LIFE CYCLE ASSESSMENT OF WILD ALASKA POLLOCK
FINAL ISO LCA REPORT

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For:

Genuine Alaska Pollock Producers

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- GAPP_WAP LCA_Data Survey_Shore-based and Mothership processors_V1_Quantis.xlsx
- Life Cycle Assessment Explanatory Notes Catching vessels_V1.docx
- Life Cycle Assessment Explanatory Notes Catcher-Processors_V1.docx
- Life Cycle Assessment Explanatory Notes Shore-based and Mothership processors_V1.docx
- GAPP_WAP LCA_Data Survey_Catching vessels for Shore-based and MS_V2_Quantis.xlsx
- GAPP_WAP LCA_Data Survey_Catcher-Processors_V2_Quantis.xlsx
- GAPP_WAP LCA_Data Survey_Shore-based and Mothership processors_V2_Quantis.xlsx
- Life Cycle Assessment Explanatory Notes Catching vessels_V2.docx

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ABBREVIATIONS AND ACRONYMS

CO_2	Carbon Dioxide
CPUE	Catch per unit effort
EI	Ecoinvent
EOL	End of Life
eq	equivalents
GAPP	Genuine Alaska Pollock Producers
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram = 1,000 grams (g) = 2.2 pounds (lbs)
km	Kilometer = 1000 meters (m)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
m^2	Square meter
m^3	Cubic meter
MJ	Megajoule = 1,000,000 joules, (948 Btu)
MSW	Municipal solid waste
PM	Particulate Matter
US	United States
USEPA	United States Environmental Protection Agency

1 Introduction

Heightened concern around the environmental and social sustainability of society's consumption habits has focused attention on understanding and proactively managing the potential environmental and societal consequences of production and consumption of products and services. Nearly all major product producers now consider environmental and social impacts as key decision points in product design, including but not limited to material selection, product manufacturing, distribution, use and disposal, and sustainability is a recognized point of differentiation in many industries, including food and agriculture.

The Association of Genuine Alaska Pollock Producers (GAPP), the organization for the world's largest certified sustainable fishery, has commissioned Quantis to use life cycle assessment[1] (LCA) methodologies and practices to measure and document the estimated environmental impacts of catching, processing, and delivering Wild Alaska Pollock products to primary customers.

Among other uses, LCA can be used to identify opportunities to improve the environmental performance of products, inform decision-making, and support marketing, communications, and educational efforts. The importance of the life cycle view in sustainability decision-making is sufficiently strong that over the past several decades it has become the principal approach to evaluate a broad range of environmental problems, identify social risks and to help make decisions within the complex arena of socio-environmental sustainability.

It is the intention for this LCA to conform to ISO 14040 and 14044 standards (ISO 2006a; ISO 2006b) for public disclosure of comparative statements. In addition to alignment with ISO, the study will align with recommendations from the Publicly Available Standards (PAS) 2050-2 for seafood and other aquatic food products (BSI, 2012) with regard to scope and data boundary, time period for data collection, and other relative general instructions for LCAs in fisheries. The study was peer-reviewed as a requirement of ISO LCA standards.

2 Goal of the study

This section describes the goal of the study, intended audience and declarations.

[1] LCA is an internationally recognized approach that evaluates the relative potential environmental and human health impacts of products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, manufacturing, use, and end-of-life treatment.

2.1 Objectives

Key objectives of the initiative are to:

1. Provide internal knowledge to GAPP as to the industry-average life cycle environmental impacts of Wild Alaska Pollock products (including fillet, surimi, roe, fish oil, and fishmeal, see Section 3.1 for more details) across several key impact categories, such as Climate change, Land use, and Water consumption;
2. Enable GAPP members to provide their customers with credible production-weighted average (see Section 3.3.1 for more details) environmental impact information on five Wild Alaska Pollock products (and average of frozen product including fillet, surimi and roe) that adheres to leading LCA standards (ISO 14040 and ISO 14044; PAS2050-2);
3. Identify improvement opportunities to further reduce environmental impacts of the Wild Alaska Pollock fishing, processing, and delivery;
4. Gain a deeper understanding of where Wild Alaska Pollock products fall on the animal protein continuum in terms of environmental impacts, without making competitive or derogatory claims about other forms of seafood or land-based animal protein.

The specific goals of this study are as follows:

1. Carry out an ISO 14040/14044 compliant LCA of products derived from Wild Alaska Pollock produced by GAPP's members;
2. Understand the contributions that production of Wild Alaska Pollock products make to resource depletion (e.g., energy use, water use, etc.) and environmental concerns (e.g., climate change). Identify environmental hotspots (top contributors of environmental impacts) of Wild Alaska Pollock products and identify potential improvement opportunities. Identify opportunities for further environmental impact reduction of Wild Alaska Pollock fishing, processing & delivery.
3. Explore key data points, uncertainties and methodological choices that might influence results;
4. Enable GAPP to communicate Wild Alaska Pollock product impacts credibly with internal and external stakeholders, via use of leading LCA standards and practices;
5. Identify how to best add this information to Wild Alaska Pollock's sustainability story, without disparaging other sea and land protein sources.

2.2 Intended audiences

This project report is intended to provide the estimated contributions to resource depletion and environmental concerns of Wild Alaska Pollock products in a clear and useful manner, in order to inform GAPP's communication of environmental performance to internal and external audiences such as customers and suppliers of GAPP members, members of the media, policymakers, and consumers. Communication options could include meetings with customers, marketing materials, and web tools, among others. The level and quality of support for the conclusions has been evaluated during the critical review to ensure that the results are appropriate to support a public disclosure of the LCA findings.

2.3 Disclosures and declarations

GAPP seeks to evaluate the environmental performance of Wild Alaska Pollock products. The project conforms to the ISO 14040 and 14044 standards, including a critical review by a panel of independent experts.

It is the intention for this LCA to conform to ISO 14040 and 14044 standards (ISO 2006a; ISO 2006b) for public disclosure of comparative statements. In addition to alignment with ISO, the study will align with recommendations from the Publicly Available Standards (PAS) 2050-2 for seafood products (BSI, 2012) with regard to scope and data boundary, time period for data collection, and other guidance for conducting LCA related to fisheries and seafood products. The study was peer-reviewed as a requirement of ISO LCA standards.

Because the results of this study apply only to particular products (five Wild Alaska Pollock products produced by GAPP members, see Section 3.1), the results of this study are not expected to negatively affect any external interested parties. The results of this study will be made public and may be used by GAPP or external parties to compare with other products. If the results of this study are used to compare with the potential impacts of other products, care must be taken to interpret the results in light of potential differences in scope (e.g., system boundary, raw products versus consumer-ready products) and methodology.

3 Scope of the study

3.1 General description of the products studied

This section describes the scope of the assessment. It includes a description of the product functions and product systems, the system boundaries, data sources, and methodological framework. This section also outlines the requirements for data quality as well as review of the analysis. Additional, specific data pertaining to each system can be found in Section 3.2. The entire data inventory is included in Appendix D to the full report.

GAPP wishes to evaluate the potential environmental impacts of weighted industry average Wild Alaska Pollock products, taking into account:

- Wild Alaska Pollock produced in two fishery locations: Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA);

Figure 1. Fishery locations of Wild Alaska Pollock

- Wild Alaska Pollock products produced by catching and three processing methods: Catcher-processors, