through economic downturn) of facilities may also occur. There is also increasing occurrence of extreme weather conditions, with flow-on effects to PH facilities – including fish auctions, transport, processing activities and storage – which have to shift to be as physically close to landing locations as possible. There is also much greater understanding that climate change impacts are restructuring EU fisheries, with EU retailers and banks requiring much greater transparency on GHG emissions in both upstream and downstream supply chains, as well as for energy consumption and use of plastic packaging. This industry-wide call for transparency has resulted in higher motivation within the industry to optimise resource use, including reducing water usage, energy consumption and plastic packaging, while also utilising and valorising 'waste' resources, such as residual warmth from processing.

There is evidence now that particular processing activities associated with PH value chains have high usages of natural resources and high environmental impacts. For example, filleting, battering, canning, smoking and mincing all utilise high levels of fossil fuels, producing substantial GHG emissions compared to PH chains that deliver fish products as a whole (without or with hardly any processing).. Holistic adaptation planning along the supply chain – underpinned by targeted information into how the catch, processing and distribution, and marketing phases are impacted – is needed. Effort into greater understanding is needed now, as some adaptation options have long lead times, and a delay in adaptation planning may limit future options. Based on the range of information provided within case studies, climate change has increased uncertainty for PH value chain actors, in the short and long term. Risk-averse management of fish stocks and aquaculture is therefore vital to adaptation planning, and future investments are needed to ensure the sustainability of the PH value chain sector within a rapidly changing climate.

Resilience of EU postharvest value chains

The valorisation of waste products from processing and a shift toward circular economy may enhance the physical and economic resilience of EU PH value chains. In this respect, self-sufficiency within the EU may be improved by the processing industry utilising a higher diversity of products than previously. This will include finding further uses for the processed 'waste' within PH value chains. This kind of valorisation of by-products from PH value chain processing may enable the development of alternative value chains, protecting SMEs against disruptions in the main value chain while also mitigating effects on value chains associated with reductions in wild caught fisheries. However, although it will be important to recycle and upgrade side streams for human consumption, it will become a trade-off with raw material availability for the feed industry supporting a growing aquaculture.

Technological advances in multi-species aquaculture may enhance the physical and economic resilience of EU PH value chains. Within this are the development and utilisation of plant-based and algal-based feeds in fish farming, and the expansion of Integrated Multi-Tropic Aquaculture (IMTA) systems. These systems may reduce the environmental costs of using fish meal or transporting feeds over large distances while also reducing the need for effluent treatment for a range of different types of aquaculture facilities. Another challenge to address is the decreasing utilisation of EU aquatic production capacity. With a self-sufficiency of only 38,9% of total EU seafood production, the PH value chains are heavily reliant on imports from third countries. This international transport movements increases GHG emissions instead of reducing them, and it has a negative contribution to climate change. Adaptation and mitigating strategies by EU fisheries and aquaculture on a micro-level and by the CFP on a macro-level could optimise the potential of EU supply flows to the PH value chains for the future, despite the effects of climate change.

Major financial constraints and reliability of the postharvest industry

There is a stated willingness to invest in logistic facilities and a willingness to enhance the use of renewable energy. However, there are clear and substantial issues with the development of this infrastructure, mostly associated with the lack of insurance cover for this kind of development. For example, although stakeholders have stated their willingness to install solar panels on the roofs of production buildings, they have found that insurance companies are unwilling to cover the risk of fires associated with solar panels, which would result in large damage to stored fish products and production capital. In addition, this work also found that insurance agencies are unwilling to cover damage associated with extreme weather events. Another burden is the lacking infrastructure, which hinders the expansion of connected solar panels.

The majority of EU PH value chain stakeholders stated that climate change is not their immediate focus, with it often being perceived as indefinable and something to deal with in the future. However, there is an understanding that utilising early-phase investing in renewable energy or reducing GHG emissions could support PH companies in aligning their business practices more readily with changing environmental legislation.

Direct changes in resources are the main focus for the majority of PH value chain stakeholders. First is the increasing array of imported goods into the EU, which may undercut the costs of EU wild capture or farmed fish. In addition, where processing costs change, price increases are unable to be passed onto the customers during the season, due to the type of fixed price contract for the certain period that processors have with EU retailers. Lastly, the Russian war of aggression against Ukraine has raised the urgency in facilitating the energy transition and reducing the current reliance on fossil fuels.

Role of management in implementing introductions of new species to the market

A range of warm water commercial species (e.g. squid, red mullet, gurnard and bream) are increasing in abundance in areas where they have not been found historically (i.e. the North Sea and Baltic Sea). Thermophilic alien species from the Indo-Pacific, introduced in the eastern Mediterranean through the Suez Canal (e.g. rabbitfishes, lionfish), dominate fish communities replacing native stocks. These changes could minimise the risk of climate change reducing historically important stocks. However, often, the production volumes of these new species do not fully compensate for the number and traditional landing volumes of displacing species (e.g. flatfish, small pelagics and cod). The success of bringing these new species to market is likely associated with producers and retailers introducing them to their existing foodservice customers, as samples to taste and try. Importantly, it is the support of the HORECA sector (more than retailers) that leads to the successful introduction of new species to the market.

Structure of EU postharvest value chains and GHG emissions

Three hotspots for GHG emissions within EU PH value chains that are dominant for most products have been identified: packaging material (especially packaging associated with retailers), high-emission transport modes (e.g. small lorries with likely half loads) and long-term frozen storage. Each of these, despite being identified as being associated with high GHG emissions, is vital for the economic success of EU PH value chains. These three factors allow processors to better serve market demand while also extending the refrigerated shelf life of processed goods. In the current EU PH value chain system, where there is still little perceived impact of climate change on the economics of the PH value chains, these solutions are still cost-effective. Further changes in the costs of fuel and plastics, as well as further consumer understanding of the emissions associated with EU seafood, may reduce this cost-effectiveness.

Overall volumes of bulk packaging (e.g. from processor to distribution centre) are limited and have little overall impact on GHG emissions throughout PH value chains. However, for a range of processors and retailers, polystyrene boxes are widely used but not currently recycled, leading to high GHG emissions. In addition, consumer packaging can involve more packaging material than the product being sold, with the highest emissions being for canned products (in glass or metal packaging), with typically 0.6 kg CO_2-eq per kg product in glass jars and around 1 kg CO_2-eq per kg product for canned tuna in aluminium cans.

Throughout EU PH value chains, GHG emissions are predominantly produced by the transportation of goods. International travel is undertaken with large trucks while local/regional transport utilises medium and small trucks; the use of such different sized trucks has a substantial impact on total GHG emissions. For example, for 100 km, large trucks produce GHG emissions of 0.02 kg CO_2-eq per kg product, medium sized trucks produce 0.1 kg CO_2-eq per kg product, while for small lorries, GHG emissions may be as high as 0.5 kg CO_2-eq per kg product.

Importantly, although international road transport can produce high GHG emissions, local and regional transport, where loads are of a lower capacity, may produce higher GHG emission intensity per tonne produced. Importantly, fresh fish supply chains rely on regular routes to be operated to meet supermarkets' demand for rapid delivery (usually within 24 hours of landing), leading to loads that may be substantially less than what can be economically transported, increasing GHG emission intensity. Lastly, air cargo emissions are some of the highest recorded for PH value chains, with a climate impact of over 10 kg CO2-eq per kg product. However, several PH value chains rely on air freight, mostly for live crustaceans or ultra-fresh fish fillets; international imports (e.g. frozen hake from Chile) are also flown into the EU.

In addition to the above-mentioned hotspots, significant GHG emission are associated with long-distance transport (around 0.2 kg CO_2-eq per kg product when transported 1,000 km in a large truck). Also significant are energy use refrigeration in retail (typically 0.05 to 0.1 kg CO_2-eq per kg product) and indirect effects of losses along the postharvest chain – which induce extra catch and postharvest operation to fulfil the market demand (adding extra up to 0.2 kg CO_2-eq per kg product).

The third hotspot is long-term frozen storage. A substantial amount of energy is used for refrigeration, freezing (including frozen storage for up to one year) and ice flake production. Typical total GHG emissions related to energy use in processing and storage vary from <0.01 to 0.09 kg CO_2-eq per kg product. There can be a high variability in supply chains due to the heterogeneity of installations and refrigerants used in processing plants and cold storage. Another substantial source of GHG emissions are refrigerant losses because the emission power of some refrigerants is far higher than CO_2. There is, however, no systematic record of refrigerant losses in the supply chain, which would help quantify the effect of these losses.

Current limitations for structural improvements to GHG emissions

In understanding how hotspots develop, GHG emission levels are mainly affected by two factors. First is the diversity of infrastructure and the materials utilised across the chain, including energy used for refrigeration, fuel for transport and materials for packaging. For example, there are specific logistic aspects within PH value chains that are associated with product type. Fresh products have a shelf life of no more than a few days, so time is the most important constraint for the supply chain, resulting in transport that is associated with time and not value per se. In comparison, processed products (i.e. cooked, canned and frozen) with a much longer shelf life do not result in the transport having time constraints. In this respect, the transport of these goods may also be grouped with other product families, resulting in a much more efficient transport system.

The level of GHG emissions is also associated with the respective yields versus the losses along the PH value chain. Where energy consumption, water use, refrigerant losses, inclusion of ingredients or use of packages is mapped across EU PH value chains, the distinction between waste and co-product modifies GHG allocation. For example, for fish filleting, 1 kg of whole fish may produce 333 grams of fillets, depending on species, season and freshness (higher freshness can ensure higher filleting yields). If the trimmings are disposed as waste, all GHG emissions associated with fillet production are summed (i.e. production, transport, storage and processing). In comparison, if the trimmings are considered as co-products, only a fraction of the GHG emissions associated with the production of the fillets are accounted for.

Efficiency in processing may also have an impact on total GHG emissions associated with the final product, as only a fraction of landed individuals ends in an edible product (i.e. filleting/peeling yields vary from 25 to 70%). However, residue streams generated (e.g. head, trimmings and skin) may sometimes be valorised for other applications (including fish meal and oil). The level of GHG emissions may also be high from the actual processing operations, with the majority of energy utilised for refrigeration, freezing (including frozen storage for up to one year) and ice flake production.

Reducing GHG emissions by structural improvements

In understanding the structural improvements that are needed to enhance the EU PH value chains, several essential tools need to be implemented are currently not being used in these chains, hindering the development of a coherent fresh fish market that would allow for route optimisations, better local options, leading an ultimately more organised and less centralised market. These tools are: (i) alignment of auction catalogues; (ii) information on future auctions; (iii) alignment in fish auctions at the EU level; (iv) development of digital traceability; (v) lack of standardisation in data exchange formats (in support of digital traceability), and (vi) a central marketplace.

Reducing GHG emissions by technical means

Although literature exists for almost the entire range of technologies and industrial strategies used and applied in PH value chains, literature on each of the specific technologies and strategies is often scarce. As such, stakeholders have provided valuable insights into how technologies and industrial strategies are being implemented, how they perform and what challenges the stakeholders face. Additionally, there is a vast amount of technical and strategic expertise among individual stakeholders, but this is often considered the intellectual property of the stakeholders and thus reports on this knowledge are almost non-existent.

The stakeholders consulted in the case studies gave a range of examples where new technologies have been implemented. For example, access to funding has made refrigerated seawater tanks and pumps available to different stakeholders, while new technologies that increase processing yield and create side-product streams, as well as climate and energy friendly transport systems, high-tech packaging materials, tapping renewable energy sources and reducing energy by heat recovery systems are examples of these kinds of solutions. In addition, changes in industrial strategies may lead to positive climate and GHG emissions impacts. Cleaner production strategies, the certification of raw materials, seasonal processing strategies, short value chains (both geographically and in the number of stakeholders in the PH value chain) and collaborative transport strategies are a few examples. Importantly, the implementation of technologies is often combined with a new strategy that aims for the most efficient application of a technology. Automation and subsequent consistent data collection is one of the main examples of technology and strategy working as an integrated approach and will become a powerful tool in the future.

From the literature review and stakeholder engagement, there seem to be a number of technological advances that would result in direct GHG emission reductions. These include steam recovery equipment, which can be used to recover steam condensate and power machinery (i.e. already utilised within fishmeal plants, reducing the total fossil fuels needed to power machinery). The installation of Light Emitting Diode (LED) lighting, which has a range of advantages over incandescent light sources, including lower power consumption, longer lifetime and improved physical robustness. In addition, more insulation of pipes used within PH processing to reduce the loss of heat or cold, further use of heat exchange equipment to ensure heat utilised within the processing is reused, and a change to renewable energy sources across the entire PH value chain.

The main technical and strategic challenges to future-proofing EU PH value chains are as follows. As the companies that contribute to the PH value chain are economic entities, their priorities lie within the realms of consumer service, financial profitability (return on investments) and feasibility; climate and GHG emissions are lower down the list. Huge financial investments from within the PH value chain – for example through cost reduction and investment of profit – are necessary to make technical and strategic changes and will need to be part of the approach to future-proof PH value chains. These investments need strong financial, technical and strategic incentives. Lastly, research and stakeholder expertise, although already high, is still lacking in many aspects. Therefore, increased knowledge gathering, knowledge sharing and awareness of all involved parties is needed now and in the future.

RÉSUMÉ EXÉCUTIF

Ce contrat spécifique avait pour objectif de fournir une vue d'ensemble des chaînes de valeur post-capture de la pêche et de l'aquaculture au sein de l'Union européenne. L'étude décrit les problèmes associés à ces types de chaînes de valeur en ce qui concerne les marchés qu'elles approvisionnent, la transformation effectuée au sein de la chaîne de valeur et la manière dont le changement climatique peut avoir un impact sur leurs activités. Dans ce cadre, un résumé descriptif des différents secteurs (segments) qui composent les chaînes de valeur post-capture est présenté. Ces descriptions soulignent la diversité des chemins empruntés par les chaînes de valeur post-capture et le lien étroit entre le transformateur, le détaillant ou la distribution alimentaire et le client. L'étude présente les facteurs qui améliorent ou réduisent la résilience financière et physique de ces chaînes de valeur par rapport au changement climatique. Ce projet étudie ensuite l'impact de la structure des chaînes de valeur post-capture sur les émissions de GES dans l'ensemble du secteur et comprend une description des principaux points de développement des émissions de GES. Afin de contribuer à la réduction de ces foyers et des émissions de GES en général, les améliorations structurelles apportées aux chaînes de valeur post-capture au sein de l'UE - et au niveau mondial (détaillées dans la littérature spécialisée) - sont résumées. Ce projet passe également en revue les tendances des évolutions technologiques et des stratégies industrielles déployées depuis 2002 en vue d'améliorer l'efficacité énergétique et de réduire les émissions de GES au sein des chaînes de valeur post-capture. Ces évolutions et stratégies ont été identifiées en raison de leur impact sur la réduction des émissions de GES, et un aperçu de ces technologies est fourni. Enfin, cette étude identifie les technologies émergentes visant à fournir des gains supplémentaires dans la réduction des émissions de GES au sein des chaînes de valeur post-capture, notamment en examinant la meilleure façon de préparer l'avenir des chaînes de valeur post-capture au sein de l'UE.

Principaux impacts du changement climatique dans le secteur post-capture des produits de la mer

Il existe peu d'informations dans la littérature évaluée par des pairs sur les effets du changement climatique sur les chaînes de valeur post-capture. La plupart des publications traitent de l'impact sur les récoltes de poissons, tant dans le secteur de la capture sauvage que dans celui de l'aquaculture. À cet égard, l'impact majeur associé au changement climatique sur les chaînes de valeur post-capture de l'UE est la mise en danger de l'accès aux matières premières, tant pour la consommation humaine que pour la production d'aliments pour l'aquaculture. Ce point est également constaté dans l'engagement des parties prenantes, qui a montré que les effets du changement climatique sont ressentis par les chaînes de valeur post-capture au sein de l'UE. Ces répercussions sont principalement associées à des changements dans la disponibilité des produits de la pêche pour la transformation au sein de la chaîne de valeur post-capture, résultant de changements (généralement des réductions) dans l'abondance régionale et saisonnière des stocks et, par conséquent, de la disponibilité pour la transformation. En mer ou dans les installations d'aquaculture, ces effets entraînent souvent une inflation des coûts (c'est-à-dire une réduction des volumes de débarquement, ce qui augmente les premiers prix de vente et les coûts de transport et provoque le gaspillage de poissons périssables) ; pour l'aquaculture, la perte (en raison de la récession économique) des installations peut également se produire. Les situations météorologiques extrêmes sont également de plus en plus fréquentes, ce qui a des répercussions sur les infrastructures de post-capture - y compris les marchés aux poissons, le transport, les activités de transformation et le stockage - qui doivent se déplacer pour être aussi proches que possible des lieux de

débarquement. Par ailleurs, on comprend désormais mieux que les effets du changement climatique restructurent les activités de pêche de l'UE. Les détaillants et les banques européennes exigent une transparence beaucoup plus grande sur les émissions de GES dans les chaînes d'approvisionnement en amont et en aval, ainsi que sur la consommation d'énergie et l'utilisation d'emballages en plastique. Cet appel à la transparence lancé à toute la filière s'est traduit par une motivation accrue au sein de l'industrie pour optimiser l'utilisation des ressources, notamment en réduisant l'utilisation de l'eau, la consommation d'énergie et les emballages plastiques, tout en utilisant et en valorisant les ressources "résiduelles", telles que la chaleur résiduelle issue du traitement.

Il est aujourd'hui prouvé que certaines activités de transformation associées aux chaînes de valeur post-capture utilisent beaucoup de ressources naturelles et ont d'importantes incidences sur l'environnement. Par exemple, le filetage, le panage, la mise en conserve, le fumage et le hachage utilisent tous des niveaux élevés de combustibles fossiles, produisant des émissions de GES substantielles par rapport aux chaînes de valeur post-capture qui fournissent des produits de pêche entiers (sans ou avec très peu de transformation). Il est nécessaire de planifier une adaptation holistique tout au long de la chaîne d'approvisionnement, étayée par des informations ciblées sur la façon dont les phases de capture, de transformation et de distribution, et de commercialisation sont affectées. Il est nécessaire de faire des efforts pour mieux comprendre la situation dès maintenant, car certaines options d'adaptation nécessitent des délais importants, et un retard dans la planification de l'adaptation pourrait limiter les options futures. D'après les informations fournies dans les études de cas, le changement climatique a accru l'incertitude pour les acteurs de la chaîne de valeur post-capture, à court et à long terme. Une gestion prudente des stocks de poissons et de l'aquaculture est donc essentielle à la planification de l'adaptation, et des investissements futurs sont nécessaires pour assurer la durabilité du secteur de la chaîne de valeur post-capture dans un climat en évolution rapide.

Résilience des chaînes de valeur post-capture de l'UE

La valorisation des déchets issus de la transformation et le passage à l'économie circulaire peuvent améliorer la résilience physique et économique des chaînes de valeur post-capture au sein de l'UE. Dans cette optique, il est possible de renforcer l'autosuffisance de l'UE en faisant en sorte que l'industrie de transformation utilise une plus grande diversité de produits qu'auparavant. Il s'agira notamment de trouver d'autres utilisations pour les "déchets" transformés au sein des chaînes de valeur post-capture. Ce type de valorisation des sous-produits issus de la transformation dans les chaînes de valeur post-capture peut permettre le développement de chaînes de valeur alternatives, en protégeant les PME contre les perturbations de la chaîne de valeur principale, tout en atténuant les effets de la réduction de la pêche sauvage sur les chaînes de valeur. Cependant, même s'il est important de recycler et de valoriser les flux secondaires pour la consommation humaine, il faudra trouver un compromis avec la disponibilité des matières premières pour l'industrie de l'alimentation animale nécessaire au développement de l'aquaculture.

Les avancées technologiques dans l'aquaculture multi-espèces peuvent améliorer la résilience physique et économique des chaînes de valeur post-capture de l'UE. Il s'agit notamment du développement et de l'utilisation d'aliments à base de plantes et d'algues en pisciculture, et de l'expansion des systèmes d'aquaculture multitrophique intégrée (AMTI). Ces systèmes peuvent réduire les coûts environnementaux liés à l'utilisation de farine de poisson ou au transport d'aliments sur de longues distances, tout en réduisant le besoin de traitement des effluents pour plusieurs types d'installations aquacoles. La diminution de l'utilisation de la capacité de production aquacole de l'UE est un autre défi à relever. Avec une autosuffisance de seulement 38,9 % de la production totale des produits de la mer de l'UE, les chaînes de valeur post-capture dépendent fortement des importations en provenance de pays tiers. Ces flux de transport internationaux augmentent les émissions de GES au lieu de les réduire et contribuent de manière négative au changement climatique. Les stratégies d'adaptation et d'atténuation mises en œuvre par les secteurs de la pêche et de l'aquaculture de l'UE à un niveau microéconomique et par la PCP à un niveau macroéconomique pourraient optimiser le potentiel des flux d'approvisionnement au sein de l'UE pour les chaînes de valeur post-capture à l'avenir, malgré les effets du changement climatique.

Principales contraintes financières et fiabilité de l'industrie post-capture

Il existe une volonté affirmée d'investir dans des infrastructures logistiques et de renforcer l'utilisation des énergies renouvelables. Cependant, le développement de ces infrastructures pose des problèmes importants et manifestes, principalement liés à l'absence de couverture d'assurance pour ce type de travaux. Par exemple, bien que les acteurs concernés aient fait part de leur volonté d'installer des panneaux solaires sur les toits des bâtiments de production, ils ont constaté que les compagnies d'assurance ne sont pas disposées à couvrir le risque d'incendie associé aux panneaux solaires, ce qui entraînerait des dommages importants aux produits de la pêche stockés et au capital de production. En outre, cette étude a également révélé que les agences d'assurance ne sont pas disposées à couvrir les dommages liés aux événements climatiques extrêmes. Un autre problème est le manque d'infrastructures, qui entrave l'expansion des panneaux solaires connectés.

La majorité des intervenants de la chaîne de valeur post-capture de l'UE ont indiqué que le changement climatique n'était pas leur préoccupation immédiate, car il est souvent perçu comme indéfinissable et comme un problème à régler dans le futur. Toutefois, il est admis que l'utilisation d'investissements de démarrage dans les énergies renouvelables ou la réduction des émissions de GES pourrait aider les entreprises du secteur de post-capture à aligner plus facilement leurs pratiques commerciales sur l'évolution de la législation environnementale.

Les variations directes des ressources constituent la principale préoccupation de la majorité des acteurs de la chaîne de valeur post-capture. Il y a d'abord l'éventail croissant de produits importés dans l'UE, qui peuvent être moins coûteux que le poisson de capture sauvage ou d'élevage de l'UE. En outre, lorsque les coûts de transformation changent, les augmentations de prix ne peuvent pas être répercutées sur les clients pendant la saison, en raison du type de contrat à prix fixe pour une certaine période que les transformateurs ont avec les détaillants de l'UE. Enfin, la récente guerre d'agression de la Russie contre Ukraine a mis en évidence l'urgence de faciliter la transition énergétique et de réduire la dépendance actuelle aux combustibles fossiles.

Rôle de la gestion dans la mise en place des introductions de nouvelles espèces sur le marché

Plusieurs espèces commerciales d'eau chaude (par exemple, le calmar, le rouget, le grondin et la dorade) deviennent de plus en plus abondantes dans des zones où on ne les trouvait pas auparavant (la mer du Nord et la mer Baltique). Les espèces exotiques thermophiles de l'Indo-

Pacifique, introduites en Méditerranée orientale par le canal de Suez (par exemple, le poisson-lapin, le poisson-lion), dominent les populations de poissons et remplacent les stocks indigènes. Ces changements pourraient minimiser le risque de réduction des stocks historiquement importants par le changement climatique. Toutefois, il arrive souvent que les volumes de production de ces nouvelles espèces ne compensent pas entièrement le nombre et les volumes de débarquement traditionnels des espèces déplacées (par exemple, les poissons plats, les petits pélagiques et le cabillaud). Le succès de la mise sur le marché de ces nouvelles espèces est probablement lié au fait que les producteurs et les détaillants les présentent à leurs clients déjà existants, sous forme d'échantillons à goûter et à essayer. Il convient de noter que c'est le soutien du secteur CHR (plus que celui des détaillants) qui permet l'introduction réussie de nouvelles espèces sur le marché.

Structure des chaînes de valeur post-capture de l'UE et émissions de GES

Trois principaux points pour les émissions de GES au sein des chaînes de valeur post-capture de l'UE, qui sont dominantes pour la plupart des produits, ont été identifiés : les matériaux d'emballage (en particulier les emballages associés aux détaillants), les modes de transport à fortes émissions (par exemple, les petits camions susceptibles d'être chargés à moitié) et le stockage congelé à long terme. Chacun de ces éléments, bien qu'ils aient été identifiés comme étant associés à des émissions de GES élevées, est vital pour le succès économique des chaînes de valeur post-capture de l'UE. Ces trois facteurs permettent aux transformateurs de mieux répondre à la demande du marché tout en prolongeant la durée de conservation réfrigérée des produits transformés. Dans la structure actuelle de la chaîne de valeur de l'UE, où on perçoit encore peu l'impact du changement climatique sur l'économie des chaînes de valeur post-capture, ces solutions sont encore rentables. De nouveaux changements dans les coûts du carburant et des plastiques, ainsi qu'une meilleure compréhension par les consommateurs des émissions associées aux produits de la mer au sein de l'UE, pourraient réduire cette rentabilité.

Les volumes globaux d'emballages en vrac (par exemple, du transformateur au centre de distribution) sont limités et ont peu d'impact global sur les émissions de GES tout au long des chaînes de valeur post-capture. Cependant, pour un certain nombre de transformateurs et de détaillants, les boîtes en polystyrène sont largement utilisées, mais ne sont pas actuellement recyclées, ce qui entraîne des émissions élevées de GES. En plus, l'emballage des produits de consommation peut impliquer plus de matériaux d'emballage que le produit vendu, les émissions les plus élevées étant celles des produits en conserve (dans des emballages en verre ou en métal), avec généralement 0,6 kg d'équivalent CO2 par kg de produit dans des bocaux en verre et environ 1 kg d'équivalent CO_2 par kg de produit pour le thon en conserve dans des boîtes en aluminium.

Au sein des chaînes de valeur post-capture de l'UE, les émissions de GES sont principalement produites par le transport des marchandises. Les trajets internationaux sont effectués par de gros camions, tandis que les transports locaux/régionaux sont effectués par des camions de taille moyenne ou petite ; l'utilisation de camions de tailles différentes a un impact considérable sur les émissions totales de GES. Par exemple, pour 100 km, les gros camions produisent des émissions de GES de 0,02 kg d'équivalent CO_2 par kg de produit, les camions de taille moyenne produisent 0,1 kg d'équivalent CO_2 par kg de produit, tandis que pour les petits camions, les émissions de GES peuvent atteindre 0,5 kg d'équivalent CO_2 par kg de produit.

Par ailleurs, bien que le transport routier international puisse produire des émissions de GES élevées, le transport local et régional, où les cargaisons sont d'une capacité inférieure, peut produire une intensité d'émissions de GES plus élevée par tonne produite. Il est important de noter que les chaînes d'approvisionnement en poisson frais dépendent de l'exploitation de routes régulières pour répondre à la demande de livraison rapide des supermarchés (généralement dans les 24 heures suivant le débarquement), ce qui conduit à des chargements qui peuvent être sensiblement inférieurs à ce qui peut être transporté de manière économique, augmentant ainsi l'intensité des émissions de GES. Enfin, les émissions du fret aérien sont parmi les plus élevées enregistrées pour les chaînes de valeur post-capture, avec un impact climatique de plus de 10 kg d'équivalent CO_2 par kg de produit. Cependant, plusieurs chaînes de valeur post-capture dépendent du fret aérien, principalement pour les crustacés vivants ou les filets de poisson ultra-frais ; les importations internationales (par exemple, le merlu congelé du Chili) sont également acheminées par avion dans l'UE.

Outre les points critiques susmentionnés, d'importantes quantités d'émissions de GES sont associées au transport sur de longues distances (environ 0,2 kg d'équivalent CO_2 par kg de produit transporté sur 1 000 km dans un gros camion). La réfrigération dans le commerce de détail (généralement 0,05 à 0,1 kg d'équivalent CO_2 par kg de produit) et les effets indirects des pertes le long de la chaîne post-capture - qui entraînent des captures supplémentaires et des opérations après récolte pour répondre à la demande du marché (ajoutant jusqu'à 0,2 kg d'équivalent CO_2 par kg de produit) - sont également importants.

Le troisième point critique est le stockage congelé à long terme. Une quantité importante d'énergie est utilisée pour la réfrigération, la congélation (y compris le stockage en congélation jusqu'à un an) et la production de glace en écaille. Les émissions totales de GES liées à l'utilisation de l'énergie dans la transformation et le stockage varient généralement de <0,01 à 0,09 kg d'équivalent CO_2 par kg de produit. Il peut exister une grande variabilité dans les chaînes d'approvisionnement en raison de l'hétérogénéité des installations et des réfrigérants utilisés dans les unités de transformation et les entrepôts frigorifiques. Les pertes de réfrigérants constituent une autre source importante d'émissions de GES, car le pouvoir d'émission de certains réfrigérants est bien supérieur à celui du CO_2. Il n'existe cependant pas d'enregistrement systématique des pertes de réfrigérants dans la chaîne d'approvisionnement, ce qui permettrait de quantifier l'effet de ces pertes.

Limites actuelles des améliorations structurelles en matière d'émissions de GES

Pour comprendre comment les points sensibles se développent, il faut savoir que les niveaux d'émissions de GES sont principalement affectés par deux facteurs. Le premier est la diversité des infrastructures et des matériaux utilisés tout au long de la chaîne, notamment l'énergie utilisée pour la réfrigération, le carburant pour le transport et les matériaux d'emballage. Par exemple, il existe des aspects logistiques spécifiques dans les chaînes de valeur du secteur qui sont associés au type de produit. Les produits frais ont une durée de conservation qui ne dépasse pas quelques jours, le temps est donc la contrainte la plus importante pour la chaîne d'approvisionnement, ce qui entraîne un transport associé au temps et non à la valeur en soi. En comparaison, les produits transformés (c'est-à-dire cuits, en conserve et congelés), dont la durée de conservation est beaucoup plus longue, n'entraînent pas de contraintes de temps pour le transport. Par conséquent, le transport de ces marchandises peut également être regroupé avec d'autres familles de produits, ce qui permet d'obtenir un système de transport beaucoup plus efficace.

Le niveau des émissions de GES est également associé aux rendements respectifs par rapport aux pertes le long de la chaîne de valeur post-capture. Lorsque la consommation d'énergie, l'utilisation d'eau, les pertes de réfrigérant, l'inclusion d'ingrédients ou l'utilisation d'emballages sont représentées dans les chaînes de valeur du secteur post-capture, la distinction entre les déchets et les coproduits modifie l'allocation des GES. Par exemple, pour le filetage du poisson, 1 kg de poisson entier peut produire 333 grammes de filets, en fonction de l'espèce, de la saison et de la fraîcheur (une fraîcheur plus élevée peut garantir des rendements de filetage plus élevés). Si les chutes de parage sont éliminées comme des déchets, toutes les émissions de GES associées à la production de filets sont additionnées (c'est-à-dire la production, le transport, le stockage et la transformation). En comparaison, si les chutes de parage sont considérées comme des coproduits, seule une fraction des émissions de GES associées à la production des filets est prise en compte.

L'efficience de la transformation peut également avoir un impact sur les émissions totales de GES associées au produit final, car seule une fraction des individus débarqués aboutit à un produit comestible (les rendements de filetage/pelage varient de 25 à 70 %). Cependant, les flux de résidus générés (par exemple, la tête, les parures et la peau) peuvent parfois être valorisés pour d'autres usages (notamment la farine et l'huile de poisson). Le niveau des émissions de gaz à effet de serre peut également être important du fait des opérations de transformation proprement dites, la majorité de l'énergie étant utilisée pour la réfrigération, la congélation (y compris le stockage à l'état congelé jusqu'à un an) et la production de glace en écaille.

Réduire les émissions de GES au moyen d'améliorations structurelles

Pour comprendre les améliorations structurelles nécessaires à l'amélioration des chaînes de valeur post-capture au sein de l'UE, plusieurs outils fondamentaux doivent être mis en œuvre. Ces outils ne sont actuellement pas utilisés dans ces chaînes, ce qui entrave le développement d'un marché du poisson frais plus cohérent qui permettrait d'optimiser les filières, d'offrir de meilleures options locales et de créer un marché plus organisé et moins centralisé. Ces outils sont les suivants : (i) l'alignement des catalogues des criées ; (ii) l'information sur les criées futures ; (iii) l'alignement des criées au niveau de l'UE ; (iv) le développement de la traçabilité numérique ; (v) le manque de normalisation des formats d'échange de données (en faveur de la traçabilité numérique), et (vi) une place de marché centrale.

Réduire les émissions de GES par des moyens techniques

Malgré la disponibilité de publications sur la quasi-totalité des technologies et des stratégies industrielles utilisées et appliquées dans les chaînes de valeur post-capture, la documentation relative à chacune des technologies et stratégies spécifiques est souvent rare. Ainsi, les parties prenantes ont fourni des informations précieuses sur la manière dont les technologies et les stratégies industrielles sont mises en œuvre, sur leurs performances et sur les défis à relever par les intéressés. En outre, les différents acteurs du secteur disposent d'une vaste expertise technique et stratégique, mais celle-ci est souvent considérée comme la propriété intellectuelle des intéressés, de sorte que les rapports sur ces connaissances sont presque inexistants.

Les acteurs consultés dans le cadre des études de cas ont donné une série d'exemples de mise en œuvre de nouvelles technologies. Par exemple, l'accès au financement a permis à différentes parties prenantes de disposer de réservoirs d'eau de mer réfrigérés et de pompes, tandis que les nouvelles technologies qui augmentent le rendement de la transformation et créent des flux de produits secondaires, ainsi que les systèmes de transport respectueux du climat et de l'énergie, les matériaux d'emballage de haute technologie, l'exploitation de sources d'énergie renouvelables et la réduction de l'énergie par des systèmes de récupération de chaleur sont des exemples de ce type de solutions. En outre, des changements dans les stratégies industrielles peuvent avoir des effets positifs sur le climat et les émissions de GES. Parmi les exemples, on peut citer des stratégies de production plus propre, la certification des matières premières, des stratégies de transformation saisonnière, des chaînes de valeur courtes (tant sur le plan géographique que sur le plan du nombre d'intervenants dans la chaîne de valeur) et des stratégies de transport collaboratif. Il faut savoir que la mise en œuvre des technologies est souvent associée à une nouvelle stratégie visant à l'application la plus efficace possible d'une technologie. L'automatisation et la collecte rationnelle de données qui en découle sont l'un des principaux exemples de technologie et de stratégie fonctionnant comme une approche intégrée et qui deviendra un outil puissant à l'avenir.

D'après l'analyse documentaire et l'engagement des parties prenantes, il semble y avoir un certain nombre de progrès technologiques qui entraîneraient des réductions directes des émissions de GES. Il s'agit notamment des équipements de récupération de la vapeur, qui peuvent être utilisés pour récupérer les condensats de vapeur et alimenter les machines (ils sont déjà utilisés dans les usines de farine de poisson, ce qui permet de réduire la quantité totale de combustibles fossiles nécessaires pour alimenter les machines). L'installation d'un éclairage à diodes électroluminescentes (LED), qui présente une série d'avantages par rapport aux sources lumineuses à incandescence, notamment une consommation d'énergie plus faible, une durée de vie plus longue et une meilleure robustesse physique. En plus, une meilleure isolation des tuyaux utilisés dans le traitement post-capture pour réduire la perte de chaleur ou de froid, une utilisation plus importante d'équipements d'échange de chaleur pour s'assurer que la chaleur utilisée dans la transformation est réutilisée, et un changement vers des sources d'énergie renouvelables dans toute la chaîne de valeur post-capture.

Les principaux défis techniques et stratégiques à relever pour assurer l'avenir des chaînes de valeur du secteur post-capture dans l'UE sont les suivants. Les entreprises qui contribuent à la chaîne de valeur post-capture étant des entités économiques, leurs priorités se situent dans les domaines du service aux consommateurs, de la rentabilité financière (retour sur investissement) et de la faisabilité ; le climat et les émissions de GES sont des préoccupations moins importantes. D'énormes investissements financiers au sein de la chaîne de valeur post-capture - par exemple par la réduction des coûts et l'investissement des bénéfices - sont nécessaires pour apporter des changements techniques et stratégiques et devront faire partie de l'approche visant à assurer l'avenir des chaînes de valeur post-capture. Ces investissements nécessitent de fortes incitations financières, techniques et stratégiques. Enfin, l'expertise des chercheurs et des acteurs du secteur, bien que déjà importante, fait encore défaut sur de nombreux aspects. Par conséquent, il est nécessaire de renforcer la collecte et le partage des connaissances ainsi que la sensibilisation de toutes les parties concernées, aujourd'hui et à l'avenir.

1 INTRODUCTION

1.1 Background

Ongoing changes in the climate are causing substantial changes to the global seafood industry. Changes in distribution of migratory fish stocks due to shifting water temperatures, ocean acidification and extreme weather events are just a few of the major impacts occurring to marine systems (Christensen and Kjellström, 2018; Gustafsson and Gustafsson, 2020; Meier and Saraiva, 2020). These impacts must be recognised and understood by the industry, including fishery management. These effects not only affect the primary production sectors (i.e. fisheries and aquaculture), but they are also affecting downstream processing and the marketing of seafood products. In this respect, all sectors of the fishing industry, from catching to selling, must contribute to mitigating the potential effects of climate change.

The postharvest (PH) sector is comprised of a diverse group of sectors spanning from first sale and/or auction, to transport, processing, packaging, distribution/retailers, to the final consumers. It is the group of sectors downstream of fishery and aquaculture production; it includes a large number of different actors and activities with their specific characteristics, traditions and needs. Stakeholders within the PH sector have to prepare for upcoming changes in their industry associated with a changing climate. Some may already be well aware of this and have initiated measures. Others may continue to operate almost unchanged, potentially endangering their long-term existence.

The seafood PH sector involves high levels of processing and product transformation. It is likely that these processes consume high levels of energy (either directly or indirectly) and generate significant levels of waste that must be treated. The sector largely operates with an almost just-in-time logistic philosophy[1], making it sensitive to material disruptions. Exactly how much energy is consumed, GHGs produced and how sensitive the sector is to climate change is unknown. This study aims to provide more insight into these aspects.

It is to be expected that GHG emissions in the PH sector need to be reduced. The adjustments that may be required for this sector are related to the European 'Green Deal' (COM, 2019) (amongst other factors), which sets framework conditions for the transition of the PH sector to ensure and promote the medium and long-term existence of this sector within the European Union (EU). It will be necessary for fisheries, aquaculture and the PH sectors to engage in a permanent process of coordination with science and politics in order to respond to the changes and secure their own future.

1.2 Objective

The overall objective of this study is to provide the European Commission (EC) with insights into the PH value chain of EU seafood supply chains with regard to issues related to markets, processing and climate change. By 31 December 2022, the EC will prepare a report on the functioning of the Common Fisheries Policy (CFP). The report will take stock of the implementation of the CFP as well as assessing whether climate adaptation, social dimensions and clean oceans are sufficiently addressed by the current policy framework (as outlined in Commissioner Sinkevičius' mission letter). Similarly, Regulation (EC) No 1379/2013

[1] Just-in-time logistics aim to deliver goods immediately before they are needed for the next stage in the logistics process.

'Common Market Organisation Regulation' (CMO) includes a reporting obligation on its implementation by the same deadline, covering the market policy.

The purpose of the present report is to provide insights into issues related to markets, processing and climate change. Here, 'climate change' means the sum of changes in ocean chemistry and physical attributes that are driven by direct and indirect anthropogenic increases in atmospheric GHGs, including acidification, deoxygenation and temperature increases. Three overarching topics are dealt with:

- Value chain resilience: an overview of the available information about the financial and physical resilience of EU fisheries and aquaculture PH value chains in relation to climate change;
- Reducing GHG emissions by structural improvements: a description of EU seafood PH value chains structures and how the structure impacts the sector's GHG emissions; and
- Reducing GHG emissions by technical means: a review of trends in technological evolutions and industrial strategies implemented since 2002 aimed at improving energy efficiency and reducing GHG emissions within PH value chains. Additionally, emerging technologies aimed at providing further gains in reducing GHG emissions have been identified and discussed.

The scope of the study encompasses PH value chains throughout Europe, including the Atlantic EU western waters, North Sea, Baltic Sea and Mediterranean Sea. In addition, where relevant, PH value chains have also been provided that involve countries outside the EU, namely the United Kingdom and Norway, due to these value chains being intricately associated with the EU markets.

2 APPROACH AND METHODOLOGY

In order to address the three overarching topics, three main data gathering tools were used. First, detailed desk research was used to provide the background and understanding of both the EU-specific and global factors (where possible) affecting PH value chains. A case study (CS) approach was then utilised, where specific PH value chains within the EU (and in some cases outside but connected to the EU) were examined in detail and used to develop a clear picture of the diversity of steps (i.e. segments) comprising PH value chains, including the factors enhancing or reducing the resilience of these value chains to climate change. Lastly, supporting the CS approach, stakeholder consultations within each of the CSs were undertaken to provide a detailed understanding of the segments that comprise each PH value chain, the costs and emissions (where available) associated with each segment, as well as the structural and technological innovations being undertaken (as well as proposed in the future) to enhance the resilience of each respective PH value chain to climate impacts.

2.1 Desk Research

Desk research was utilised to acquire the following information about the EU fisheries and aquaculture PH value chains for both products sold within the EU and sold from the EU to the international market:

- Identification of important stakeholders involved in PH activities;
- Structure of PH value chains;
- Major impacts of climate change;
- Physical and financial resilience;
- Examples of management interventions that mitigate the impact on resilience;
- GHG emissions for all activities, within each segment of the value chain;

- Insight into how the current distribution systems may benefit from advances in logistics, particularly the development of decentralised systems. Comparison with alternative distribution systems in food and non-food sectors;
- Trends in technological evolutions and industrial strategies since 2002, with a focus on reduction of GHG emission; and
- Potential company strategies to reduce GHG emissions in the future.

Part of the information was collected in a literature review, using relevant keywords and a snowballing technique, where reference lists of relevant papers or the citations within the paper were used to identify additional papers for assessment. The desk research also consisted of a data mapping exercise, with data on energy and resource flows found in different sources (e.g. peer-reviewed literature, Life Cycle Assessment (LCA) databases and stakeholders' engagement) being mapped in flow diagrams. Using these maps, the range of GHG emissions was estimated in typical chains per unit product. This enabled the identification of hotspots of GHG emissions in the PH value chain.

Sources of data utilised within this work include: the European Market Observatory for Fisheries and Aquaculture products (EUMOFA), national statistics agencies, reports from the Scientific, Technical and Economic Committee for Fisheries (STECF), the Food and Agriculture Organization of the United Nations (FAO) and international organisations such as European Union Fish Processors and Traders Association (AIPCE) and the European Federation of National Organizations of Importers and Exporters of Fish (CEP) (both EU fish processing organisations). Lastly, an important source of data for evaluation of the economic performance of the EU processing industry was the biannual reports of the STECF Expert Working Group on the Economic Performance of the EU Fish Processing Industry.

A flow chain approach was used to evaluate the balance between local supply and consumption. Gains and losses associated with the connection between segments within a value chain were assessed, and the locality of production and sales volumes (consisting of an analysis of annual volumes and seasonality) was also described.

2.2 Case Studies

A CS approach was applied in this project with 23 CSs, each focusing on a specific PH value chain. Within each CS, combinations of the fishing or aquaculture sector and geographical area were selected. The total group of CSs provides a diverse range of examples of PH value chains across Europe and, as stated above, outside the EU, where relevant. Annex 1 summarises the case studies; Annex 2 describes them in detail. Seven categories of CS are covered; in brackets the number of CSs by category:

- Species marketed as fish meal and oil (2)
- Small pelagic species: herring, mackerel, horse mackerel, sardine and anchovy (3)
- Gadoids and other Roundfish (6)
- Demersal fisheries (2)
- Invertebrates: crustaceans, squid, octopus, gastropods and bivalve shellfish: (6)
- Tuna and similar species (2)
- Technology for GHG reduction (2)

2.2.1 Stakeholder engagement

Within the CS approach and to acquire the information and data needed for the three objectives, all CSs engaged with the relevant stakeholders within their respective PH value chains. To facilitate this stakeholder engagement, the Commission provided the consortium an introduction letter, which concisely explained the project. This was used by the majority of the CS leaders, and has had a positive effect on engagement. However, a number of stakeholders were happy to engage with the project, but were not willing to provide detailed commercial data on PH value chain costs. In these instances, stakeholders provided average values for or a narrative about their PH value chain.

Stakeholders were selected for their relevant PH activities within the broad categories suggested in the original project terms of reference and to cover important specific species or species groups within the EU fishing industry. For the section on technology and industrial strategies, stakeholders were selected based on the range of technologies that could be utilised in many of the selected categories and species in the CSs. In addition to the formal selection criteria set out to identify stakeholders, specific stakeholders were also selected based on long-standing relationships between the stakeholders and the consortium partners and CS leaders. As the current project is, in essence, exploratory research into an under-researched sector, the relationship between the stakeholders and consortium partners was important to ensure the necessary breadth and depth of information were available to the project.

An overview of all stakeholders interviewed within the CSs was created to enable identifying coverage of the various types of stakeholders and potential overlap between CSs. In total, 1,465 stakeholders were consulted; 141 of which were professionals (i.e. not consumers) (Table 1). All consumers interviewed came from one CS that dealt with invasive species (CS13): consumers were consulted to assess their willingness to consume these invasive species. In other CSs, the focus of interviews was only on professionals.

Table 1: Number of stakeholders interviewed by category within the Project

Group	Stakeholder Category	Number Interviewed
1. Producers	Aquaculture Producer	7
1. Producers	Fishery Producer	1
1. Producers	Fisher's co-op/Trader	6
1. Producers	Producer Organisation	18
1. Producers	Producer, processor/trader	4
1. Producers	Producer/processor	5
1. Producers	Producer/trader	1
2. Fish Auction	Fish auction	3
3. Processors	Fish food producer	1
3. Processors	Processor	9
3. Processors	Processor/trader	41
4. Trader	Seafood importer	2
4. Trader	Trader	4
5. Transport	Transport logistics	6
6. HORECA	HORECA	1
6. Retail	Retail	15
6. Wholesale	Wholesale/logistics	2
7. Auxiliary	Oil Distributor	1
7. Auxiliary	Technology producer	4
8. Government	Authority	6
9. Other	Other (journalist, NGO, seafood council)	4
10. Consumer	Consumer	1,324
	Total	**1,465**

For each topic, a list of questions based on available literature and the expertise of the consortium partners was provided and combined into a ‘Reference questionnaire for stakeholder engagement’ (**see Annex 3**). Utilising a range of questions relevant for all tasks allowed for information to be gathered across tasks in a single CS; unmarked questions are topic-specific. As the maximum level of flexibility during interviews was necessary and because each CS represented a unique case, all CS leaders selected questions that relevant to their CS for use in their interviews. Interviews were held either face-to-face or remotely. The reference questionnaire provided the interviewer with the opportunity to prepare a customised interview for each stakeholder, but also made it possible to have a semi-structured interview. However, ample flexibility for both the interviewer and interviewee was left to snowball questions on relevant topics.

3 VALUE CHAIN RESILIENCE

Based on the desk research, which was supplemented with information from stakeholder consultations when more details were needed, PH value chains for all CSs were described in detail (see Case Study reports in Annex 2). There is a substantial level of diversity, which is associated with the product, preservation and the distribution channel and location of target markets (Figure 1). Variations in the type of product (e.g. whole, gutted, fillet) and preservation (e.g. fresh, frozen, dried, salted) results in PH value chains showing a multitude of variations. This is also affected by the country of origin, the level of (re)imports, the type of distribution channel and the country/location of consumption.

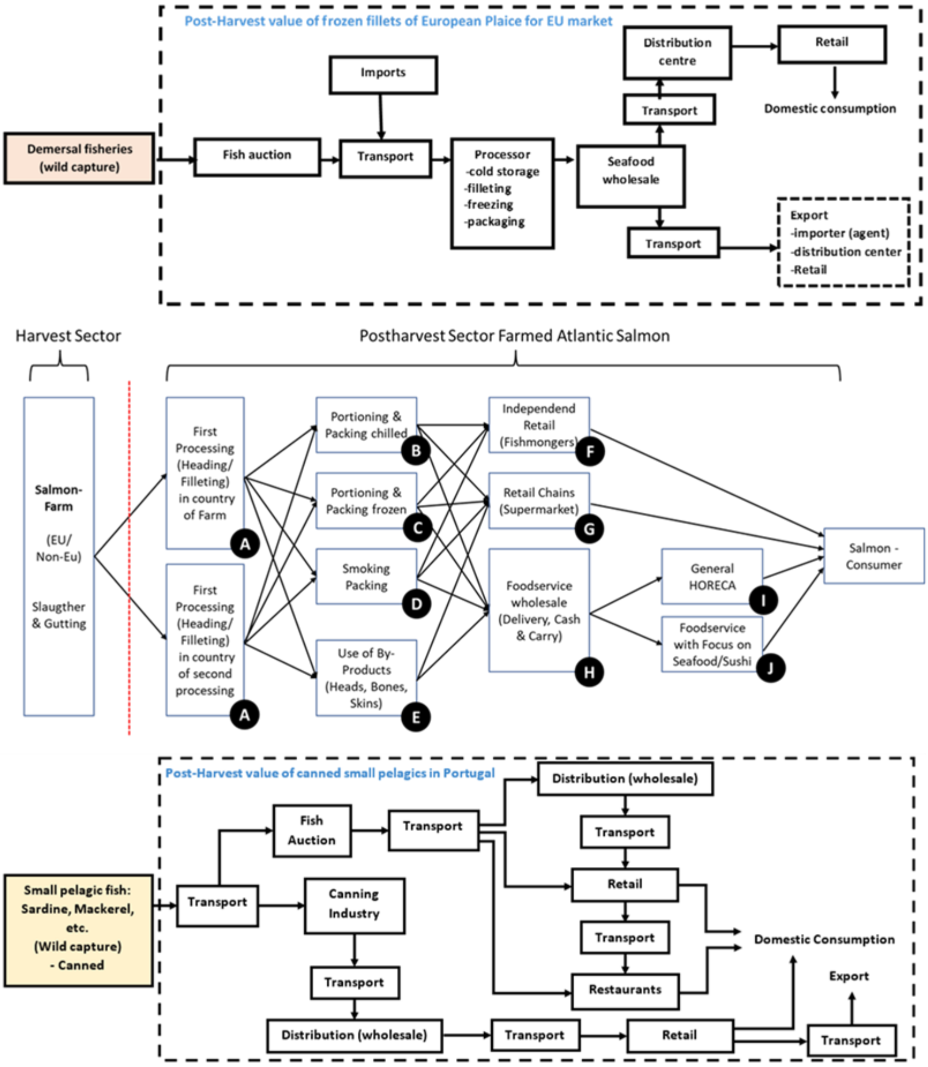

Figure 1: Three examples of PH value chains developed in the CSs illustrating the range of variations between different value chains. More details about these examples are described in Annex 2 in CS12 (plaice and sole); CS6 (salmon); and CS4 (small pelagics). The letters A–J in the second PH value chain are explained in CS6 (salmon).

3.1 Physical and financial resilience of EU PH seafood value chain

Climate change affects the PH sector in two main ways: direct change (in relation to changes in fish stocks, fish condition, extreme weather events, etc.) and indirect change, owing to policy and societal responses to climate change (urging industry towards the use of renewable energy, resulting in higher energy costs, etc). This section deals with the resilience of the PH value chain to both types of influence.

3.1.1 Major impacts of climate change on the PH sector

The major impact of climate change on PH value chains occurs primarily to stock biomass and availability (i.e. primary production), both within wild capture fisheries and aquaculture. The impacts described in the literature include rising sea water temperatures, acidification, oxygen depletion, floods, storms that cause algae blooms, higher mortality among fish species, lower feed availability for larvae and displacement of fishing stocks and habitat loss for bivalves (Pörtner and Peck, 2010; Christensen and Kjellström, 2018; Aghakouchak et al., 2020; Griffith and Gobler, 2020; Gustafsson and Gustafsson, 2020; Meier and Saraiva, 2020). Furthermore, some fisheries, e.g. small-scale fisheries in the eastern Mediterranean (CS13), are severely affected by the increased frequency and intensity of bad weather, substantially restricting days at sea and thus causing irregular supply to the PH chain.

Both demographic and population-level changes in fish stocks have been associated with climate change. For example, higher water temperatures impact seasonal fluctuation of populations, gender balance (e.g. increased ratios of males to females and therefore loss of potential reproduction) and smaller individual body size (Olafsdottir et al., 2016; Queiros et al., 2018). Importantly, the impacts of global climate change have also resulted in latitudinal (or depth) changes in commercial fish stocks, which has led to declines in wild capture (e.g. sardine, anchovy, cod, flatfish) and northern **displacement of stocks** (e.g. mackerel) (Britten et al., 2016; Sumaila et al., 2020). The emergence of invasive species is another natural occurrence in the last several decades that has been fostered by ocean warming and represents an additional biotic menace, compounding the stressful impact of abiotic factors on native species (Havel et al., 2015; Marras et al., 2015). Thermophilic invasive species have exerted additional pressure to native fish stocks through various mechanisms, such as competition, predation, essential habitat destruction, and food web shifts (Katsanevakis et al. 2014; Tsirintanis et al. 2022). In addition, the direct impact of fishing activities in conjunction with climate change may lead to structural changes in fished populations. For example, intensively fished species that are also vulnerable to the impacts of climate change can show a much more substantial **decline in mean body size** due to the impacts of both warmer waters and fishing pressure.

Accordingly, climate change exerts a threefold pressure upon the PH seafood sector: **endangering access to main raw materials**, both for human consumption but also the development of feed for aquaculture (Cottrell et al., 2019), causing **substantial disruption to coastal areas and fishing grounds**, while also **potentially increasing energy costs**, due to changes in the type and quantity of product provided for processing (Britten et al., 2016; Fleming et al., 2014; Kara et al., 2021; McKenzie et al., 2021; Sumaila et al., 2020).

These effects at sea and in aquaculture facilities often result in **cost inflation**: scarcity in landing volumes drives up first sales prices, leading to increased transport costs and increased waste of perishable fish. For aquaculture in particular, the effects can also lead to the loss of facilities through economic downturn. The performance of supply chains (i.e. efficiency and effectiveness) shows a negative trend with increasing climate change consequences (Kara et al., 2021).

At the EU level, the impact of increased water temperatures is expected to be negative for **cod recruitment** (CS10) (successful reproduction and survival) and individual body condition, both directly and indirectly, through changes in the abundance and diversity of zooplankton communities (Gogina et al., 2020; Snickars, et al., 2015). Importantly, changes in fish prey distribution may not be mirrored by the movement of cod populations (MacKenzie and Köster, 2004). For example, although sprat may expand northward as water temperatures increase (MacKenzie and Köster, 2004), cod may not show the same northward population movement, as this species lives close to the benthos, where vertical stratification leads to water temperatures not showing substantial temperature changes. Climate change may also contribute to the slower growth of individual cod (Rogers et al., 2011). Any decline in the average size of individuals will have a substantial effect on the PH industry, since small cod (termed **slim cod**: Neuenfeld et al., 2020) are harder to process into valuable fillets and therefore command a lower price than larger cod (Hammarlund, 2015).

Stakeholders interviewed for this study identified that the displacement of stocks is an important effect of climate change. One result of displacement is that fishing vessels have to relocate their fishery to waters further away from their home ports, leading to increased steaming distances and higher energy consumption to reach stocks. **PH facilities may have to adjust to these changes**. Fish auctions, transport, processing activities and storage preferably should physically be as close as possible to landing locations to optimise the quality and freshness of the seafood. For instance, flatfish are more often landed in Norway and Denmark instead of where they have historically been landed in the Netherlands, Germany and Belgium due to northern displacement of species by rising sea water temperatures.

EU PH value chains may indirectly mitigate climate effects of decreasing landing volume by utilising local fisheries and aquaculture while simultaneously importing biomass from other regions. Fisheries supporting this kind of PH value chain have also shown switches in fishing activities, **targeting 'new' species** that are increasing in abundance. For example, a range of commercial species now targeted and utilised within PH value chains thrive in warmer water temperatures, with squid, mullet (CS7) and bream (CS10) being more abundant in northern regions owing to changes in sea water temperatures (Van der Kooij et al., 2016). In a number of regions within the EU, these switches in fishery activity – and therefore the associated PH value chains – are still ongoing. For example, within the Baltic Sea (CS10, CS11), there are still substantial uncertainties and complexities associated with forecasting how fish populations, communities and industries dependent on an estuarine ecosystem might respond to future climate change. Fishing fleets that presently target marine species (e.g. cod, herring, sprat, plaice, sole) in the Baltic Sea will likely have to relocate to other marine areas or switch to different species that can tolerate decreasing salinities (Mackenzie et al., 2007). Another example of new species are the invasive rabbitfishes and the lionfish in the eastern Mediterranean. Their increased abundance, in combination with their nutritional value, has led to a redirection of fishing efforts targeting the species. Rabbitfish are now ranked first in terms of both catches and value in the Cypriot fisheries, and are highly appreciated among consumers (CS13).

PH value chains and the processing activities associated with them may have substantial environmental effects and therefore high economic costs; most important in terms of impact is the biomass of raw material used in EU PH value chains. More than 70% of the seafood on the EU market is imported from third countries outside the EU area (EUMOFA, 2022; Lofstedt et al., 2021), representing seafood from the Pacific Ocean and South Atlantic Ocean, as well as from Canada, Norway and Iceland. Such **extensive**

imports into the EU entail large transport-related costs, associated with the international movement of products and, therefore, likely high GHG emissions. However, they may also mean that EU PH value chains are more resilient to climate change than primary producers (fishers and fish farmers) because they are able to import seafood from a globalised trade market. This trend of increasing imports and exports from third countries is not unique to the EU market. A large share of locally produced fish and aquaculture products (FAPs) are often exported from around the world due to a mismatch between domestic fisheries and aquaculture supply and domestic consumer preferences.

Although, in relative terms, processing costs in EU PH value chains are not particularly high, some processing activities are particularly demanding in terms of their **use of natural resources** (including thermal energy) and environmental footprint, such as filleting, battering and canning (Almeida et al., 2014; 2015). In this respect, EU PH companies are now being asked to provide **greater transparency** about GHG emissions (CO_2), energy consumption and their use of plastic packaging by EU retailers and financial institutions (e.g. banks). In addition, enterprises with an annual turnover of over EUR 100 million are often required to report on corporate social responsibility, which increases the administrative costs of doing business as well as furthering the amount of transparency between the processing industry and the capture industry. In these reports, companies have to administer sustainability goals and monitor improvements in reducing GHG emissions – both of which enhance the cost of business.

The demand for data on the ecological footprint of all activities in EU PH value chains by retailers and financial institutions has increased. This has stimulated more monitoring of the processes within the value chains and reductions to GHG emissions. Furthermore, there is greater motivation to optimise resource use, including reductions in fresh water usage, energy consumption and plastic packaging, while also utilising 'waste' resources, such as the residual warmth from machines used for power production.

The economic success and costs of EU PH value chains are associated with a number of measures within MS for mitigation of climate change impacts. These **measures may negatively affect the resilience** of the PH sector. For example, measures that promote the replacement of fossil fuel energy with more expensive energy forms (e.g. high CO_2 taxation) may substantially impact the economic success of the industry, given the large fuel consumption of transport, in canning and other industrial processes (Kara et al., 2021). A fair, level playing field is needed to avoid the EU PH seafood value chains from outsourcing the polluting PH activities to third countries as a hidden cost, to act upon EU regulations to combat climate change. In the highly globalised seafood market, this could be undesirable short-term action taken by the EU PH chains to avoid their responsibilities combating climate change, shifting activities with high GHG emissions to developing countries where there is hardly any policy or legislation penalising polluting production.

3.1.2 Resilience of EU postharvest value chains

As the majority of fisheries products within the EU are imported, the **self-sufficiency** of the industry is calculated at 38.9% (EUMOFA, 2022). However, according to the stakeholders interviewed for this study, there is scope for developing fisheries within the EU. This is predominantly associated with increased volumes of landed fish through a more efficient use of quotas and increased production capacities within EU aquaculture facilities. This higher production of raw material within the EU would increase the self-sufficiency of the EU seafood sector. This kind of enhancement is essential to decrease the reliance on imports from third countries. In particular, with the Russian war of aggression against Ukraine war and after the COVID-19 pandemic resulting in disrupted logistics, the vulnerability of globalised supply chains has been made clearer than ever. Currently, however, more attention is being paid to ensuring the self-sufficiency of fish production and increasing local PH activities within the EU according to consulted processors.

Self-sufficiency depends on the **availability of raw material** from EU production. As many commercially fished or cultivated species – like mackerel (CS3), salmon (CS6), cod (CS10) and flatfish (CS12) – are negatively affected by rising water temperatures, other species – like carp (cyprinids) (CS10, 11), squid, mullet, gurnard (CS7) and albacore tuna (CS21) – have higher temperature optima and are predicted to have increasing abundance with climate change (Froese and Pauly, 2022; Blanchet et al., 2019). Carp is also a more robust species to farm compared to salmon, for example, with different feed requirements and a generally higher resistance to unfavourable environmental factors compared to many other species (National Research Council, 2011; Antychowicz et al., 2017). However, the potential production volumes of these **upcoming species** by fisheries or aquaculture are more of a niche production than one that will enhance the conventional production volumes of more conventional species (mackerel, salmon etc.). Therefore, any decreases associated with climate change in the production volume of the conventional species utilised within the EU will not be entirely compensated by upcoming species.

Self-sufficiency may mean an **increasing aquaculture production volume** and a higher diversity of aquaculture products through new technologies. This includes finding circular uses of the processed 'waste' within PH value chains (CS4). Valorisation and reuse of by-products (e.g. heads, bones, guts, shells and processing water or warmth from production machines) of the processing within PH value chains would result in reductions of the environmental cost per tonne of marketed seafood. It would also enable the development of alternative value chains that may protect Small to Medium Enterprises (SMEs) against disruptions in the main value chain (Lopes et al., 2015). This change in product availability may help to mitigate the effects that PH value chains have to deal with in terms of reduced landings in fisheries due to climate change (Gao and Beardall, 2022; Turolla et al., 2020).

Aquaculture potentially enables further production of seafood within EU Member States (MS) and lead to seafood being produced **geographically closer to the consumers and the markets**. For instance, Recirculating Aquaculture Systems (RAS) are receiving more attention for use in the land-based aquaculture of species like salmon (CS6), trout and tropical shrimp within the EU. RAS may reduce transport costs, lowering associated GHG emissions while also making the sector more resilient to higher fuel prices and logistic disruptions. Aquaculture production can be carried out inland and, as such, may have lower exposure to extreme conditions, such as storms, tidal surges and strong winds.

One way to deal with potential effects of climate change on shrimp production in Southeast Asia and Latin America (heavy stormy weathers, rising water levels, shifting seasons and warmer water temperatures) is to have **large enough stocks** of frozen shrimp in the EU. This helps secure the ability of EU retailers to supply customers.

The development and utilisation of **plant-based feeds in aquaculture** and the expansion of Integrated Multi-Tropic Aquaculture (IMTA) systems within the EU may reduce the environmental costs of using fish meal and transporting feeds over large distances while also reducing the need for effluent treatment. Moreover, carbon fixation by algae and other cultivated aquatic organisms can reduce the carbon footprint of production (Gao and Beardall, 2022). However, aquaculture is not a panacea for seafood availability in the EU, as environmental impact is not always reduced by switching from wild-capture to aquaculture, for a range of reasons, such as some farming practices being more energy demanding than certain fisheries (Cottrell et al., 2019; Gephart et al., 2021).

Technological innovations or product **innovations** were mentioned during interviews with stakeholders as a way to increase resilience. For example, a feed producer for aquaculture chains mentioned that innovative alternatives for packaging and feed (novel ingredients, insect-based and algal-based meal) were already presently available. However, markets are not always ready or do not show demand for these alternatives. Similarly, seafood producers in shrimp supply chains reported an alternative processing method, which made use of shrimp peeling processing equipment in local facilities, instead of requiring hand peeling 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 in the consumer market.

There are a range of **legislative changes** that may enhance the resilience of the PH industry within the EU. During interviews, PH companies expressed the need for clear legislation and financial instruments (such as enhanced subsidies) to support actions to decrease the industry’s dependence on fossil fuels and, therefore, GHG emissions. However, stakeholders also stated the need for the CFP to motivate and enhance innovation in order to ensure PH value chains are resilient to climate change, rather than increase administrative burdens or restrictions to further produce fish and aquaculture products within EU PH value chains.

3.2 Major financial constraints and reliability

Stakeholders were interviewed about their understanding of the impact of climate change on GHG emissions in the value chain. Their insights have been summarised and categorised below into strengths and weaknesses (both internal to the respective EU PH value chain) and opportunities and threats (both external to the respective EU PH value chain) (Table 2). The majority of EU PH value chain stakeholders stated that climate change was not their immediate focus: it was often perceived as indefinable and something to deal with in the future. In comparison, direct changes in resources associated with local, regional or international developments are much more likely to affect PH value chain stakeholders. For example, the Russian war of aggression against Ukraine has been a catalyst for increasing the urgency of facilitating the energy transition and reducing interdependencies between globalised supply chains and the current reliance on fossil fuels. The Russian war of aggression against Ukraine has resulted in higher fuel prices, which could not be fully compensated for by higher consumer prices, which has impacted the financial margins of PH stakeholders. The recent conflict has also resulted in a scarcity of resources for processing activities, such as flour and sunflower oil.

Table 2: Strengths, Weaknesses, Opportunities and Threats identified in EU PH value chains.

	Strengths	***Weaknesses***
Internal origin (attributes of the organisations)	• Energy self-sufficiency (to a certain extent) by using solar panels • Reduced packaging materials (less plastics, more recycling) • Recycling residual warmth from production machines. • Added value products by own processing in EU compared to outsourced processing to third countries of fish products. • Ecolabels and sustainable certifications acquired by PH enterprises to enable supplying EU retailers. • EU processors could import fish from third countries as climate change results in lower landing volumes locally or harvested volumes by aquaculture. • Vertical integration between fisheries and processing ensures sufficient flow of raw materials. • Frozen fish products transported via sea freight and therefore less GHG emissions compared to air freight.	• Investment in renewable energy (e.g. solar panels) not always possible due to overloaded capacity of the energy infrastructure or high investment costs to implement the modern infrastructure. • Difficult to renovate existing buildings as newly built buildings are more efficient for renewable facilities, such as heat pumps. • Certain processing activities require high energy consumption (electricity and gas), such as battering, freezing and smoking. • Self-sufficiency of EU seafood market is only 38.9% of the total production volume. Too reliant on imports (61.1%), which means many food miles and a lot of international transporting movement that could indicate large GHG emissions, in particular when FAPs are transported by aeroplane.
	Opportunities	***Threats***
External origin (attributes of the environment)	• Current high energy prices stimulate PH enterprises to invest in renewable energy or reduce gas and oil consumption • Diversification to other species within the PH value chain, including salmon (aquaculture) and cod (wild capture), sourced and imported from outside EU. • 'New' species (e.g. squid, red mullet, gurnard) that have higher abundance in northern EU waters caused by climate change (rising sea water temperatures) introduced to market to mitigate decreasing catchability of other traditional targeted species that are displacing to non-EU waters (e.g. flatfish, cod). • Thermophilic alien species will further increase in abundance in the eastern Mediterranean and can (partially) cover the decline of native species in the PH chain. • Further opportunity to process within EU that provides greater reliability and fewer food miles (and therefore GHG emissions from transport) than outsourcing processing of fish to China due to challenges with transport and customs associated with Chinese zero-tolerance COVID-19 policy. • Sustainability is a unique selling point: if you can tell a positive story to the consumer about how sustainable the product is, this makes the product more attractive as sustainability receives more attention and value, especially in the northern European market. This awareness is growing among customers and is due to increasing attention being paid to climate change.	• Scarcity of raw materials (unprocessed fish) within EU, resources (e.g. flour, sunflower oil, fossil fuels, energy, fresh water). • Displacement of fishing stocks to northern waters, needing high effort and costs to relocate PH activities. • Climate change reduces the predictability of production of shrimp in ponds in Asia and Latin America, and growth and mortality of cultivated salmon (e.g. owing to sea lice, algae blooms). Therefore, production cost increases passed on in the EU PH value chains. • Spatial displacement by climate change effects (e.g. rising sea water temperatures) could result into shifting commercial fishing stocks to non-EU waters (e.g. northern, third countries such as Norway, United Kingdom). PH value chains could suffer as Total Allowable Catch (TAC) and quota does encounter these shifting fish to caught by EU fishers. • Increasing energy costs. • Retail supply contracts often have fixed prices for one year. Difficult to increase contract prices in case of cost inflation during the contract period. • Buyers of seafood in southern Europe are less willing to pay more for sustainability than buyers in northern Europe. So, if prices increase because the GHG emissions of the production process have to be reduced, prices may become too high for the market in southern Europe. • Increased impacts of invasive species (e.g. invasive jellyfish) are expected to further disrupt fishing activities and the provision of raw materials to the PH chain.

3.2.1 Strengths

There are clear gains to be made within the PH industry for vertically integrated companies. These are more likely to be resilient to overcome external challenges in the supply of raw materials. Importantly, these companies are also able to source their raw materials from around the globe thanks to partnerships that consist of multiple subsidiaries and divisions. Moreover, the resilience of these companies is high due to their overall higher purchasing power, due in part to their size.

Another strength of the EU PH value chains is the ability to import raw materials (to be processed) to potentially mitigate local changes in resources. The EU is the largest import market for fish products. By importing, the negative effects of climate change on the EU's own fisheries or aquaculture production can be mitigated.

3.2.2 Weaknesses

The EU PH value chain (importers and traders) increased their resilience to climate change effects in the countries their products originated from by maintaining stocks of frozen tropical shrimp stocks (CS18) in the EU. This way, they value chains secure the ability to supply important customers at all times. However, from a financial perspective, it has the downside that increased storage volumes lead to more products being in the product chain, more transport and longer storage periods of the product in the chain, and more tied up capital that has to be pre-financed.

3.2.3 Opportunities

Early phase investing into renewable energy and reducing GHG emissions could support PH companies by aligning their business practices more readily with changing environmental legislation. For example, consulted herring processors explained they are already exploring new ways to implement electrical trucks instead of current petrol trucks as they foresee that transport will be restricted in city centres in the near future.

Another example is further investment in technical innovations to ensure locally caught products are processed by local machines. This could improve productivity and reduce transport costs and emissions (food miles), while shorter and closer supply chain loops reduce risks of disrupted logistic global supply chains (i.e. perceived during COVID-19 pandemic).

3.2.4 Threats

Multiple PH value chain stakeholders stated their willingness to further invest in the size of their logistic facilities, including enhanced use of renewable energy use, but were hampered by lack of insurance cover. For example, several stakeholders stated their willingness to install solar panels on the roofs of production buildings. However, insurance companies are often unwilling to cover the risk of fire associated with solar panels. In this respect, insurance companies are also unwilling to cover damage associated with extreme weather events to large parts or entire factories, including the storage of fish products.

Another issue hampering the development of the PH industry is the mismatch between the wish to generate renewable energy and the capacity of the energy infrastructure. For example, a Dutch and German company interviewed for the project stated their interest in investing in solar panels on the roofs of their buildings. However, if these solar panels generate optimal renewable energy, the capacity of the energy infrastructure would be overloaded. In the worst-case scenario, an overload of energy could cause a power cut to an entire industrial area in a city. For perishable chilled or cooled stored fish products, this would be disastrous. This shows that there is a distinct need for further investment into the net infrastructure to enable larger processing capacity. This lacking energy infrastructure issue should technologically be solvable. In the Baltic countries for the fishmeal and fish-oil PH value chains (CS1), there is a similar challenge in the transition from non-renewable energy sources (e.g. gas, oil and coal) to renewable energy sources (e.g. wind, solar and hydro). However, in this case, it was a matter of high investments costs (e.g. required cables to transmit the energy source) that would increase the burdens for PH companies to adapt these reducing GHG emission techniques.

There are a range of economic factors that may hamper the development and sustainability of EU PH value chains. First is the range of imported goods, which can undercut the costs of wild captured and landed fish in the EU, resulting in such locally/regionally landed species becoming too expensive for the market (e.g. Nephrops can be substituted with imported Argentinian red shrimps). In addition, where changes in the costs of processing occur, price increases are not usually able to be adjusted for the consumer (i.e. inflation costs are passed on), although this will be dependent on the type of contract processors have with EU retailers. For instance, sea freight container prices increased by five or six times between 2019 and 2022. This often results in decreased financial margins for PH value chains. Lastly, freezing products that have been processed is known to increase the product shelf-life compared to fresh fish. However, the utilisation of freezing results in increased energy consumption, greater GHG emissions and incurs costs associated with processing. These costs are not able to be passed onto the consumer as fresh products (more so than frozen products) are more likely to be sold at a premium.

An indirect effect of climate change on the PH value chain of cultivated Atlantic salmon (CS6) is the assumed correlation between growing numbers of sea lice and increased water temperatures. Higher life stock mortality is assumed to be the result of infestations with sea lice, with emerging costs to fight the infestations. Another climate change effect for salmon aquaculture in northern countries is that, in some areas, colder water temperatures are occurring because of broken-off, melting icebergs floating southwards. Cooler water may result in slower-growing salmon that consume less feed. This will indirectly negatively influence the productivity of salmon aquaculture chains as the required time for ready to market will be longer, therefore raising the costs of feed, labour, owing to delayed processing and storage costs are likely to rise as well, since traders are not utilising the full potential of their cold stores and cooling capacity before delivering batches to distributing channels, including wholesalers, retail and HORECA.

Although climate change is not a priority for many EU PH value chain stakeholders, it is affecting their businesses. For example, there are a range of species that are now more likely to be present in higher quantities in EU waters, including squid, tuna, red mullet and gurnard. This new array of species is perceived as an opportunity to the PH value chains of northern EU countries and has resulted in a change in the composition of species sold in markets. For example, at a Dutch fish auction in 2000, 92% of total annual sales volumes consisted of the two flatfish species plaice and sole, decreasing to the current value of 54%.

Following political changes, such as Brexit for the United Kingdom, the EU has to agree with multiple third countries (Norway, Iceland, UK, Faroe Islands) to determine the TAC of each commercial species for fisheries in coastal states' waters. Theoretically, quota management by TACs can still be determined and agreed and even managed through the year, including by swapping. However, this has a price. If EU has more need for swapping certain commercially, high priced, but scarcer TACs of fishing species, this could result into a worse bargaining position with third countries. Therefore, the costs of sustainably utilising EU TACs and quotas for fishers could suffer owing to climate change. As sea water temperatures rise, commercial fishing stocks could shift into non-EU waters. As landing volumes are likely to decrease owing to this phenomenon, the self-sufficiency rates of EU PH seafood chains will decrease further. Similarly, longer hauls and steaming times by the EU fleet could result in higher costs that may be passed on to the PH value chain.

The increasing occurrence of extreme weather conditions was also mentioned by stakeholders. When these conditions occur, there are smaller landing volumes because fishing vessels cannot go out to sea for as long. For example, stakeholders mentioned that, for the North Sea, there were five storms in the first two months of 2022. In addition, transport trucks cannot drive during strong winds, and there is also a higher risk of flooding of fish auctions and processors located close to sea. In the summer season, more extreme weather results in heat waves. Although several PH companies are now better equipped to maintain cold storage capacity to overcome the risk of heat waves, this depends on the age of the cold storage facilities. The consulted companies do not have buildings more than 15 years old. If buildings are older, heat waves may cause more problems.

Some species (e.g. *Penaeus* shrimp, CS18 and CS19) that are imported from Southeast Asia and Latin America by EU PH value chains are perceived to be vulnerable to climate change. The direct effects in their country of origin, like changing water temperatures in the shrimp ponds, extreme weather events and shifting seasons indirectly affect the EU PH value chains. There are also problems due to the slowly rising sea levels, which are forcing some farms to relocate every few years as they are located in the immediate vicinity of the sea for water supply and exchange. These changes are leading to measures in the countries 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 and the end consumer. The farming conditions have become far less predictable over the last 20 years, and almost all consulted stakeholders related this to climate change.

Consulted industry stakeholders recommended further research be undertaken into the ecological effects of upscaling offshore windfarms at sea. Windfarms are implemented in order to reduce the dependence on fossils fuels by EU MS and to accomplish the Sustainable Developments Goals (SDG) set out in the Paris Climate Agreement. Multiple industry stakeholders observed changing winds and water flows around offshore windfarms, while others were concerned with changes in the spawning season of a range of commercially important species for fisheries close to or within offshore windfarm sites.

3.3 Role of management in implementing introductions of new species to the market.

There is now a range of warm water species, including squid (*Loligo vulgaris*), mullet, and gurnard (CS7), that is moving into northern EU waters that may serve as important commercial species. For example, squid have historically been fished from the Gulf of Biscay and Mediterranean seas. Although a non-quota species, with an appropriate fishing right based management system (e.g. quota, licenses, restricted fishing efforts and restrictions on ownership), these species could sustainably be caught within northern EU waters. These fishing activities then extend the fishing activities for squid past its historical end (February) until mid-April. This kind of extended period helps to enhance the production capacity for the PH value chains associated within this species, which have historically been based around a short and intense production of fishing.

Two alien rabbitfishes dominate fish communities in the coastal reefs of the eastern Mediterranean, and the lionfish is a successful Lessepsian invader, rapidly spreading in the eastern and central Mediterranean (CS13). Promoting the marketing of these new thermophilic species has been successful in Cyprus, indicating important prospects also for the Greek market. Rabbitfishes are now the most important target species in Cyprus in terms of both catches and value (Michailidis et al. 2021). Lionfish used to be discarded in 2016-2017 by Cypriot fishers but since 2021 a new market has emerged and lionfish dishes in restaurants obtained high prices. Targeting these new species contributes to securing the small-scale fisheries supply chain, which has been plagued by the decline of native stocks and the increased frequency of storms and extreme weather events.

Another example is Cyprinids, such as bream (CS10), which can be used as an alternative to cod because they are expected to benefit from a warmer climate. However, markets and management are not yet well developed, and the future landing volumes by MS around the Baltic Sea are likely to be lower than traditional cod landings.

In the case of albacore tuna in Irish waters, there is currently no significant local PH value chain (CS21). The fished tuna is directed to the PH value chains in France and Spain. Some of this tuna is imported to Ireland after processing, where it is sold on the high street and in selected gourmet food stores. Hence, there is an opportunity for the PH sector in Ireland that would also reduce GHG emissions simply by removing transport of raw tuna to France and Spain and importing processed tuna products to Ireland. Processors that are impacted by climate change driven events that cause decreasing landings or harvested volumes in local fisheries or aquaculture (e.g. through the displacement of targeted species, algae blooms and invasive species) could start introducing these new species to their existing foodservice customers as samples, so they can taste and try them. If these customers are convinced by the quality and freshness, PH companies could supply increasing volumes to their customers, hopefully leading to more demand within the market. For example, in Cyprus, increased consumer demand for lionfish fillets has been motivated by advertising and samples of fillets being provided to local restaurants (CS13).

As often occurs in the food sector, subsequent to the use of new resources within HORECA, retail follows demand for these new species. With this strategy, the effects of one increasingly abundant species in local fishing areas could be mitigated due to climate.

The utilisation of new species within the EU PH market would enhance the likelihood of joint ventures with local producers in foreign countries. In this respect, partners can be supported (economically and technologically) to immediately freeze landed catch at the place of origin. This may enhance the ability to bring new species to the market, as costs for transport are reduced (as specialised transport is not needed), and EU processing facilities are supported.

Joint ventures may also strengthen the physical resilience (specialisation, outsourcing activity close to place of landing, processing and distribution) and financial resilience (buying power for materials, predictability of supply flows etc.), enhancing the overall resilience of the PH company. Related to the management intervention strategy of joint ventures, another approach to reduce vulnerability to climate change is geographical diversification. This means by having production locations in different locations worldwide, the PH value chain will not be completely disrupted if one location is hit by a storm, algae bloom or a drought, for instance. In particular for aquaculture, which is often more controllable and less reliant on a natural local biomass (fishing stocks) than fisheries, the strategy of geographic diversification is recommended.

Another strategy to strengthen the resilience that appears to be successful (e.g. in small-pelagic, salmon and shellfish PH) is vertical integration. This integration – whether downstream or upstream – provides PH companies with scale advantages, resulting in higher efficiency of primary production, processing, transport and distribution as well as larger buying power and longtail advantages, such as being able to offer a broader range of products and more market penetration via multiple distribution channels.

To fight sea lice in the cultivated Atlantic salmon PH value chain, net cages are often moved to areas with colder water or seawaters with a lower salinity. Land-based aquaculture could be a way to mitigate the issue of sea lice and other challenges like algae blooms or dioxides in the sea water. Atlantic salmon farmed in RAS are located near areas where value adding or consumption takes place, requiring far less transport compared to conventional production in coastal waters or open sea. Most of the consulted stakeholders believe that this will be important in the future; they cannot foresee when it will happen, but not in the next years. Similarly, the ‘climate balance’ of indoor 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? Further research is needed.

In enhancing the resilience of EU PH value chains, stakeholders stated that further organisation of waste streams could help to stimulate recycling and the reuse of products that would otherwise have been discarded from the value chain. This furthering of the circular design of PH value chains would likely reduce consumption and reliance on fossil fuels. For instance, residual warmth generated by production machines could be reused to warm households, reducing the gas or electricity used by that household. Another example is recycling processing water and the circular use of residual streams (e.g. bones, guts, heads, shells) as by-products for pharmaceuticals, pet food or human consumption markets. These activities are becoming increasingly important due to increases in the price of fossil fuels and the likelihood of the implementation of EU policy banning or taxing the use of certain fossil fuels in coming years.

4 REDUCING GHG EMISSIONS WITH STRUCTURAL IMPROVEMENTS

This chapter is aimed at understanding the climate impacts of PH value chains and identifying the potential impact of reductions in GHG emissions through non-technological means.

The first section highlights how the organisation of the EU PH value chains may impact GHG emissions levels. The second section explores the potential for alternative supply chain organisations. The third section summarises the current limitations for structural improvements in GHG emissions and highlights the imbalance between production and consumption at the EU level.

4.1 Structure of EU postharvest value chains and GHG emissions

This study analyses the impact of climate change on PH value chains for seafood products. This means all operations from the point of landing the product to consumer-outlets (point of sale) are included in the scope. Information about EU PH value chain structures and how these structures impact GHG emissions was obtained through the CS.

If available, GHGs from production (aquaculture or fisheries) are presented to show the PH value chain contribution in relation to total GHG emissions.

Significant factors that are taken into consideration are energy use (mainly electricity), emissions related to transport (fuel use), packaging material and other material use. Where emission factors for these inputs were not available from the CS, they have been adopted from secondary sources (LCA datasets and scientific literature); these include emissions related to the generation of the inputs. The emissions are estimated per unit (kg) seafood product sold to the consumer.

4.1.1 Secondary sources: Life Cycle Assessment (LCA) and literature

Life Cycle Assessment is a broadly accepted approach for assessing the burden of production. With regard to sustainability challenges, the interest in seafood LCAs has grown rapidly over the last decades (Ziegler et al., 2022). LCA studies commonly address a broad range of environmental impacts as well as economic and social sustainability aspects. LCA methods are used for accounting for the impacts of companies, countries, cities, services, product categories and products, amongst other things[2]. LCA is codified by the ISO standard 14040:2006[3]. LCAs are, however, challenging to interpret and compare, as several core elements of the method differ between studies, such as the boundaries of the system (e.g. cradle to grave, cradle to gate), the allocation rules for environmental burdens (e.g. by weight or by the value of the main product relative to co-products), specific data and background data base used or the impact assessment method. In this study, a product approach is used. Analysis of prior LCAs and reporting here includes specifications of products and results, plus information about the scope, included processes, data sources and methodological choices, however, it does not include the harmonisation of values between CSs.

LCAs are used for comparing product categories, processing and supply chain options, among other applications. In these comparisons, trade-offs between processing intensity and shelf life are sometimes not considered, resulting in spurious comparisons of GHG emissions between fresh whitefish fillet and canned tuna despite the shelf life of these

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[2] see e.g. https://ghgprotocol.org/standards

[3] ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework.

products being very different (a few days for the fresh option compared to several years for the canned fish). Since food losses along the PH value chain induce extra demand for fish from fisheries to obtain a certain amount of product for the consumer, emissions from these 'extra fisheries' have been added to the PH emissions when information on losses is available.

A broad literature study on seafood LCAs shows that the majority of climate impact studies focus on the role of fisheries and aquaculture activities in producing GHG emissions. There is a paucity of work examining the impact of PH value chains, and the production of GHG emissions associated with these, on climate change. Despite this, there is an increasing number of relatively recent papers that have focused on the development of GHG emissions within PH value chains. For example, Denham et al. (2016) examined GHG emissions from an Australian value chain, Thrane (2006) presents a case study on Danish PH value chains, while Winther et al. (2009) and Winther et al. (2020) evaluate different value chains in the Norwegian seafood industry.

Within our reviewed literature, there are relevant studies that have detailed inventories of inputs and outputs (for instance, the use of hand soap and pallet wraps), while recent literature provides essential parameters for the climate impact calculations in this study. For example, Williams (2011) presents the climate impact of packaging materials, and Terehovics et al. (2019) provide insight into energy use in freezing. One of the most thorough analyses has been performed by the Norwegian team of Sintef, which details several seafood supply chains in Norway, differentiating between production and PH activities (Winther et al., 2009, Winther et al., 2020). All These studies converge in showing that energy use is the most significant contributor to GHG emissions in value chains for marine products.

The analysis of PH value chains, when examining the range of literature available, has received more attention in low and middle-income countries than in high-income countries. This is due to low and middle-income countries having less developed and formalized value chains, consequently higher losses and more perceived need to assess the fine details of value chains. In comparison, within high-income countries PH chains for perishable food products are highly interconnected, with less perceived loss, with the literature more broadly oriented, away from specific value chains.

4.1.2 Mapping logistic pathways in value chains

The aim was to map typical PH value chains based on the CSs. Factors that induce GHG emissions (e.g. fuel and energy use, packaging material use, indirect effects of losses) were derived from interviews or derived from secondary sources, including scientific literature and values for other food categories.

Value chain schemes and descriptions of the specific parameters structuring the value chain were created based on information from stakeholders and literature. From these, maps of value chains were developed, explicitly focusing on describing the logistic pathways. For example, the different steps from first sale (in an auction) to a supermarket for a fish that is primarily filleted (processor I) before being included in a preparation (processor II), with all intermediary steps (transport, cold storage) identified are described in Figure 2 (left).

This map focuses on the different contributions to GHGs occurring in the value chain: energy consumption, water use, refrigerant losses, the inclusion of ingredients and the use of packages. Each stage of this map is represented using the same dimensions (Figure 2 –

right). Raw material and final product are the weight of the product entering and exiting the stage, the waste and co-product. The distinction between waste and co-product is important as it modifies GHG allocation rules in the value chain, usually based on mass balance. For example, for fish filleting, 1 kg of whole fish may produce 333 grams of fillets, depending on species, season and freshness (higher freshness can ensure higher filleting yields). If trimmings are disposed of as waste, all GHG emissions associated with fillet production are summed (i.e. production, transport, storage and processing). In comparison, if trimmings are considered as co-products, only a fraction of the GHG emissions associated with the production of the fillets are accounted for.

Several CSs used this framework to assess typical GHG emissions associated with their respective supply chains (CS1, CS3, CS7, CS8, CS9, CS11, CS12, CS14, CS15, CS16, CS18 and CS20). However, the calculations presented in the CSs are only indicative of the emissions associated with the stakeholders contacted and may not be generalised at sectoral level.

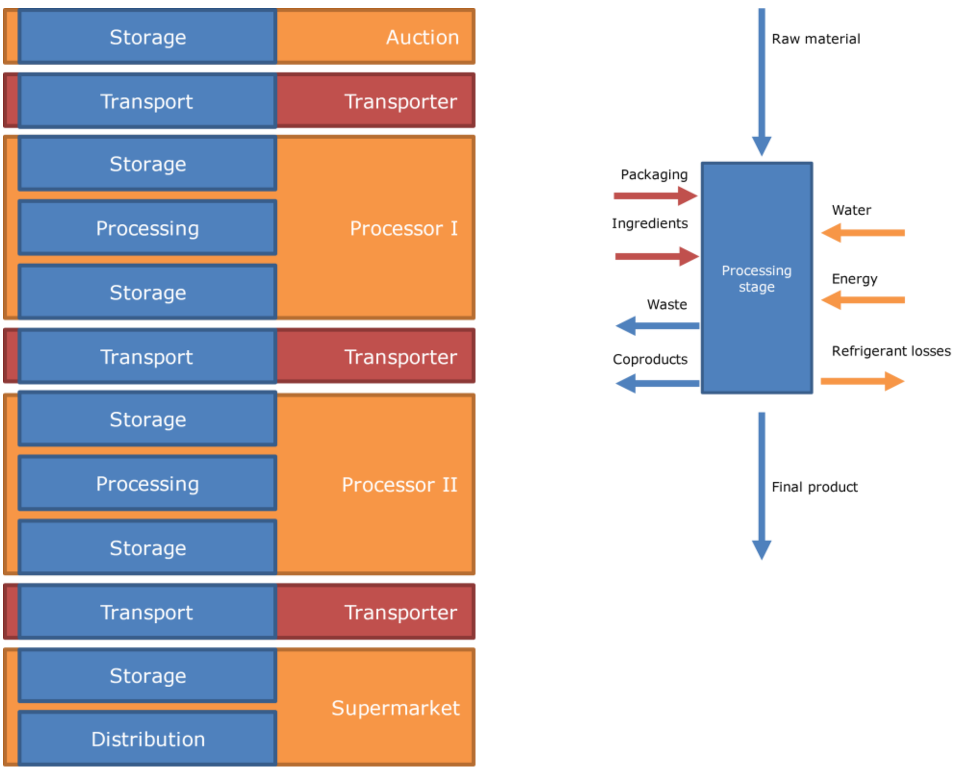

Figure 2: Example of a value chain map describing the logistic pathways and all unit steps for a product with two processing stages (left) and detail of the information gathered for each step of the value chain map (right)

4.1.3 Gaps in the understanding of GHG emissions in PH value chains

The common theme amongst CSs is the absence of specific data provided by stakeholders, at every level. This is partly due to stakeholders not wanting to provide detailed data on specific parameters within their value chain since this data is commercially sensitive. However, the lack of specific parameters is predominantly associated with an absolute lack of available data:

- Very few processors have a precise grasp of their detailed energy consumptions for each activity (i.e. freezing, cold storage, cooking and processing), which hinders

the possibility of fully understanding where the hotspots are at the processing plant level and assessing these hotspots at sectoral level.
- Conversion ratios (i.e. the ratio $(\boldsymbol{fish\ out})/(\boldsymbol{fish\ in})$) are mostly verified at the macro level and not for every lot transiting through processing plants, limiting the ability to understand potential seasonal variations.
- Stakeholders' understanding of the emissions from previous actors in the chain is mostly minimal. For example, where energy use is related to the processing of one species in a plant that handles multiple species or imports products from different sources, any assessment of GHG emissions will be based on averages for various product categories, with little ability to characterise energy use for a specific species.
- Stakeholders' understanding of the impact of the logistic options is also limited by the fact that logistic companies develop offers for multiple sectors (e.g. seafood, meat, vegetables, flowers), and this may not be fully understood by seafood stakeholders. In terms of data collection, this means that very few stakeholders are actually able to describe the precise route taken either by their supplies or their products. Technically, there are no records of the distance each fish lot has travelled, hindering the ability to evaluate the GHG emissions associated with any final product sold in the EU.

There is a consensus among interviewees that after several years of financial hardship (financial crisis in 2007–2008, Spanish crisis from 2010–2014), the effects of Brexit, the COVID-19 pandemic and the consequences of the Russian war of aggression against Ukraine, climate change and GHG emissions are at the bottom of the priority list for most executives of the PH sector in Europe. Several of the crises can, however, be seen as being related to climate change, such as the increasing costs of energy and fossil fuels.

To solve the issue of missing data and information on GHG emissions from different value chains examined within this study, a generic framework for assessing the climate impact of seafood value chains was formulated, covering the most common operations in the value chains. This framework was derived from the Agro-Chain GHG emissions calculator[4], adapted for the specificities of seafood value chains within this project. This generic framework partitions value chains into six separate steps to develop a broad understanding of the GHG emissions inherent within the value chain. These six steps are:

1. Supply of landed or farmed seafood (climate impact per kg fish from other studies);
2. Primary processing step (e.g. filleting): processing yield, energy use in refrigerated storage, packaging material used, valorisation of side streams, use flakes usage;
3. Transportation (various modalities);
4. Secondary processing step (e.g. industrial production of consumer products), with the same emission impact factors as the primary processing step;
5. Energy use related to storage at processing factories, wholesale and distribution centres; and
6. Refrigeration, on ice or frozen storage in retail.

The first of these steps is ignored in this study, as the focus of this study is on PH value chains. The other steps have been regrouped and are described in Section 4.1.4:
- <u>Processing</u> (Section 4.1.4.1): consisting of cutting the fish (filleting, deboning), cooking (various modalities), or breading (steps 2 and 4);

[4] https://ccafs.cgiar.org/agro-chain-greenhouse-gas-emissions-acge-calculator

- Conserving (Section 4.1.4.2): in cold stores under positive (0 to +4 Celsius) or negative (-25 to -18 Celsius) temperatures at various points of the supply chains, packaging (steps 5 and 6);
- Transporting (Section 4.1.4.3): using trucks, planes, or ship (step 3).

4.1.4 Principal factors for GHG emissions in seafood postharvest chains

Emissions are specified per typical activity along the PH value chain[5].

4.1.4.1 Processing fish

Most processing operations are mechanical. In general, energy use is relatively limited.

Filleting yield is a relevant factor for GHG emissions associated with the final product. Only a fraction of the caught fish ends up in the edible product. Residue streams (head, trimmings, skin) may be valorised for other applications (including fish meal and oil). The services required to collect these residues may, however, not be available for all processing locations, resulting in these residues ending up as waste.

Efficiency in processing may, therefore, have an impact on the total GHG emissions associated with the final product, as the GHG emissions upstream along the supply chain (mostly: catching + transport) are multiplied by the fraction $\frac{1}{filleting\ yield}$ from the value for whole fish if the residue stream is destined for another economic application.

Filleting/peeling yields vary from 25 to 70%. When asked specifically about processing yield, primary processors indicated that conversion factors recorded by EUMOFA[6] were mostly accurate and that these yields were not recorded for every lot processed, but only analysed at a macro level to monitor operational efficiencies.

Small differences in processing yield may have substantial impacts. Harman et al. (2008) compared two supply chains for cod fillets: (i) cod landed, filleted and frozen in the United Kingdom and (ii) cod landed and frozen whole in the United Kingdom, exported to China for filleting, frozen and transported back to the United Kingdom. Their calculations showed that differences in filleting performance (55% processing yield in the United Kingdom compared to 60% processing yield in China) may offset the additional GHG cost of transport and an additional step of freezing for cod sent to China. In their calculation, the GHG balance is in favour of the Chinese supply chain (Harman et al., 2008), highlighting the need to understand the full value chain.

Indirect effects due to losses/waste along the chain[7]

From interviews with retail representatives, a typical loss percentage of 7.5% was derived. All GHG emissions upstream along the supply associated with the lost products are considered GHG emissions due to the PH value chain.

Note: removing inedible or unwanted fractions from the product in processing does not contribute to total GHG emissions if the residues are collected at no cost (or for a very low

[5] Emissions of activities that add little emissions, like auctions, are included in 'storage'. All values mentioned are typical values; the actual values depend on situational conditions, like transportation distance in a PH chain, packaging size and fraction of packaging capacity utilizedutilised.
[6] EUMOFA. Metadata 2 – Data management. ANNEX 7. Conversion factors by CN-8 code, from 2001 to 2021. https://www.eumofa.eu/documents/20178/24415/Metadata+2+-+DM+-+Annex+7+CF+per+CN8_%252707-%252714.pdf/7e98ac0c-a8cc-4223-9114-af64ab670532?t=1581951857053
[7] Emissions related to wastewater treatment are often considered beyond the scope of the analyses.

price; mostly for fish feed and fish oil industry), all the emissions upward along the chain are allocated to the fraction traded as a food product.

Packaging and ingredients may be important for GHG contributions and additional weight. Each stage may need water (other than as an ingredient), and energy and can generate refrigerant losses.

Breading fish

Another form of processing is breading fish. Breaded fish products are produced from fillets. These products are covered with a layer consisting of ingredients including starch and bread crumbs and are pre-fried before packaging. The products are distributed in either refrigerated or frozen supply chains.

For breaded products, emissions related to the bread/batter, oil and processing typically add 1 CO_2-eq per kg fish ingredient.

4.1.4.2 Conserving fish

In processing operations, energy use is relatively limited, however, a more significant amount of energy is used for refrigeration, freezing (including frozen storage for up to a year) and ice flake production. Typical total GHG emissions related to energy use in processing and storage vary from less than 0.01 to 0.09 kg CO_2-eq per kg product. Some stakeholders mentioned that high variability could be observed in supply chains due to the heterogeneity of installations and refrigerants used in processing plants and cold storage.

Refrigerant losses are also notable sources of GHG emissions because the emission power of some refrigerants is far higher than CO_2. There is, however, no systematic record of refrigerant losses in the supply chain, which would help quantify the effect of these losses.

Freezing on land: Many species are frozen on land, which induces typically 0.05 kg CO_2-eq GHG per kg fish.

Packaging

The volumes of material for bulk packaging (e.g. from processor to distribution centre) are limited; consequently, this material's climate impact is not significant at the chain level. It is, however, a challenge for several actors in the supply chains because polystyrene boxes are widely used, but are not currently properly disposed of, as very few recycling options exist. Several supermarkets are implementing the use of reusable washable boxes, similar to the fruit and vegetable supply chains.

Consumer packaging, however, involves more packaging material per unit product:

- For canned products (in glass or metal packaging), the impact of the package production and packaging process is relatively high (typically 0.6 kg CO_2-eq per kg product for pickled herring fillet in glass jars and around 1 kg CO_2-eq per kg product for canned tuna in aluminium cans).
- Polystyrene boxes and cartons are often used in deliveries to restaurants and supermarkets. This typically adds 0.1 kg CO_2-eq per kg product.
- For the consumer plastic packaging type common for chilled fresh seafood products (varying from typically 50 to 80 grams of plastic per kg seafood), the contribution of the packaging is estimated at 0.15 to 0.24 kg CO_2-eq per kg packaged seafood.

4.1.4.3 Transporting fish

Three transport means are:

- road transport, on trucks and vans,
- air freight, and
- sea transportation.

Road transport: The impact of international transport is quite significant, typically 0.2 kg CO_2-eq per kg product for 1,000 km in a large truck. Local/regional transport is often done with lower capacity vehicles with higher GHG emission intensity per tonne produced, sometimes with multiple stops. With medium size trucks, GHG emissions related to local/regional transport below 100 km are significantly below 0.1 kg CO_2-eq per kg product. With small lorries, the emission during local/regional transport may be as high as 0.5 kg CO_2-eq per kg product. Some stakeholders commented that these values may increase if truck loads were not complete or if pallets were not optimally organised, in the notable absence of standard package sizes. Also, fresh fish supply chains rely on regular routes that need to be operated to meet supermarkets' demands for rapid delivery (usually within 24 hours of landing).

Air freight: In the case of air cargo, the emissions are substantially higher. Several stakeholders referred to some imports by air freight. One of the examples described seafood shipped from Western Canada to NW-Europe, for a flight distance of about 8,000 km, with a climate impact of over 10 kg CO_2-eq per kg product. Several European supply chains rely on air freight, mostly for live crustaceans (Nephrops, European and American lobsters) and ultra-fresh fish fillets (cod from Iceland, various tuna species and swordfish from several Indian Ocean fisheries, and export to China and Japan). Seafood supply for supermarkets in outermost regions is also partly transported by air freight on regular passenger flights, allowing supermarkets to offer 'continental' species on their fresh counters to the local population. A recent visit to a supermarket in La Réunion Island (April 2022, see Figure 3) allowed one of the authors of this study to spot several species transported by airfreight from Paris (Nephrops, cod, spider crab, sardine, freshly cooked whelks, freshly cooked shrimps) and Chile (live brown crabs, *Cancer edwardsii*) on a fresh counter.

Example: For reasons of quality and shelf-life, cod is airfreighted from Iceland to Norway. Based on the typical GHG emission intensity of continental refrigerated air freight and estimated flight distance of 1,750 km, this transportation contributes around 3.5 kg CO_2-eq. per kg product. This exceeds the sum of all other operations in the PH value chain. Stakeholders also mentioned this kind of transportation being used for fresh cod products from Iceland to Spain or France.

Sea transportation through (traditionally) refrigerated reefer containers induces only a small amount of GHG emissions compared to air cargo: typical 2–4%. Technological innovations (e.g. superchilling applied in reefer containers) can contribute to maintaining quality and shelf life (EFSA, 2021, Eliasson et al., 2019) and substantially reducing GHG emissions. In this, the slightly higher energy use of superchilling compared to traditional refrigeration is taken into consideration, and it would not largely increase the GHG emissions of refrigerated transport (Hoang et al., 2015).

Figure 3: Fresh fish counter in a supermarket in La Réunion Island. Picture by one of the authors, April 2022.

4.1.5 Lessons learned from case studies

4.1.5.1 The importance of co-products

In some supply chains, co-products potentially comprise a larger fraction of the fish caught. For example, several gadoids have typical conversion ratios lower than 0.5. The emissions associated with the non-edible fraction can only be set aside if this fraction is destined for another economic usage. The generalisation of the use of co-products could significantly reduce the level of GHG emissions in the supply chains.

4.1.5.2 The importance of transportation

Several CSs collected enough data to develop estimates of GHG emissions for typical products. Nonetheless, the lack of actual data means that these results have to be considered indicative at best and that, even for the same species, each filet will have a different level of emissions due to the importance of transport in the calculation. Another difficulty in performing these GHG emissions analyses is the variability that may arise from a few percentage changes for a few critical parameters.

4.1.5.3 Link between structural improvements and technological improvements

Several processing techniques mentioned in case studies aim to preserve fish: sterilising tuna, anchovies or sardines in cans or jars, cooking shrimp and freezing cod filets. All these processing techniques are energy intensive, and some are also material intensive (cans or jars for sterilised fish), increasing the GHG emissions associated with the final product. Fish meal and fish oil production are also performed to stabilise the fish. All these techniques are further described from a technological perspective in Chapter 5. Nonetheless, the implementation of these techniques is the result of the structural organisation of various supply chains and may be the result of:

- Distant fishing: freezing-on-board has become the standard for several long-distance fisheries that would struggle without this preservation step (tuna in tropical waters, hake in South America, South Africa and Namibia).

- Strong seasonality, with the fishery concentrated on a few weeks every year, while providing volumes that could not be absorbed by the fresh market, like mackerel and herring (see CS3). Frozen storage allows for uncoupling seasonality/peaks of supply and year-round market demands.
- A trade-off for seafood products imported from Asia or America: either importing it fresh using airfreight (live American lobster, fresh tuna loin from the Indian Ocean) or transporting it frozen using container ships (most of the tropical tuna consumed in the EU, most tropical shrimps, warm water catfish, tilapia).
- A trade-off between freshness and shelf life: European-caught fresh fish (sardine, anchovies, albacore tuna, see CS20) may only last a few days compared to several years for canned products. Material use for packaging has risen substantially for reasons relating to hygiene, handling and to reduce losses in the retail channel through maximising shelf life.

These examples highlight that the evolution of the structure of a supply chain is intertwined with the technologies available to develop and maintain it. Several of these supply chains would not exist without these processing techniques.

4.2 Alternative distribution systems

Alternative distribution systems differ from the ‘centralised’ distribution systems, where flows of materials are structured and driven by human decisions. These alternative systems can arise either:

- in existing supply chains when traditional actors (namely the supermarket chains and regional wholesalers) implement changes allowing the decentralisation of the decision-making process inside their supply chains; or
- in parallel with existing supply chains when new entrants (start-ups) develop innovative approaches to obtain a competitive advantage over traditional players by reducing the need for transportation.

Very little information on alternative distribution systems was gathered from the different CSs. Instead, additional interviews with retailers, transport companies, blockchain specialists, software companies and start-ups were undertaken to prepare this section. The section is organised into four subsections:

1. The first subsection describes innovation in supply chains organisation, highlighting the theoretical approaches supporting the development of these alternative distribution systems.
2. The second subsection describes the current organisation of seafood supply chains in Europe to better understand where evolution could happen.
3. The third subsection explores the arrival of e-commerce; new entrants to the seafood supply chains, online marketplaces.
4. The fourth subsection highlights the different technological changes needed for the development of alternative distribution systems in Europe.

4.2.1 Innovation in supply chain organisation

Sustainable supply chains have been the subject of several research articles over the last ten years, focusing mainly on the importance of data in the design of these supply chains. The concept of industry 4.0 was introduced in Germany in 2011, as “a completely automated and intelligent production project, capable of communicating autonomously with the main corporate players relying on the horizontal and vertical integration of production systems driven by real-time data interchange and flexible manufacturing to further enable customized production” (Piccarozzi et al., 2018).

This concept has been central to most of the developments in terms of new approaches leveraging the information available to optimise supply chains. The concepts of green logistics (see Helo and Ala-Harja 2018) and logistics 4.0 (Winkelhaus and Grosse 2019) are derived from the idea that logistic systems may benefit substantially from several technological innovations, such as:

- The Internet of Things, namely interconnected objects that may be individually addressable;
- Ubiquitous Manufacturing, which is the ability to produce any product anywhere, relying on 3D printing technologies or on other technologies;
- Supply Chain Management (SCM), which is the ability to oversee the entire supply chain, from raw resources to the end-product;
- Big data, which represents the ability to generate and exploit very large databases to improve the understanding of the supply chain;
- AI technologies allowing decentralisation the decision-making process in the supply chain;
- Supply Chain Management (SCM) is the ability to oversee the entire supply chain, from raw resources to the end-product.

Alternative distribution systems build on a combination of these tools to improve the efficiency of the supply chain, by optimising the material flows, thus reducing the need for transport. Optimisation integrate several dimensions: costs, transportation time and GHG emissions.

Since these theoretical developments, Büyüközkan and Göçer (2018) conducted a thorough literature review of articles on the concept of Digital Supply Chain (DSC), highlighting that the potential operationalisation of the DSC concept at the sectoral level would only be possible if additional research was conducted before.

4.2.2 The current organisation of distribution systems in the EU

The definition of the PH sector used in this study aggregates seafood-centric actors: fish auctions, primary and secondary processors, and actors for whom fish and shellfish may only represent a fraction of their business model, such as logistic companies (transport and cold storage), wholesalers and, for the most part, distributors, with the exception of fishmongers. This distinction is essential for understanding operational models that may not seem logical from a seafood value-chain perspective. Depending on the viewpoint, this description of seafood supply chains may seem highly centralised (i.e. from the transporters and supermarkets’ perspectives), yet highly decentralised from the perspective of SMEs processing seafood. Overall, when consulted, interviewees would rather qualify the sector as disorganised rather than centralised.

4.2.2.1 Logistic companies

Few logistic companies dedicate their business model entirely to seafood transport, which comprises a significant niche of live shellfish logistic specialists who have faced several critical threats in recent years, mainly owing to the disruption created by COVID-19 and the slow-down at the border between the UK and continental Europe, as the UK was one of the vital live crustaceans (crab and lobster) providers for the single market pre-Brexit. For most logistic companies, seafood is only one of the many commodities transported, which means that the sub-operations related to seafood transport may seem sub-optimal.

The logistic constraints are different depending on the stability of the seafood transported:

- Fresh products have a reduced shelf life of no more than a few days, placing time as the most important constraint on the entire supply chain, particularly on primary processors, and transport companies. According to interviewees, this time

constraint is key to understanding the current organisation of fresh seafood supply chains in Europe.
- Processed products have a longer shelf life, lowering the time pressure on the supply chain. The transport of these goods may also be grouped with other product families, allowing optimisations at a broader level.

Most companies can transport several families of products on a single lorry. Still, with the constraint of two temperature zones: a truck may have one compartment for fresh seafood and a second for flowers on the same journey. This allows them to be more flexible in organising their routes. This also helps logistic companies avoid empty return trips. A macro flow map of the seafood products in Europe would show an imbalance for several seafood supply chains, with important productions in Northern Europe (whitefish fisheries in Icelandic and Norwegian waters, salmon aquaculture in Norway and Scotland) and South-Eastern Europe (seabass-seabream aquaculture in Greece and Turkey) with important consumption areas in South-western Europe (France, Spain, Italy). The seafood logistics needed to move these productions to their consumers generates potentially empty returns, as the production areas cannot eat the locally produced volume.

These transport companies face external constraints that make their operating models more complex. Average lorries speed has decreased in recent years due to changes in the maximum speed limits. In several MS, debates on the merit of limiting further maximum speed limits for roads and motorways regularly take place in order to reduce CO2 emissions, noise and atmospheric particles. For example, the maximum speed limit for single carriageways with no central separation went from 90 km per hour to 80 km per hour in France in July 2018. In several MS, the maximum speed in urban areas went down from 50 km/h to 30 km/h. These constraints are even more strict for the last kilometres that are usually achieved in urban and sub-urban areas. The average speed in city centres is decreasing yearly, with additional restrictions being placed on the hours allowed for truck deliveries. Transport companies face the necessity to develop a specific localised fleet of low-emission vans (electricity mostly, some are testing hydrogen-powered trucks) to reach noise limits and emission limits in some cities. With the current technological level, this may only be achievable by adding a de-grouping stage to unload lorries and load refrigerated low-emission vans.

4.2.2.2 Supermarket chains

Supermarket chains may operate their own fleet of trucks and vans and their own dispatch platforms to control entirely their distribution organisation, or they may engage in long-term contracts with logistic specialists who may provide a dedicated fleet of truck and vans, and cold warehouses to be used as dispatch platforms, especially for the daily flow of fresh seafood. The logistic organisation depends on the internal organisation of these groups and is essential to understand most constraints imposed on the upstream seafood supply chains. Several models exist in Europe, which we discuss below.

Some supermarket chains are based on centralised logistic systems, with a few grouping platforms that aggregate all the chains' products to optimise their operations through massification. This has been the operating mode of integrated supermarket groups where all stores operate on the same model, particularly the hard discount supermarket groups. For example, Lidl (the largest group of supermarkets at the EU level) operates one or two grouping platforms per Member State, aggregating most of the products sourced for each national network. Once the products are received, operators reorganise them into pallets that are sent to regional platforms to be delivered to each supermarket in the network. Lidl communicates its promotional offers nationwide, which implies that the delivery timeframe is almost identical for the entire network of supermarkets, similar to groups like Aldi and Carrefour. This type of organisation is usually implemented by hard-discount supermarkets and chains that are highly integrated.

In this model, the fish landed, processed and packed in a fishing port travel to the grouping platform over sometimes long distance (more than 600 km in some Member States) to be reshuffled on pallets before being shipped to the regional platform supplying the supermarket next to the processor. From a seafood supply chain perspective, this may sound extreme, unprofitable, carbon-intensive and unoptimized, with a total transfer of sometimes more than 1,000 km, two passages in warehouses for a few packs of fish fillets, compared to 4 km from the port to the supermarket. However, it is highly efficient from the distributor's perspective, for which these fish fillets are just one option amongst hundreds of references that need to be delivered weekly in stores. The store organisation relies on limited, multi-tasking staff, and for which every task is optimised. Receiving multiple deliveries is not efficient from the store's perspective, which is why massification has been at the core of the business model of most supermarket groups for the last few decades and with even more optimisation in the hard discount model. Massifying the flow of goods and grouping deliveries by temperature groups (frozen, ultra-fresh, stationary) is essential for these stores to maintain adequate profit levels.

Some supermarket chains operate with more decentralised systems, where individual stores order their specific needs on an internal marketplace. Once the transactions are completed, the orders from each supermarket are collected by regular transport services organised by the seafood team. Specific routes are organised from the processing areas, usually located around fishing ports but also close to important processing hubs to grouping platforms, allowing the packages to reach their final destination after a few hours. In this case, logistic flows appear to be massified, but the internal organisation of flows is decentralised.

4.2.2.3 Current constraints imposed on the fresh seafood supply chains

Most supermarket chains also impose critical constraints on fresh seafood supply chains. The most significant of these are:

- Early morning delivery allows preparing the fresh fish counter before the opening – this entails delivering fresh fish by 6.00 am in some MS.
- Grouped deliveries: supermarkets are organised with a minimum of staff to lower costs. Most supermarket chains require grouped deliveries to minimise the time spent per pack.
- Fast deliveries: most supermarket chains require their suppliers to deliver fresh seafood within 24 to 48 hours from landing in the country and from 48 to 72 hours when importing the fish, with all intermediary steps achieved (i.e. auction sale, first processing, packaging and transport).

Combining these constraints means that for most MS, fish landed in the morning of a particular day has to be sold, processed (i.e. filleted, peeled, sometimes deboned), packed and transported to a supermarket located in the same country by the early morning of the next day or to a supermarket in another Member States by the early morning of the following day. Although not requiring this particular organisation, fishmongers benefit from it and receive their orders in a similar timeframe. This has several consequences on the logistic organisation of the supply chain:

- Multiple departures: logistic companies are organising up to three departures per day in some auctions, in order to serve the different markets: in France, most auctions in Bretagne have three departures per logistic company (2 to 3 national players) to be able to serve all supermarkets by the next morning. None of these departures is operated at full load, increasing de facto GHG emissions per kg of fish transported. This happens to various degrees in other European countries too.
- Markets lost for some auctions: maintaining the short timeframe for delivery while facing a constant decrease in average speeds has pushed logistic companies to request earlier departures in auctions and supermarkets to stop operating in some auctions: it has been mentioned in exchanges that the Roscoff auction (North Bretagne, France) was not integrated in several supermarkets national buying options because supermarkets based in the South-East of France could not be reached within the 24 hour timeframe.
- The development of small city supermarkets by several supermarket chains has also led to the multiplication of points of deliveries, which must be served daily as the limited space is restricting storage areas to the minimum. This trend toward limited storage area has also manifested in larger supermarkets, which reinforces the need for daily deliveries to avoid shortages, which were experienced in some supermarket networks during the COVID-19 pandemic throughout the entire EU.
- The decreasing size of the individual lot: because of the multiplication of stores and because daily fresh delivery is considered the norm, the average size of individual lots is decreasing, which adds more pressure onto the logistic companies, since more lots need to be handled for the same overall weight to be transported. It is also increasing the amount of packaging needed to transport the seafood products in terms of weight of packaging per kg of fish transported, lowering the net load of trucks. Overall, this leads to an increase in the GHG emissions per kg of fish transported.

4.2.3 Effect of the emergence of the e-commerce

Several start-ups have developed logistic concepts to eliminate intermediaries in the supply chain, by connecting fishermen directly to supermarkets (e.g. ProcSea and Rooster in Europe) or consumers (e.g. Poiscaille in France, Fresh Fish Delivery in the UK and ZappFresh in India). Prominent players in e-commerce have also started to distribute fresh fish, such as Amazon in the USA. These systems have been reinforced during the COVID-19 lockdowns when shoppers switched to online options. The business model of these start-ups still relies on existing cold storage infrastructure, on logistic specialists common to all seafood supply chains and on companies specialised in cold deliveries to consumers. Several express shipping specialists have developed specific offers to deliver fresh products (including DHL and Chronopost), which are leveraged by these start-ups to build new provisions. In Europe, the business-to-consumer provisions focus mainly on connecting small-scale productions to a particular group of consumers (e.g. some companies decided to avoid fish caught by mobile gears).

In the business-to-consumer food supply, e-commerce/online shopping is emerging. Over the last decades, logistics that serve traditional ‘offline’ markets (retail and out-of-home) have been primarily optimised through the development of cross-docking points like distribution centres. The current system facilitates the use of efficient vehicles with relatively low GHG emissions per tonne capacity. Developing e-commerce/online shopping has different effects on environmental impact (Mangiaracina et al., 2015; Viu-Roig et al., 2020): transportation planning and management, warehousing, packaging, and distribution network design. Two types of actors have created e-commerce options:

- Traditional supermarket chains that are leveraging their existing network to offer pick-up or home delivery solutions to their customers,
- New entrants (start-ups) that are developing alternative supply chains to serve consumers.

With respect to transportation, there is no general consensus regarding the environmental impact effect of transportation activities related to B2C e-commerce. On the one hand, the increase in the number of inefficient deliveries and in shipping needs in general (e.g. home delivery of chilled products) significantly increases GHG emissions. On the other hand, under specific assumptions – such as high-population density, usage of low-carbon-emission vehicles – the environmental impacts can be positive, in terms of CO_2 emission reductions, for example. In the current situation, however, small delivery vans (with relatively high GHG emissions per tonne of product) replace the more efficient, large distribution trucks. The net effect depends on efficiency of the new delivery system.

New entrants tend to limit the use of warehousing to a small number of dedicated platforms compared to the supermarket network infrastructures. This is expected to lead to a reduction in losses in the distribution phase. Also, since refrigeration energy use in retail is a significant contributor to total GHG emissions in the PH value chain, the net effect is reduction of GHG emissions related to warehousing.

Packaging is a critical factor for the alternative distribution system. Home delivered chilled perishables are commonly packaged in polystyrene (GHG emission intensity ±3 kg CO_2-eq. per kg), possibly combined with other materials. The amount used per kg product varies depending on the delivered volume.

With respect to e-commerce/online shopping, it is expected that it will most likely increase GHG emissions related to buying seafoods. Only once car rides to physical shops are minimised (i.e. complete shopping packages are ordered) can the concept be broadly adopted (which facilitates efficient distribution) and the use of additional packaging material be minimised.

4.2.4 Technological blocks for alternative distribution systems

Discussions with retailers, logistic companies and EDI[8] service providers led to the conclusion that several essential technological advancements have not currently been implemented in seafood supply chains. This is hindering the development of a cohesive fresh fish market that would allow route optimisations, better use of local options, ultimately leading to a more organised and less centralised market. Taken individually, these blocks may not directly reduce the GHG emissions in the seafood supply chains, but combined, these blocks would improve the efficiency of the supply chain and thus reduce the GHG emissions.

4.2.4.1 Alignment of auction catalogues

Despite being defined at the European level by EU regulation 2406/96[9], stakeholders recognised that there is no coherence in the grading system at a regional, national or EU level: size grades and quality grades are not implemented uniformly, which hinders first-buyers and traders from understanding the available quantities available for the market.

In some auctions, fish landed by small-scale vessels are systematically graded with a quality E when the full spectrum should have been used (E, A, B).

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[8] Electronic Data Interchange (EDI) is the electronic interchange of business information using a standardised format; a process that allows one company to send information to another company electronically rather than with paper.

[9] Council Regulation(EC) No 2406/96 of 26 November 1996 laying down common marketing standards for certain fishery products

> *"The fish box in front of us was labelled as seabass, size 2, quality E. Not only this fish was a bit small and should have been graded as a size 3, but some of the seabass was slightly injured and should have at least been separated to be graded as quality A. All the buyers that were physically present and could see the product didn't bid for it. The online catalogue had only the description, not the picture of the box. So, the box was adjudicated at the price of a seabass of size 2 and quality E to one of the online buyers. But they may have had an unpleasant surprise when receiving the box in their shop."* Seafood buyer for a supermarket platform recalling a visit to a fish auction.

Some stakeholders commented that grading could be performed by a trusted third party who would not have the same relationship that auction staff may have with fishers.

4.2.4.2 Information about future auctions

Despite the introduction of the electronic logbook, several stakeholders felt that transparency surrounding future auctions was lacking. The absence of information on the catch already made by offshore vessels sometimes causes buyers issues in organising their daily supplies:

> *"Supermarkets are sending each Monday afternoon their pre-orders for the weekly special offers that are usually in store Friday and Saturday. At this point, we're unable to know the floating stock on vessels that are going to land Wednesday and Thursday in our regional ports. To serve these pre-orders, we're importing fish from Northern European countries. If we had the possibility to know what vessels have in their cold storage, we wouldn't have to import fish to meet the supermarkets' demands."* Primary processor ("mareyeur") in France.

4.2.4.3 Alignment in fish auctions at the EU level

The COVID-19 pandemic has accelerated the digitalisation of auctioning across Europe, with most auctions now available online for registered remote buyers. Several stakeholders identified that the different timings and organisations of auctions were limiting the ability of buyers and processors to optimise their bids. Some stakeholders indicated that different auction timings combined with the absence of auction catalogues in advance had led them to buy some species remotely under the first auction in the morning to secure their ability to fulfil some supermarkets' orders, while the same species was available in sufficient quantities under closer auctions.

4.2.4.4 Development of digital traceability

Most of EU seafood chains are still reliant on partial paper-based traceability, which does not allow building on available data to optimise the supply chain: traceability data is often lagging and may only be fully available several days after the sale to the final consumer. Despite the recent development of electronic logbooks, which are mandatory for all vessels over 12m, logbook information may not be available for first buyers who rely on partial information provided by the auctions, which may contain erroneous information (particularly about the gear or the area where the fish were caught). Interviewees mentioned that very few processors and wholesalers were able to pull data from their suppliers or push data to their clients, resulting in an overreliance on paper-based solutions.

4.2.4.5 Coherent format to transmit information

One of the key hurdles to the digitalisation of traceability systems is the lack of standardisation in data exchange formats in the seafood supply chains. International efforts such as the Global Dialogue on Seafood Traceability or the Seafood Alliance for Legality and Traceability are developing specific exchange formats to allow coherent data exchange along the supply chains, which is currently still paper-based, causing a lot of errors and mishandlings, causing a lot of friction in the supply chain.

There is, for example, no standard for designing package labels in business-to-business exchanges, as each supermarket network uses its own coding system and layout. Stakeholders indicated that this caused errors during transport operations as staff were sometimes confused by the information on the package. It has also caused some rejections from boxes that were not labelled as per clients' requests. A logistic operator interviewed mentioned that, in December 2021, an outbreak of COVID-19 in one of their platforms led to the last-minute recruitment of temporary staff to keep the platform open, resulting in mishandlings multiplied by a factor of four in the last three weeks of December due to the lack of experience in reading the labels.

4.2.4.6 Development of IoT

Implementing real-time tracking systems is seen as essential to improve efficiency in supply chains, notably if the information associated with these objects involves some seafood aspects (e.g. species, size, quality). Currently, most reusable fruit and vegetable boxes used in supermarket are equipped with trackers, without any information about the contents of the box. Currently, the systems implemented in the seafood industry suffer from the same limitations.

4.2.4.7 Central marketplace

There is no central marketplace comparable to the central reservation systems (CSR) extant in the travel industry. These CSR, such as Amadeus, allow for bookings on a unique platform for all flights, hotel rooms, train tickets and rental cars. No operator has access to this complete a vision of the fresh seafood market at the EU level, which inevitably leads to inefficiencies in the system, as operators must optimise their business models using incomplete information. This could be achieved if auction information systems were connected at the regional or national level (which is already the case in a few areas in Europe) or if such organisation was possible at the first processing level. It should however be pointed out that there is no equivalent of these CSR in any fresh or ultra-fresh food supply chains.

4.3 Current limitations for structural improvements in GHG emissions

4.3.1 Availability of fish supplies

One of the most important limitations is the irregularity of production, which 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 monopolised by a few members of the chain, which focuses the supply of a species for the rest of the value chain, raising prices or forcing them to resort to imports.

4.3.2 Efficiency and cost trade-offs

Applying structural improvements to reduce GHG emission is not straightforward and will, in most cases, lead to 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 consumer demand requests 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 short-term investment models (e.g. private equity), 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, changes to refrigeration systems) require large investments, which will not be possible unless the return of investment can be met in a reasonable time frame.

4.3.3 GHG hotspots

The hotspots ‘packaging material use’, ‘high-emission transport modalities’ and ‘long-term frozen storage’ have commercial motivations: they contribute to better serving market demand and extending refrigerated shelf life. In the current system, where climate impact is still ‘external’, these solutions seem cost-effective. In addition, the trade-off of reduced losses on the retail shelf also contributes to reducing GHG emissions per unit product sold.

4.3.4 Transport

With respect to e-commerce/online shopping, it is expected that it will most likely increase GHG emissions related to buying seafood. Only if car rides to physical shops are minimised (i.e. complete shopping packages are ordered) can the concept be broadly adopted (which facilitates efficient distribution) and the use of additional packaging material be minimised.

4.4 Balance in local supply and consumption

Geographic disconnection between production areas, processing centres and consumption areas is central to understanding the complexity of some PH value chains in Europe. From a systemic perspective, the EU has been a net importer of seafood products for decades but, internally, fish products have also been traded over long distances. In addition, consuming habits are very different between EU MS. Data retrieved from the EUMOFA country profiles highlights the gap between the main species consumed for each Member State and the provenance of the species, which tend to be imported (Table 3).

Table 3: Most consumed species and related production areas (based on EUMOFA country profiles)

Species in bold are produced nationally

Member State	Most consumed species	Production areas
Austria	Salmon Skipjack tuna	Norway, Scotland Tropical waters
Belgium	Salmon Cod Mussel Skipjack Tuna	Norway, Scotland Icelandic and Norwegian waters Netherland Tropical waters
Bulgaria	Mackerel Coldwater shrimp **Carp** Sprat **Trout**	North Sea fisheries North Sea and Nordic waters fisheries **National aquaculture** North Sea fisheries **National aquaculture**
Croatia	**Sardine** Squid **Hake**	**National production** Imports from Spain **National production**
Cyprus	Freshwater catfish Squid Skipjack tuna Salmon **Gilthead seabream**	North Pacific fisheries Imports from Spain Tropical waters Norway, Scotland **National aquaculture**
Czech Republic	Alaska pollock Herring **Carp**	North Pacific fisheries North Sea fisheries **National aquaculture**
Denmark	**Herring** Salmon **Mussel**	**National production** Norway **National aquaculture**
Estonia	Herring Trout	**National production** **National aquaculture**
Finland	Salmon **Trout**	Norway **Local aquaculture**
France	Salmon Cod Alaska pollock Skipjack tuna	Norway, Scotland Icelandic and Norwegian waters North Pacific fisheries Tropical waters
Germany	Alaska pollock Salmon Skipjack tuna Herring	North Pacific fisheries Norway, Scotland Tropical waters North Sea fisheries, partially imported
Greece	Squid **Sardine** Cod **Anchovy**	Import from Spain **National production** Icelandic and Norwegian waters **National production**
Hungary	**Carp**	**National production**
Ireland	**Mackerel** **Horse mackerel** Cod Herring Salmon Prawns	**National production** **National production** Icelandic and Norwegian waters North Sea fisheries, partially imported **National aquaculture**, partially imported **National production, partially imported**

Member State	Most consumed species	Production areas
Italy	Yellowfin tuna Squid Salmon **Mussel** Skipjack tuna Cod	Tropical waters Import from Spain Norway, Scotland **National production** Tropical waters Icelandic and Norwegian waters
Latvia	**Sprat** **Herring**	**National production** **National production**
Lithuania	Mackerel Horse mackerel **Sprat** **Herring**	North Sea fisheries North Sea fisheries **National production** **National production**
Luxembourg	Salmon Cod	Norway, Scotland Icelandic and Norwegian waters
Malta	No apparent consumption calculable (data skewed by Maltese bluefin tuna fattening)	
Netherlands	Sardine Tuna Freshwater catfish Warmwater shrimp	- Tropical waters Aquaculture South-east Asia Aquaculture South-east Asia and South America
Poland	**Herring** Alaska pollock **Sprat** Mackerel Atlantic horse mackerel Cod	**National production**, partially imported North Pacific fisheries **National production** North Sea fisheries North Sea fisheries Icelandic and Norwegian waters
Portugal	Cod	Icelandic and Norwegian waters
Romania	Mackerel **Carp** Herring	North Sea fisheries **National production** North Sea fisheries
Slovakia	Alaska pollock	North Pacific fisheries
Slovenia	Skipjack tuna Squid	Tropical waters Import from Spain
Spain	Hake Cod Yellowfin tuna **Mussel** Squid	African coast, South American coasts Icelandic and Norwegian waters Tropical waters **National production** imports
Sweden[10]	Salmon Cod **Herring**	Norway Icelandic and Norwegian waters **National production**

Discussing the possibilities of encouraging consumers to buy local seafood has been on the agenda of several agencies in Europe but, to the knowledge of stakeholders, it has never been achieved successfully. Culinary habits are enshrined in local cultures and the ease of accessing seafood options to meet these habits has been detrimental to the development of

[10] Please note, Cod is also produced in Sweden, but have been marginalized due to collapse of stocks and are now mainly imported. For herring, Sweden produces a lot, but most is destined for fish meal and oil and the herring that is consumed is mainly imported

localised supply chains. Some species are dominant in eating habits across Europe that require important transport, as their production is very localised while their use is widespread:

- Cod, mackerel and herring are mostly produced in North-European waters, while being favoured by several national markets in Europe
- Salmon is farmed in Norway, Scotland and Chile, while seabass and seabream are mostly farmed in East-Mediterranean waters (Greece and Turkey). These three species are amongst the most demanded in major consumption areas in Europe.
- Alaska pollock, warm water shrimp, freshwater catfish and tropical tuna are all produced outside the EU area while being on the top of shopping lists for most EU consumers.
- Hake (*Merluccius merluccius*) is fished in Europe, but there are several options in distant fisheries either operated by European vessels (along the African coast) or by fleets close to European interests (e.g. Namibia, South Africa, Argentina) that provide far more hake than European production for the EU market.

The organisation of seafood processing hubs in port areas (Bremerhaven, Urk, Boulogne-sur-Mer, Lorient, Vigo, Humberside before Brexit) or, more recently, in east European countries (particularly Poland) is also playing a role this disconnect. Supply chains passing by these platforms may generate less GHG than localised supply chains due to efficiency gains in processing (better yields) and transportation (grouping of flows). Producers and processors have developed implicit or explicit strategies to help maximise company profits by reaching the best markets for production, which may have accelerated the disconnect between local production and local consumption.

- Before Brexit, UK brown crab (*Cancer pagurus*) production exceeded the potential British consumption by far. The UK sector was exporting brown crab to other MS (France, Italy and Spain) while importing brown crab from Denmark for their consumption. Different consuming habits meant it was more profitable for the British sector to export large crabs to the markets that valued them while replacing them with small crabs that would be peeled and sold as crab meat to British consumers who were not interested in buying the crab shell-on.
- The French fleet targeting monkfish (*Lophius piscatoris*) targets larger sizes that are destined for the Spanish market, for the HORECA sector in particular. During the first month of the COVID-19 pandemic, Spanish HORECA sector was closed, limiting the ability for French producers that were still at sea at the time. French supermarkets still wanting to provide fresh fish had to reorganise their supply chains by identifying French processors that could detail the monkfish tail as most supermarkets were not able to process them at their fish counters.
- The value chain associated with a Spanish octopus fishery in Asturias (*Octopus vulgaris*) was deeply affected by the eco-certification of the fishery. Prior to the certification, vessels mainly served the Spanish fresh market, but once certified, their product started to be exported to markets that recognise more eco-certification than the Spanish market, such as North European countries and the USA.

This imbalance is a key feature for most European species, as noted by multiple EUMOFA publications showing the level of coverage of national consumption by national production, as shown by the example of cod (Table 4), plaice (Table 5) and gilthead seabream (Table 6). Overall, the production of key species is geographically concentrated, sometimes outside the EU:

- Cod is one of the most important species for the EU market, notably for Belgium, France, Greece, Ireland, Italy, Spain and Portugal. It is, however, mostly caught outside EU waters (Icelandic and Norwegian waters) by non-EU vessels;
- Although salmon, tropical tuna, warmwater shrimp and Alaskan pollock are some of the most important species for the EU in terms of consumption patterns, all are predominantly (or entirely) produced outside the EU;
- Fisheries for small pelagic species (mackerel, herring, sardine, anchovies) are concentrated geographically (North Sea, Bay of Biscay, Mediterranean) and are highly seasonal;
- Hake is an important species, notably for the Spanish market. Although it is produced in Europe, the majority of hake consumed in Europe is imported from African and South American fisheries;
- Plaice is caught in the North Sea by several fleets, mainly from the Netherlands, Denmark, the United Kingdom and Belgium. Italy is however currently the first market for this species; and
- Seabream is mainly a farmed species, produced mostly in Greece. A large quantity is exported, and Italy is currently the first market for seabream.

One key issue in conducting this kind of analysis is the lack of trade data for minor species that are sometimes grouped in trade statistics.

Table 4: Apparent consumption of cod in the main consuming Member States and the United Kingdom (2018, in tonnes of live weight equivalent) – from EUMOFA

Member State	Catches	Imports	Exports	Apparent market	Apparent coverage
United Kingdom	34,680	258,840	32,766	260,754	13%
France	7,844	181,543	10,234	179,153	4%
Spain	13,972	178,834	48,959	143,847	10%
Poland	10,906	90,104	57,550	43,460	25%
Sweden	3,753	185,282	147,151	41,885	9%
Germany	14,721	132,994	105,877	41,838	35%
Portugal	7,556[11]	90,104	57,550	40,110	19%
Belgium	876	35,515	9,726	26,666	3%
Ireland	861	11,528	474	11,915	7%
Denmark	15,394	176,038	185,778	5,654	100%
Finland	59	1,878	40	1,897	3%
Estonia	2,033	430	1,623	839	100%
Latvia	2,305	10,419	12,195	529	100%
Lithuania	1,149	20,973	25,356	-3,234	Negative
Netherlands	584	321,258	325,112	-3,270	Negative

Table 5: Apparent consumption of plaice in the main consuming Member States and the United Kingdom (2014, in tonnes of live weight equivalent) – from EUMOFA

Member State	Catches	Imports	Exports	Apparent market	Apparent coverage
Italy	0	28,002	130	27,873	0%
United Kingdom	19,136	6,630	3,197	22,569	85%
Germany	4,634	13,887	6,195	12,326	38%
Netherlands	28,779	25,772	45,790	8,760	100%
France	3,205	6,363	1,860	7,708	42%
Denmark	20,851	3,679	18,011	6,519	100%
Belgium	8,868	6,058	12,928	1,997	100%
Poland	88	3,947	2,402	1,632	5%

[11] Please note, cod is not fished in Portuguese waters, but is landed in Portuguese ports

Table 6: Apparent consumption of gilthead seabream in the main consuming MS (2019, in tonnes of live weight equivalent) – from EUMOFA

Member state	Production	Import	Export	Apparent market	Apparent coverage
Italy	10,154	35,341	6,046	39,449	26%
Spain	13,115	8,177	2,550	18,743	70%
Portugal	1,928	12,837	314	14,451	13%
France	3,484	10,785	949	13,320	26%
Greece	56,005	8,038	54,207	9,835	100%
Germany		6,124	917	5,207	0%
Croatia	6,898	162	4,585	2,475	100%
Netherlands		7,530	5,697	1,833	0%
Cyprus	5,182	58	3,557	1,682	100%
Romania		1,498	90	1,408	0%
Bulgaria		986	73	913	0%
Austria		909	255	654	0%
Belgium		631	29	602	0%
Slovenia	11	463	38	436	3%
Poland		503	74	429	0%
Slovakia		463	38	425	0%
Luxemburg		345	36	310	0%
Malta	1,802	13	2,407	-592	Negative

5 REDUCING GHG EMISSIONS BY TECHNICAL MEANS

To describe and discuss the technical means by which GHG emissions can be reduced, first, an overview of trends in technological evolutions and industrial strategies based on literature searches was made (Section 5.1, Annex 4 and 5). Second, relevant information and lessons were compiled from CSs based mainly on stakeholder consultations (Section 5.2). Finally, an overview of challenges for the future and gaps in knowledge is given (Section 5.3).

5.1 Trends in technological evolutions and industrial strategies

To create an overview of technologies and industrial strategies used throughout PH value chains, relevant information was collected through a literature review. The literature review delivered only limited results, especially for the past 20 years (from 2002 onwards). This was also the case for literature on future technologies and industrial strategies. Due to this, websites with technology information specific sheets were sourced for information. One example of an already existing work where much of the described technologies were already summarised is the book “Seafood Processing: Technology, Quality and Safety” by Boziaris (2013). This work and its references have been extensively referenced in the technology sheets (see Annex 4).

Information obtained through the consultation of different types of literature was inserted in technology sheets (Annex 4). Technology sheets were created for each process, either for each occurrence or grouped by occurrence (conventional, emerging or continuous) in order to represent the past 20 years, present and future. A similar approach was used for both the technological evolution overview and the industrial strategies (see Table 7 for an overview).

Table 7 shows the technologies and industrial strategy category overview. Each category is subdivided into processing types, processes and occurrence. The occurrence indicates either conventional technologies or strategies (i.e. from 2002 to present) and emerging technologies and strategies (future). Right of the technology or industrials strategy name, the ‘GHG’ column indicates if the specific technology or industrial strategy has a positive (green), negative (orange), or unknown (blank) GHG impact. Note that this colour coding is an oversimplification and only considers the technology itself, and therefore omits indirect GHG impacts of the production of these technologies or other GHG impacts. Also note that emerging technologies are not always more GHG-efficient compared to conventional technologies. Technologies can have a neutral GHG impact because, for example, they may be in use but they are less well known or are in the research and development (R&D) stage so their GHG-impact is unknown. If the technology is presently in use or in the R&D stage, this is indicated in the ‘usage’ column. The last two columns of the table indicate the advantages and disadvantageous of each technology and industrials strategy.

In Annex 5, each technology and industrial strategy is described, focussing mainly on GHG emissions (as this is the aim of the current report) and cost (as this is a recurrent important result). Each technology and strategy section describes first conventional technologies and strategies (from 2002 onward) and second, emerging technologies and strategies, unless the occurrence is continuous.

Table 7: Overview of technologies and industrial strategies used in diverse PH value chains.
This table can be used to look up a detailed description (Annex 5) and/or the specific technology sheets (Annex 4). GHG: GHG impact in green (positive), orange (negative) or grey (unknown). Usage: U=in use; R&D=Research and Development.

Category	Process type	Process	Occurrence	Name	GHG	Usage	Advantages	Disadvantages
Technology	Pre-processing	Thawing	Conventional	Water immersion-spray thawing		U	-Cost -Capacity	-Energy -Processing time -Food contamination
				Air thawing		U	-Low cost -High capacity	-Energy -Processing time -Food contamination
				Microwave assisted thawing		U	-Processing time -No medium -Energy	-Temperature control -Optimisation per product
			Emerging	Ohmic thawing		R&D	-Heat transfer -Energy -Processing time -No medium	-More R&D necessary
				High hydrostatic pressure for thawing		U	-Product quality -Less food waste	-Cost -Complexity -More R&D necessary
				Radiofrequency assisted thawing		R&D	-Product quality -No medium -Processing time	-Temperature control -Optimisation per product -More R&D necessary
				Ultrasound assisted thawing		R&D	-Heat transfer -No medium -Efficiency	-Energy -Optimisation per product -Work safety
	Processing	Control of water activity - drying	Conventional	Sun drying		U	-Energy -Cheap	-Food contamination -Process control -Processing time
				Solar drying		U	-Energy -Cost	-Food contamination -Process control
				Microwave drying		U	-Processing time -No medium -Energy	-Temperature control -Optimisation per product
				Airless dryer		U	-Energy usage	-Only feed production

							-Energy wastage	-Considered a GHG hotspot
				Freeze-drying		U	-Product quality	-Energy -Processing time -More R&D necessary
				Heat pump drying		U	-Energy -Efficiency	-Water loss
				Hybrid heat pump drying		U	-Energy -Efficiency	-More R&D necessary -Still in R&D stage
				Osmotic dehydration		U	-Energy	-Processing time -Medium waste
		Control of water activity -salting	Conventional	Dry, pickle and brine salting		U	-Energy -Cost	-Processing time -Process control
				Injection salting		U	-Processing time -Medium waste	-Food contamination
			Emerging	Vacuum impregnation salting		R&D	-Processing time -Product quality	-More R&D necessary
		Control of water activity -smoking	Conventional	Hot and cold smoking		U	-Energy -Cheap	-Burning process -Processing time -Food contamination
				Liquid smoking		U	-Cost -No Burning -Processing time	-Product quality
			Emerging	Electrostatic smoking		R&D	-Processing time -Cost -Product quality	-More R&D necessary
		Control of water activity -marinating	Conventional	Cold, cooked, fried and pasteurised marinating		U	-Product quality	-Energy -Processing time
				Injection marinating		U	-Energy -Processing time -Medium waste	-Food contamination
			Emerging	Vacuum impregnation marinating		R&D	-Processing time -Food quality -Food contamination	-More R&D necessary
		Heating – pasteurisation, sterilisation and canning	Conventional	Saturated steam retort (autoclave)		U	-Cheap	-Energy -Optimised equipment use -Waste medium
				Water spray retort		U	-Cheap	-Energy -Optimised equipment use

								-Waste medium
				Steam and air retort		U	-Cheap	-Energy -Optimised equipment use -Waste medium
				Water immersion retort		U	-Cheap	-Energy -Optimised equipment use -Waste medium
				Steam pasteuriser		U	-Cheap	-Energy -Optimised equipment use -Waste medium
				Microwave pasteurisation		U	-Processing time -No medium -Energy	-Temperature control -Optimisation per product
			Emerging	Pressure assisted thermal processing		R&D	-Food quality	-More R&D necessary
				Microwave assisted thermal sterilisation		U	-Processing time -No medium -Energy	-Temperature control -Optimisation per product
				High hydrostatic pressure pasteurisation		U	-Product quality -Less food waste	-Cost -Complexity -More R&D necessary
				Ultrasound assisted pasteurisation		R&D	-Heat transfer -No medium -Efficiency	-Energy -Optimisation per product -Work safety
				Cold plasma decontamination		R&D	-Food quality	-More R&D necessary
				Pulsed light decontamination		R&D		-Complex -Food quality -More R&D necessary
				Ultraviolet decontamination		R&D	-Simple -Cost	-Food quality -More R&D necessary
		Heating – cooking and frying	Conventional	Water immersion cooking		U	-Cost -Capacity	-Energy -Food contamination
				Steam oven-cooker		U	-Cost -Capacity	-Energy -Waste medium
				Sous-vide cooking		U	-Energy -Food quality	-Specific use -Processing time
				Frying - oil immersion		U	-Cost	-Energy

							-Capacity	-Medium waste
				Air frying		U	-Medium waste	-Energy
				Grilling		U	-Food quality	-Energy -Optimisation per product
			Emerging	Microwave oven		U	-Processing time -No medium -Energy	-Temperature control -Optimisation per product
				Ohmic heating		U/R&D	-Heat transfer -Energy -Processing time -No medium	-More R&D necessary
				Ultrasound assisted cooking		R&D	-Heat transfer -No medium -Efficiency	-Energy -Optimisation per product -Work safety
				Electrostatic frying		U	-Processing time -Food quality	-Limited use -More R&D necessary
				Vacuum frying		U	-Medium waste	-More R&D necessary
	Storage	Freezing	Conventional	Blast freezing		U	-Cost -Capacity	-Energy -Optimised equipment use -Conventional refrigerants -Needs good strategy
				Contact/plate freezing		U	-Cost -Capacity	-Energy -Optimised equipment use -Conventional refrigerants -Needs good strategy
				Cryogenic freezing		U	-Processing time	-Cost -Optimised equipment use -Refrigerant
				Immersion freezing		U	-Processing time	-Cost -Optimised equipment use -Refrigerant -More R&D necessary
			Emerging	Superchilling		R&D	-Food quality -Medium waste -Efficiency -Indirect benefits	-Initial steps conventional -Optimisation per product -More R&D necessary
				Super freezing		R&D	-Food quality -Medium waste	-Initial steps conventional -Optimisation per product

							-Efficiency -Indirect benefits	-More R&D necessary
				Ultrasound assisted freezing		R&D	-Heat transfer -No medium -Efficiency	-Energy -Optimisation per product -Work safety
		Cold storage - insulation	Conventional	Strip curtains		U	-Efficiency	-Maintenance -Needs good strategy
				High speed doors		U	-Efficiency	-Maintenance -Needs good strategy
				Air curtains		U	-Efficiency	-Maintenance -Needs good strategy
				Conditioned air vestibule (air lock)		U	-Efficiency	-Cost -Maintenance -Needs good strategy
				Current contact insulation materials		U	-Efficiency -Waste	-Production process
			Emerging	Future contact insulation materials		R&D/U	-Production process -Waste -Efficiency	-Cost -Production time -More R&D necessary
		Cold storage – dehumidifier	Conventional	Dehumidifiers		U	-Cost -Efficiency	-Needs a good strategy
		Cold storage – refrigerants	Conventional	Previous and currently used refrigerants		U	-Efficiency -Cost -Inert	-Ozone depletion -Greenhouse gas
			Emerging	Future refrigerants		R&D/U	-Natural -Efficiency	-Cost -Non-inert -Optimisation per product -More R&D necessary
		Packaging	Continuous	Modified atmospheric packaging		U	-Efficient	-Waste -Production process -More R&D necessary
				Active packaging		R&D	-Efficient -Information	-Waste -Production process -More R&D necessary
				Intelligent packaging		R&D	-Information	-More R&D necessary
				Edible coating and films		R&D	-Waste	-More R&D necessary
Industrial strategies	Management	General	Continuous	Cleaner production strategies		U	-Efficiency -Energy	-Needs good management

							-Waste	
				Short supply chains		U	-Efficiency -Energy -Waste	-Needs good management
			Emerging	Automation and Data collection		U	-Efficiency -Consistency	-Needs expertise
		General – high level strategies	Continuous	Incentives and methods on how to change		U	-Efficiency -Integration	-Needs strong collaboration -Needs a wider view -Integration of ecology, economy, social and institutional aspects
		General – low level strategies	Continuous	Transport		U	-Efficiency -Energy -Waste	-Needs data -Needs strong collaboration
				Processing		U	-Efficiency -Energy -Waste	-Needs data -Needs strong collaboration
				Packaging		U	-Efficiency -Energy -Waste	-Needs data -Needs strong collaboration
				Retail		U	-Efficiency -Energy -Waste	-Needs data -Needs strong collaboration
		Energy	Continuous	Replacing water boilers with steam boilers		U	-Efficiency -Energy -Waste	-Needs incentive -Cost
				Heat recovery		U	-Efficiency -Energy -Waste	-Needs incentive -Cost
				Insulate heating equipment		U	-Efficiency -Energy -Waste	-Needs incentive -Cost
			Emerging	Automation and robotics		U	-Efficiency -Energy -Waste	-Needs incentive -Needs infrastructure -Cost
				Renewable energy sources		U	-Efficiency -Energy -Waste	-Needs incentive -Needs infrastructure -Cost

		Water	Continuous	Water recovery		U	-Efficiency -Energy -Waste	-Needs incentive -Cost
				Water storage		U	-Efficiency -Waste	-Needs incentive -Cost

5.2 Comparison between literature and stakeholders' perceptions on impacts of GHG emissions on their PH value chain

Comparing the findings from literature on PH technologies and industrial strategies (Section 5.1 and Annex 5) with stakeholder perceptions (this section and case studies in Annex 2) resulted in a general broad agreement between literature and stakeholders. Topics on which both literature and stakeholders agree are briefly described below while, in following sections, examples are given from the stakeholder consultations specifically for the reduction of GHG emissions through technological and industrial strategies, and by means of an integrated technological and strategic approach. It is also important to highlight that, in some value chains, seafood products are sold mostly fresh so information concerning technologies and strategies is very limited, such as for seabass and bream, whitefish and crustaceans.

One of the major topics where literature and stakeholders agree, although never explicitly stated, is the **priority** of why either technologies, industrial strategies or a combination of both are chosen. As the PH value chain consists of small businesses and enterprises over larger companies and large multinational organisations, their priorities lie in providing products for their customers. Thus, most if not almost all choices, including choices surrounding technology and industrial strategies, are made with financial aspects in mind. In short, **money is their first priority as a driver of their choices**. As a consequence, climate impacts and GHG emissions are almost never a first priority. Several CSs came to a similar result where, after stakeholder consultation, it was concluded that the likelihood of a business prioritising reducing emissions appears low. Furthermore, in these CSs it was indicated that understanding and reducing GHG emissions appears to be a matter of priority. This does not mean that stakeholders do not see climate change as unimportant, only that it represents a second, third or lower priority for the economic entities that operate within the PH value chain.

Both literature and stakeholders strongly agree on the enormous **necessary costs and investments** that come with new, innovative and future-proof technologies and industrial strategies. In addition, the priority of 'money', or financial stability and growth, can be broken down into two topics where both literature and stakeholder perceptions agree. First, any economic entity operating within the PH value chain will try and reduce its cost. This may happen through optimising processes within value chains. Second, there is a lack of money or personal financial capital. In other words, there is often not enough available financial capital or the possibility of investment through funding. One must ask the conceptual question if it is always true whether personal financial capital for investment is indeed absent in the current, profit driven economic system. In other words, is the capital not available or is there a lack of willingness to invest the capital? In addition, finding funding or external investment, which is necessary to implement new technology or industrial strategies, may be very challenging because it may not be available, or it may come with its own financial and legal restrictions.

Additionally, even if the investment is affordable, some companies reject changes, to quote one of the stakeholders *"if something is working now, why should I change?"* In this context, stakeholders sometimes do not trust the applicability of emerging technologies, and they expect the administration or other agents to share the **risks of implementing innovative technologies**, not just funding required resources.

A topic that was only mentioned a few times in literature but more frequently by stakeholders was the **availability of infrastructure**. This topic especially relates to infrastructure for sustainable energy sources, such as solar, wind, hydropower and geothermal energy. Although substantial efforts are being made to implement the sources of renewable energy (e.g. solar panels, wind mills, dams and geothermal pumps), this infrastructure is not always present at the location where the energy can be used. Moreover, the infrastructure to connect to these renewable energy sources is often not present. Again, large financial investments, from both external sources and from within the PH value chain are necessary to alleviate these challenges.

A final topic where both literature and stakeholders agree is **knowledge and awareness**, however, this is almost never explicitly mentioned except in few cases (both in literature and by stakeholders). Large amounts of knowledge are being collected today on all levels, by the PH value chain companies, by academic and research institutes and by customers of the PH value chain, yet many more times the current amount of knowledge appears to be necessary to future-proof the PH value chain with regard to climate change. Similarly, although awareness about the impact of climate change has increased tremendously in recent years among all parties (producers, processers, customers, etc.), awareness needs to increase further. This increase in awareness should not limit itself to awareness of climate impacts but also awareness of financial resilience, production and consumption.

5.2.1 Reduction of GHG emissions by technological means

Examples of technological solutions based on stakeholder consultation are explored in this section. Note that any detailed descriptions can be read in the respective case studies. One challenge that the PH value chain sometimes faces is the **availability of technology** to adapt value chains to become financially attractive. For the fish meal/fish oil value chain in Poland, this challenge could be solved (CS1). In Poland, only a few of the largest fishing harbours have infrastructure able to land pelagic fishes at a large scale. Vacuum pumps for the vessels equipped with RSW (refrigerated sea water) systems were set up on quays in several ports. They enable fish to be transported directly to trucks that transport them to meal and oil processing plants located outside the country (Denmark, Germany and Latvia are the main destinations). In addition, larger trading companies and producer organisations have sorting systems for landed fish if fish for human consumption has to be sorted from that intended for the fish meal/oil value chain. Originally, where these technologies were not available, the vessels had to wait in the harbours before unloading could happen. The availability of this technology provided quick landings and a more consistent flow of raw materials to processing factories, which allowed the factories to optimise the processing of the raw materials. In the seabass and bream PH value chain (CS9), processors are looking for filleting and MAP packaging alternatives that could reduce up to 40% of GHG emissions.

A technical processing challenge that was flagged for northern shrimp (CS16) was peeling. Peeling shrimp by machine results in lower **yield** than by hand. However, peeling by machine offers less risk for contamination (Dang et al., 2017). Importantly, although yield varies between processing by hand or machine, so does the structure of the value chain for different products. The combination of these factors contributes to different overall GHG emissions, and the relative importance of different value chain steps related to GHG emissions. However, the shrimp processor reported that the machines used for peeling could possibly be exchanged for newer ones using less water and energy, thus reducing climate impact and GHG emissions. However, data on exact numbers of water usage, energy usage and waste should be gathered and analysed. In addition, careful calculations should be made in order to assess if newer machines do indeed reduce climate impacts and GHG emissions compared to hand peeling.

Another example of balancing yield and financial feasibility was given in CS11, where cutting out the boneless parts of common bream is a form of processing that results in a very low yield (less than 10%) and costs a lot of time. Investigations are needed to identify a cost-effective handling of cyprinids, with offering a so-called ‘double price model’ for the fish (e.g. producing both smoked boneless product and mince), which in turn creates the conditions for a low price, large-scale product.

Both the shrimp peeling and the highly technical processing of fish may result in **side products** that could go to waste. Investigation into implementing technologies that specifically process side products and add value to them may create opportunities for a more sustainable product flow. Examples of how an initially low value product can still be marketed as a high value product can be found in the strategy to implement a sustainable blue economy[12], and in research as this is currently something of a hot topic (Abu-Ghosh et al., 2021). In this regard, CS20 processors sold most of the generated side-streams to a fishmeal/oil processor located nearby (<15 km). Another more innovative example could be found on a processor from CS23 that was involved in the development of a biodegradable plastic alternative called MarinaTex[13], which is created using fish scales and red algae. This is still in development but has 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 associated with a relatively high carbon footprint.

On the other hand, regarding **inorganic waste**, a processor from CS23 (cuttlefish), in an attempt to reduce the cost of waste disposal and the impact of the material on the environment, purchased a polystyrene compactor that will save the company up to £8,320 in waste disposal annually and produce a marketable co-product in the form of compacted polystyrene. The compacted polystyrene is sold as a co-product for recycling. This provides the potential for indirectly reducing processors’ GHG emissions, because the recycling of polystyrene could reduce the use of virgin plastics, which are often associated with a greater carbon footprint.

Transport is one of the activities in the PH value chain that has a large climate and GHG emissions impact (discussed in Chapter 4). A processor in CS23 gave an example of challenges and opportunities faced with sustainable transport. The processor stated that upgrading the fleet to electric vehicles was difficult because of the purchase cost and short range (distance per charge) of the vans they had chosen. The model the processor was looking to purchase (Ford E-Transit L3H2) has a maximum range of 315 km with a purchase cost of around €50,000. The processor believed these vans would each save around €200 per week (€10,400 annually) and, therefore, fall within the five-year return of investment (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. Additionally, CS20 has also carried out a study to assess the installation of electric or hybrid machinery on boats, but there is nothing on the market for small boats, and it would not be feasible since their range is approximately three hours, which is unsuitable for most journeys.

The manufacture of packaging uses a substantial array of fossil fuels, therefore has a large climate and GHG emissions impact. Stakeholders in both CS11 and CS23 are looking into solutions to reduce the impact packaging has on climate and GHG emissions. Carp

[12] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. COM/2021/240 final

[13] https://www.marinatex.co.uk/about-3

processors are looking into replacing single-use plastics but are faced with similar challenges as shrimp processers who are looking at using alternative packaging materials to reduce the amounts of plastic used. For the shrimp processors, finding suitable alternatives is challenging due to high costs, and for both carp and shrimp stakeholders, it is vital that there are packaging options that are re-usable. The latter aspect is enforced by market requirements.

In a Norwegian report from 2006 (SINTEF, 2006)[14], it was estimated that **energy** use for the processing of pelagic fish could be reduced by 45%. Reduction opportunities entailed optimisation of all processes, such as utilising the best lighting regimes (i.e. an industrial strategy), more effective process equipment and effective cooling and ventilation. Clearly, the scope for reducing the amount of energy used and many opportunities to do so exist. Stakeholders in the mussel processing industry (CS14), tuna canning industry (CS20), cuttlefish industry (CS23) and carp production industry (CS11) invest in their own renewable energy production, via either solar panels or photovoltaic cells. The fish feed producer in CS22 noted that they are actively making plans and implementing plans to invest in infrastructure in order to harness renewable energy sources into their local processing chains. However, in CS20, even though in some months energy self-consumption reaches 50%, in other months it does not exceed 5%.

Another strategy related to energy technology is **heat recovery**. In Poland, a relatively modern processing and freezing infrastructure has been designed, with efficient and energy-saving structures for fish meal/oil processors (CS1). One of the biggest freezing facilities uses a heat exchanger: during the freezing process, heat is released that was wasted and considered a cost of the freezing process before, but it is now used to heat administrative areas, such as offices, instead. In CS22, the fish feed producer was looking into **heat recovery systems**, improved steam boiler efficiency and drying operations. The seafood producer (CS22) mentioned specific improvements for their production chain. The most energy intensive processes for the seafood producer were thawing and refreezing steps. The stakeholder was looking into alternatives for thawing in water, such as **microwave and infrared thawing**, which are currently experimental and innovative techniques (see Annex 4 and 5). For **freezing**, the stakeholder was exploring both liquid nitrogen (cryogenic freezing) and mechanical freezing (see Annex 4 and 5), which evaporates water on the surface of the product. Although they are not emerging technologies, they are alternative conventional technologies.

5.2.2 Reduction of GHG emissions by industrial strategies

Some of the case studies presented stakeholders that apply technologically well managed processes. For example, the northern shrimp stakeholders in CS16 work with a processing workflow that is technically sound, except for a few technological hotspots, such as peeling and heating strategies, which are also GHG emission hotspots. However, many industrial management strategies, especially the large overarching strategies could still help this value chain. Key knowledge is needed to identify overarching strategies. The fish feed producer in CS22 has, to that end, substantially invested in sustainability monitoring, with sustainability reports and, as a result, has managed to identify key performance indicators (KPI) in order to build both high level and low-level industrial strategies. Thus, sustainability monitoring and collecting data on KPIs represent a transferable strategy

[14] SINTEF, 'Fremtidens Enøk-bedrift innan fiskeri'. SINTEF Energiforskning AS, 2006

building method that could be adapted by multiple stakeholders ranging from small enterprises to large multinationals in the PH value chain.

A wide implementation of **cleaner production** strategies has been observed in the tuna canning companies based in the Basque Country (CS20). This is in line with the reduced economic resources of this companies to invest in new technologies. As such, companies highlight that in this strategy, a significant amount of water, energy and side streams (skin, heads, frames, viscera, or fillet cut offs) (Arason et al., 2009) have been achieved with limited investment in other matters, such as tap flow reducers and dry cleaning of wastes. However, the applicability of this strategy is limited, and it is only significant if the company is out-dated.

Another example of an important high level industrial strategy indicated by stakeholders is **certification** of both raw products and final products. This strategy was emphasised by roundfish (CS9-10), carp processors (CS12), mussels (CS15), imported shrimp (CS19), tunas (CS20), feed (CS22) and seafood (CS22) producers. In CS16 on shrimp processors, it was mentioned that certification of caught shrimp is missing, and this may improve that value chain. Certification of raw materials and final fish products may improve sustainability throughout the value chain. Utilising MSC labelled fishery products avoids sourcing fish from unsustainable fisheries, while ASC labelled products promote sustainable aquaculture practices by increasing standards for quality and waste management. Certification of raw materials sourced from non-deforested areas or sustainable agriculture may improve sustainability of land-based raw materials in feed processing value chains.

Although **seasonality** of raw materials in PH value chains may represent a challenge or even may be detrimental, it can also present opportunity. The fish meal/oil (CS1) processing industry may improve its efficiency, caused by changing fishing patterns adapted to the season providing the highest yield (most oily). Although this would mean an inconsistent or interrupted flow of animal raw material to fish meal/oil processors, a dialogue is already ongoing on how to optimise processing species, meaning that species diversity over different seasons may provide the opportunity to have a constant raw material flow to the processor after all. On the contrary, in order to deal with the seasonality of raw materials, CS20 freezes the fish so it can be processed throughout the year and maintain productivity.

The northern shrimp processing CS (CS16) indicated that for, future reference, attention will have to be paid to ensure that the **centralisation of companies is avoided.** This is because more centralised and concentrated facilities may increase transportation distances thus negatively affecting GHG-emissions. Stakeholders may use economies of scale (fewer but larger shipments or processes), but do not always investigate if the strategy has positive environmental effects as well as economic ones. The concept of centralisation versus diversification should be investigated, as much of the knowledge is fragmented and dispersed over different fields of research and different sectors (e.g. the food sector as in general) (see Chapter 4). However, **short value chains** or local value chains definitely provide opportunities to reduce climate and GHG effects. Carp production (CS11) was simplified by producing the grains and manure necessary for feed production locally, as well as having the workforce and services necessary for the processing of raw materials in the vicinity. The feed producer in CS22 is also looking into what they call ‘integrated chains’, where raw materials are grown close to the processing plants (the feed production plant), thus potentially local to the feed customers: fish farmers. The recent evolution for aquaculture to move to land-based systems (RAS systems)[15] provides an opportunity to develop local short and integrated chains. Overall, the tuna canning industry (CS20) in the Basque country is quite short in terms of processing local tuna (*Thunnus alalunga*) since the canning companies are located less than 20 km from the main landing ports.

An alternative example of the value of short value chains is their contribution to reducing waste generation and therefore positive environmental impact. Interesting opportunities exist in initiatives on the Swedish market to minimise food losses. The 'Save the Food' initiative by the wholesaler Martin and Servera is a marketplace where producers can sell their products at lower prices if the best before date is imminent. This approach appears to work exceptionally well as most products sell out quickly.

As mentioned before, **transport** has a substantial impact on GHG emissions in the PH value chain. The fish feed producer in CS22 presented an interesting solution to minimise GHG emissions from transport. Fish feed goes out to larger farms via bulk ship transport, which has lower GHG emissions than truck transport. One large customer of fish feed receives feed from competing fish feed companies, which each send their own ships with feed deliveries. The feed producer in CS22 now collaborates with the competing feed company so their deliveries can arrive in a single shipment, thus saving a second independent shipment for each delivery. This low-level industrial strategy has a potentially significant impact and is a good example of how **collaboration** between stakeholders can potentially reduce climate and GHG effects.

5.2.3 Reduction of GHG emissions by an integrated approach of technology and strategy

The implementation of new and innovative technology or industrial strategies on their own can have a positive impact on GHG emissions and overall sustainability. Although individual specific changes in technology and/or industrial strategies are of value, the **integration** of both technology and industrial strategies may prove to be an even more powerful approach in the future. One of the best examples from the stakeholder consultations were incentives that focused on automation and data collection. Both automation and data collection represent mostly new and innovative technologies but only work properly when integrated with the correct strategies.

As was noted in CS22, regarding the technical aspects of PH value chain stakeholders, **automated** processing lines have the advantage of being able to continuously and consistently monitor efficient product processes. This helps to increase the rate of the production chain and has the potential to reduce waste generation and energy needs. It also allows for continuous and consistent **data collection**. The key here is continuous and consistent data, which is necessary for data analyses. The fish feed producer in CS22 noted that their current main focus is identifying GHG emission hotspots. These hotspots were identified in production, the transport of raw materials and the transport of the finalised product. The fish meal/oil processors in CS1 also focus on understanding their climate impact but remarked this is very challenging. Accordingly, time and money are invested in collecting data and running life cycle analyses to assess where in the process the GHG emissions hotspot is. Clearly, after finding the hotspot, further data gathering and analysis are necessary to understand the cause. In order to apply this kind of far-reaching analyses, the stakeholders are gaining expertise themselves and working together with third parties.

[15] Study on state-of-the-art scientific information on the impacts of aquaculture activities in Europe, 2022. CINEA. ISBN 978-92-95225-28-2, PDF HZ-07-22-082-EN-N, DOI 10.2926/929238

It is also important to note that when new strategies and technologies are implemented, **empirical data** is also collected and analysed to interpret whether the new technologies and industrial strategies have positive environmental impacts and do not only improve yields. A seafood processor (CS22) who implemented infrared and microwave thawing – emerging technologies with improved environmental qualities (see Annex 5) – were taken out of the production process because they decreased yields. Clearly, a decision was made that favoured financial ROI rather than the climate.

The carp processing stakeholders (CS11) are looking into increasing diversification of PH harvest chains to increase efficient processing of current side streams to **reduce waste**. These approaches should be studied carefully because reducing waste has great potential for reduction of GHG by kg product (if your waste is higher, the GHG by kg consumed product increases). But technology to process waste may also result in GHG emissions. A similar conclusion can be made about the shrimp peel produced in CS 16 and CS18. One positive aspect is that high value side products act as a financial incentive to increase the technology efficiency of the initial PH value chain. Again, one must be mindful that this may not reduce GHG emissions. The feed producer in CS22 remarked on the increased customer awareness about the climate impact of packaging and demanded less **packaging waste** from customers. This awareness resulted in both an integrated method with improved technologies and an adapted industrial strategy. Currently, bulk delivery and big bags (1 tonne) are often used, both of which are recyclable. In addition, recycled plastic bags are used or new plastic bags, but these are made of higher quality, purer grade plastic, which is easier to recycle. As customers demanded less waste, the feed company implemented strategies to collect and reuse the big bags and even collect plastic bag waste.

5.3 Gaps in knowledge, limitations and questions

While literature focusses mainly on technologies and industrial strategies as such, the stakeholders provided valuable insights into how technologies and industrial strategies are implemented, how they perform and what challenges stakeholders face. Still, many gaps in knowledge and limitations to that knowledge and its implementation remain.

Results from the literature remain difficult to interpret as it is often unknown how research results or test results translate to real-world applications. Similarly, it is not always clear from the literature whether emerging technologies indeed to reduce GHG emissions. Results and information from stakeholders are also difficult to interpret. However, in contrast to the literature, stakeholders can provide real-world working situations, challenges and solutions, but the data are lacking. The lack of numbers derives from two causes. First, in some cases, no one collected any numbers or did any measurements (i.e. numbers do not exist) and this presents a ‘physical’ **gap in knowledge**. Second, in some cases, the monitoring, measurements and data collection occurs, but it remains internal with the stakeholders (i.e. numbers do exist but are not shared). This represents a **limitation** of the PH sector. Especially significant is the differences on the quality and quantity of available data when comparing information obtained from the various case studies.

Both the ‘physical’ gap in knowledge as well as the limitation of data sharing comes down to the fact the PH sector is customer-driven. Thus, financial aspects are the major incentive and drives nearly all processes. The **financial priority** which may present many opportunities can also present a limiting factor. Financial competitiveness due to open markets often obstruct a good data sharing ‘ecology’. Still, many stakeholders have a heightened awareness of both the climate and GHG emissions impacts as well as the need for data sharing and collaboration. Sometimes, there is even the willingness to do so, yet the financial importance of the value chain is never forgotten. Many new ingredients for fishmeal/oil industry and fish feed industry still lack representative data for commercial scale production (CS1), and this represents a good example of the 'physical' gap in knowledge. Fish feed producers in both CS1 and CS22 are aware that collaboration between stakeholders to share internal knowledge and expertise, as well as with external third parties, such as scientific community, legal entities, economic bodies is needed. An example of the importance of sharing data comes from a stakeholder in CS23. When asked to list the top processes within their company that has the greatest impact on GHG/carbon emissions, the stakeholder listed, 1) ice and refrigeration, 2) diesel, and 3) water. In fact, it is the companies' use of polystyrene, diesel and cardboard that contribute the most to GHG emissions within the company's value chain. This example illustrates that internal knowledge, however much expertise there may be on a matter, may not always be correct, thus presenting a limitation of knowing but not sharing. Changing technologies and strategies based on internal knowledge may potentially lead to increased climate and GHG emission effects, while if the data are shared and new insights are gained, better technologies and strategies may be implemented.

One major challenge with data collection and sharing is the enormous **variability and specificity** of the many different cogs in the PH value chain. The extent of that variability alone deserves several focussed projects, and trying to research the PH value chain overall and trying to generalise strategies for this chain even more so. As suggested in CS22, a major start would be made if consistent and continuous comparable (as far as possible) data would be collected, and more important, if consistent and more comparable LCAs could be performed. Those would be the first steps to identifying major trends or comparable aspects within the PH value chain.

Apart from financial priorities that can be considered as the main driver for any decisions in the PH value chain, there is a need for large amounts of funding to future-proof the PH value chain or make it more climate resilient. The need for **large investments** is a clear message presented in both the literature and by the stakeholders. The stakeholders can generate part of that investment by cost reduction. Indeed, the stakeholder in CS16 and CS20 noted that there are many reasons to reduce the emissions associated with the PH value chain, the main driving factor is **cost reduction**. There was also a desire to reduce the environmental impact from the company in CS16, which was evident from the various initiatives taken by the stakeholder. However, without a cost incentive, there was little impetus for change. This was highlighted by the lack of emissions monitoring (an example of the 'physical' gap in knowledge).

Ultimately, structural improvements in the PH value chain related to reducing climate impacts and GHG emissions rely on innovations and changes with a **return on investment** (ROI) that is seen as acceptable. The stakeholder in CS23 gave a five-year ROI 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 to accessing **funding** are considered the most important limiting factor by the stakeholders in implementing structural improvements in systems to reduce GHG emissions. This is similar for the fish feed producer in CS22 where the financial incentive to reduce climate and GHG emission impacts comes from **investors** investing in the customers of the fish meal/oil processors who aim for more secure long-term investments. For this stakeholder, 'green' investments (i.e. investments that benefits our climate) are the drivers for technological innovation at the fish meal/oil companies. The importance of funding is illustrated in CS1. The Polish pelagic fleet used traditional methods of transport in boxes (25 kg, or 45 litres). More recently, they changed to transporting in 'big boxes' (containers). Currently, these big boxes are used infrequently 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. At the same time, Polish ship owners were modernising 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.

Stakeholders from many case studies are definitely willing to improve their climate and GHG emission impacts. However, one of the more clear-cut technical challenges that still remains is the lack of **infrastructure**. Stakeholders in CS1 pointed out that the best possibility to cope with climate effects and risks is the use alternative and renewable energy sources and improving energy efficiency, but the main barrier is available infrastructure. There is, however, a major challenge with public infrastructure not being available for using renewable energy. That is, cables and energy storage are not sufficient to support the processing industry where it is currently located. Again, this comes down to the need for large investments from both the PH value chain stakeholders themselves and interacting parties.

An important concept that is often not literally named but is present in almost every decision is **trade-off**. Thus, an important question that has to be asked is, 'how important are trade-off analyses to build strategies to future-proof the PH value chain?' Currently, trade-off analyses are often made concerning energy sources used in PH factories, namely where it is feasible to use conventional carbon-based fuels compared to the use of renewable energy (see CS1 for an example). Another example of a trade-off analysis, although perhaps beyond the scope of the current report, is reducing climate and GHG emissions by automation and data collection, and AI in the future, versus the gigantic amounts of energy and water these processes use. The data and computing power to solve energy crises versus it causing part of the energy crises will perhaps be one of the most important trade-off analyses in the future, and its difficulty may be being currently severely underestimated.

Sourcing **raw materials** for PH value chain stakeholders also presents an important trade-off analysis and a subsequent set of balancing exercises. For fish meal/oil stakeholders, sourcing raw material from trimmings is 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 the LCA. For fish oil, a promising replacement based on nutritional value is algae oil, which has been shown to contribute to higher GHG emissions, but it 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-offs in terms of higher GHG emissions of feed production and often dominates feed related GHGs of aquaculture species (Ziegler et al., 2022).

Although **regulation** can be a powerful tool, care must be taken that these allow change to happen in an integrated manner, does not only cover a specific aspect of the PH industry, but also when implemented does not negatively affect other aspects of the industry. Stakeholders in CS16 and CS22 both noted the importance of regulation as a driver for positive change in climate and GHG emission effect changes. However, if regulations are put in place, the regulation should be integrated or at least be in-tune with regulations that cover all aspects of the value chain: economic, social, health and safety, business competition and food safety. Legal impact analyses on all aspects of the PH value chain will be necessary for potential future environmental regulation to work constructively and in a targeted manner. By extension, the impact of environmental regulations aimed at the PH value chain may have a feedback effect on the fisheries and aquaculture production sectors, which themselves are in need of a certain measure of legal consolidation[16] (particularly aquaculture). One example of the importance of careful integration of regulations was given in CS23. Polystyrene production is the single largest contributor to the stakeholder's GHG emissions and provides an opportunity to reduce GHG emission by reusing polystyrene boxes. However, it was reported that during local food hygiene inspections (based on regulations) concerns were raised over the reuse of the polystyrene boxes. This means that where boxes were cleaned and reused as standard before, all boxes are now compacted for recycling, except in a few specific circumstances.

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6 CONCLUSIONS

6.1 Resilience of EU Postharvest value chains to climate change

6.1.1 Physical and financial resilience

Postharvest value chains in the EU are very diverse. This diversity is seen in the type of seafood product (e.g. whole, gutted, filleted), preservation (e.g. fresh, frozen, dried.), distribution channel and location of target markets.

Climate impacts are being felt by PH value chains within the EU. These are predominantly associated with changes in the availability of raw materials (i.e. fisheries products to be processed). These changes in availability can lead to inflation in processing costs (i.e. reduced landing volumes enhancing first sales prices), interruptions to production processes, further transport costs and the waste of perishable fish.

Particular processing activities within the PH value chain use relatively large amounts of natural resources and can have a high environmental impact. For example, filleting, battering, canning, smoking and mincing all use a high amount of fossil fuels and produce substantial GHG emissions.

The further development of EU seafood may enhance the physical and economic resilience of EU PH value chains, with calls for further ‘new’ species to be landed, including those of which climate change is now enhancing their abundance or distribution within EU waters (i.e. in the Mediterranean), or those that have not previously been part of the PH value chain (e.g. bream, squid, alien species,).

Self-sufficiency of the PH value chains within the EU may be supported by the processing industry utilising a higher diversity of products, including processed ‘waste’ and by-products from residual or side streams. This kind of valorisation enables the development of alternative value chains, protects SMEs against disruptions and may also mitigate impacts on value chains associated with stock loss.

6.1.2 Financial constraints and the reliability of seafood products

With changes in stock availability due to climate change effects, there have been flow-on effects leading to PH facilities being shifted closer to landing sites. Further understanding of the role of climate change on fisheries within the EU has also resulted in much more accountability and transparency in the development of GHG emissions within the EU PH value chains.

Although climate impact mitigating changes are apparent within the EU PH value chains, direct resource change is the main focus for stakeholders. This is firstly associated with overseas imports undercutting the costs of EU produced biomass. Reduced flexibility in producer pricing has also resulted in producers being unable to pass on further costs incurred during the fishing seasons. Lastly, the Russian war of aggression against Ukraine has raised the urgency in facilitating the energy transition and reducing the current reliance on fossil fuels.

6.1.3 Role of management in introduction of new species to the market

A range of commercial fisheries are developing in areas where they have not been found historically. This results in changes in the availability of commercial stocks, which may compensate for the likely loss of historically important stocks. However, to ensure the success in marketing new species, producers and retailers must be willing to introduce these species to their existing foodservice customers and must have substantial support from the HORECA sector.

Other management interventions that have appeared to be successful in supporting the introduction of new species to the market are vertical integration across the PH value chain, which takes harvesting into account as well. Vertical integration leads to more successful introductions of species and also enhances the economy of scale within the industry, resulting in larger buying power and a greater number of distribution channels and markets for sales and deliveries. Lastly, the use of joint ventures, which geographically diversify fisheries and processing plants, have been shown to decrease overall risks to businesses. This is owing to production losses associated with physical damage to production locations by storms and heat waves being mitigated: where damage occurs, businesses are able to utilise other parts to ensure processing is not interrupted.

6.2 Reducing GHG emissions by structural improvements in the PH value chains

6.2.1 Contribution by step in the value chain

Data on GHG emissions in the PH value chain are scarce. The main reason is that detailed data do not exist due to businesses not collecting it, and there is no EU mandate for it to be collected. In addition, stakeholders also classified this kind of data as sensitive, reducing their willingness to provide it for this project. Nevertheless, using a generic framework for assessing the climate impact of PH value chains, as well as utilising the information sourced from the literature and supplied by each CS, an assessment of GHG emissions for each step in each CS value chain was able to be made.

Case studies show significant GHG emissions in PH value chains induced by freezing/frozen storage, long-distance transport, emissions related to packaging material use, energy use in refrigerated retail shelves and indirectly through loss of product (i.e. wastage). However, a number of specific hotspots of GHG emissions were identified throughout PH value chains. These were primarily emissions associated with the development of packaging material used for processed products. For consumer plastic packaging, commonly used for chilled fresh seafood products (varying from typically 50 to 80 grams of plastic per kg of seafood), the contribution of the packaging is estimated at 0.15 to 0.24 kg CO_2-eq per kg packaged seafood. For canned products in glass or metal packaging, the impact of the package production and packaging process is relatively high (typically 0.6 kg CO_2-eq per kg product for pickled herring fillet in glass jars, and around 1 kg CO_2-eq per kg product for canned tuna in aluminium cans). Polystyrene boxes and cartons are often used in delivery to restaurants and supermarkets may add typically 0.1 kg CO_2-eq per kg product.

High GHG emissions were associated with the transport of goods. Importantly, the impact of international transport is substantial, with typical GHG emissions ranging from 0.2 kg CO_2-eq per kg product for 1,000 km in a large truck to 10 kg CO_2-eq per kg product for products that are air freighted.

Processing products also results in high GHG emissions. Processing associated with freezing on land results in high GHG emissions, typically leading to 0.05 kg CO_2-eq GHG per kg of fish. In addition, once a product is processed the energy used for the storage of the items (including ice flakes and refrigerated/frozen storage) can vary depending on the storage period, but this can be between <0.01 and 0.09 kg CO_2-eq per kg product.

There are also indirect GHG emissions associated with losses along the PH value chain, with product losses in the retail channel estimated at 7.5%. Importantly, all GHG emissions associated with the loss of product upstream in the value chain (i.e. before landing) are considered within the PH value chain. Therefore, this loss indirectly adds approximately 8% to all emissions associated with the product, including emissions involved in catching and PH operations.

6.2.2 Alternative distribution systems

Examples of innovation in supply chain organisation focused mainly on the importance of data in the design of supply chains. A concept that has been central in most innovations is 'industry 4.0', which is structured around automation and intelligent production. There are various technological innovations (e.g. the Internet of Things; Ubiquitous Manufacturing, Supply Chain Management, Big Data and Artificial Intelligence), which may improve the efficiency of supply chains. The main improvement is likely to be the optimisation of costs, time and GHG emissions of material flows. In the CSs in this study, these kinds of innovations have not been observed.

Whether innovations can be applied to the PH value chains in the EU depends on the current organisation of logistics. Currently, most logistics companies dedicate their business models to transporting a range of products other than seafood products. In addition, supermarket chains – where the majority of seafood products are sold – tend to combine multiple product types in transportation to their stores. They often have grouping platforms where all products pass and are reshuffled to be sent off to their final destinations. This is efficient from a distribution perspective, but inefficient from a seafood supply chains perspective. For example, seafood products may be transported more efficiently from a GHG perspective, but to the detriment of the overall GHG emissions of these logistic companies (i.e. the difference between local optimum and global optimum).

With respect to the development of e-commerce/online shopping, this will most likely increase GHG emissions related to buying seafoods. Several conditions should be met simultaneously for GHG emissions to be reduced:

- Transport by car to physical shops should be minimised, with trips only undertaken for 'full' shopping activities;
- The concept of utilising online shopping is broadly adopted (i.e. not just for seafood), facilitating efficient distribution; and
- The use of additional packaging material is minimised.

6.2.3 Limitations for structural improvements

The hotspots 'packaging material use', 'high-emission transport modalities' and 'long-term frozen storage' have strong commercial reasons for being high in GHG emissions. These all contribute to better serving the market demand for seafood products, as well as extending products' refrigerated shelf life. In the current system, where the effect of climate on the PH value chain is not central to business models, these solutions are the most cost-effective economically.

The option of reducing transportation-related emissions is hindered by culinary habits. Accessing seafood options that meet these habits is enshrined in local culture, and ease of access has been detrimental to the development of localised supply chains.

6.3 Reducing GHG emissions by technical means

6.3.1 Technological solutions

Literature exists for almost the entire range of technologies and industrial strategies used and applied in the PH value chain. However, literature on each of the specific technologies and strategies is often relatively limited, indicating that further research and reporting is necessary. Stakeholders engaged in the CSs provided valuable insights into how technologies and industrial strategies are implemented, how these perform and what challenges the stakeholders face. There is a vast amount of technical and strategic expertise among individual stakeholders, but this expertise is often considered the intellectual property of the stakeholders and so reports on this knowledge are almost non-existent.

Changes in industrial strategies may lead to reduced GHG emissions. This includes cleaner production strategies, the certification of raw materials, seasonal processing strategies, short value chains and collaborative transport strategies. Importantly, the implementation of new technologies is often combined with new strategies to ensure the most efficient application of the new technology. Automation and subsequent consistent data collection is one of the main examples of technology and strategy working as an integrated approach, and this will become a powerful tool in the future.

6.3.2 Obstacles and hindrances

In PH companies, customer service and business profitability are prioritised, which translates to a reduction of costs and a need for financial investment. Choices in implementing different or innovative technologies or industrial strategies to reduce GHG emissions or resource use are based on whether they are financially attractive and functionally feasible. This does not mean that stakeholders see GHG emission reductions as unimportant; rather, it means that it is of lower priority.

Financial investments in innovative and future-proof technologies and strategies are usually substantial. Therefore, for economic entities, such as the companies involved in the PH value chain, structural improvements related to reducing climate impacts and GHG emissions rely on innovations and changes with acceptable returns on investment. In some companies, the funds to invest in new technologies and industrial strategies and their associated infrastructure are unavailable. Comparatively, in some companies, there is not enough incentive to make the needed investments. This can be because of the risks that may arise from new technologies or strategies, for example. If the current system works, or if new technology comes with an inherent risk, or if it has not been proven to function more effectively than the ‘older’ technology, then there is little impetus for companies to change.

There generally is a willingness to convert to sustainable energy sources, such as solar, wind, hydropower or geothermal energy. One issue that arises is the lack of available public infrastructure at the locations where these other energy sources could be implemented. The grid is insufficient to support the processing industry. Large investments from both external sources and within the PH value chain will be necessary to overcome these challenges.

Increasing knowledge, knowledge sharing and awareness of climate impacts, financial resilience, production and consumption is needed to future-proof the PH value chain. Collection of consistent and continuous comparable data, and consistent and more comparable LCAs would be the first steps to identify major trends or comparable aspects within the PH value chain in order to implement future-proof technologies and industrial strategies.

7 RECOMMENDATIONS

Enhance resource use, emission and waste production data collection
Further monitoring is needed on the use of resources, development of GHG emissions and production of waste within the PH industry. Such data is needed to support the development of sustainable technologies or strategies to ensure companies are resilient to climate change impacts. Such data is lacking, as the analysis and implementation of sustainable technologies or strategies are not a priority for most stakeholders.

Support needed to develop monitoring systems
Monitoring systems to collect relevant industry data are available (e.g., EMAS, Eco-Management and Audit Scheme), but would require setting up costly monitoring throughout all the steps in the processing chain. Further support from EU funding sources (e.g., EMFAF) may help to support such monitoring practices, including examining the extent to which data sources could be linked, and whether an overarching system is needed to collect and combine available and new data.

Further understanding of company's environmental vulnerability
There is still little understanding of PH companies' emissions hotspots and inherent resilience to changes in global climate. Within further monitoring, identification of GHG hotspots should then be followed with a detailed and careful trade-off analysis to determine the correct approach for utilising a technological or industrial strategy solution.

Emphasis in the future will be to improve the efficiency of currently used equipment and the efficacy of currently used industrial strategies in order to gain positive GHG-emission results, without the loss of quality and value of the produced postharvest products.

Support for infrastructure development to facilitate use of renewable energy
A willingness within the PH industry to transition towards the use of renewable energy is not matched by available regional infrastructure (e.g., electricity net providers are overloaded), with little funding available to future-proof companies' infrastructure, including the use of green technologies.

Technical studies are required to increase the capacity and resilience of electricity net providers in certain EU areas. Investment schemes to (co-)fund building the necessary infrastructure for PH enterprises to gain access to green energy, as well as build business-owned facilities that can house green energy technologies, will be needed. Increased use of renewable energy, as well as more sustainable infrastructure would increase the resilience of the PH sector and reduce GHG emissions.

Reduction, reutilization and recycling of resources
Reductions in the PH industry's carbon footprint could be achieved by reducing, reutilising and recycling resources (e.g., processing, cooling and transporting activities). However, the influence of small medium sized enterprises (SMEs) to decarbonize the PH chain entirely or partly, and the financial solvability of these SMEs to realize climate neutral production is limited.

Financial instruments (e.g., EMFAF) could help to accelerate the transition of the EU postharvest chain to become more resilient to climate driven events and to decarbonize. Such financial support will be vital as the majority of EU PH seafood chain stakeholders are SMEs. If this majority are not able to invest into decarbonizing the activities within the supply chain by small buying power or lacking solvability (enhanced by the energy crisis due to Russian war of aggression against Ukraine) the sustainability of the entire EU PH seafood chain is reduced.

GHG emission hotspot reduction
Hotspots of GHG emissions in seafood PH chains (like frozen storage, packaging material use, long-distance transportation, air transportation, cooling and food losses in retail) are largely induced by retailer/consumer preferences for fresh products and year-round availability.

Reducing GHG emissions in PH chains requires either solutions that can prevent quality and shelf-life loss on long-lasting transport (e.g. sea transport instead of air transport) or discouraging demand for species from the remote supply. The quickest route to reduce GHG emissions is likely to be in the identification of potential solutions for prevention of quality and shelf-life loss.

EPS boxes: alternatives or recycling
Perishables like seafood are delivered in EPS boxes: Expanded Polystyrene boxes, also known as styrofoam boxes or polystyrene boxes. The use of this material adds substantial extra GHG emissions.

Recycling of EPS boxes would be required to reduce emissions related to this packaging material; this is not yet in place. Otherwise, alternative packaging materials with lower GHG emissions should be used.

Knowledge exchange within PH sector
There is still little knowledge exchange within the PH sector on how best to reduce GHG-emissions associated with this industry.

Strategies to exchange knowledge about GHG-emissions within sub-streams and across the postharvest sector need to be (further) developed. Such strategies will be necessary in order for the PH stakeholders to help themselves and each other to improve GHG-emission on the long term. Moreover, this knowledge exchange will help to integrate technologies with industrial strategies.

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ANNEXES

1. Case Study Summary Table
2. Case Study Reports
3. Reference Questionnaire
4. Technology sheets
5. Summary of GHG emissions and cost impacts of technologies and industrial strategies on the PH value chain

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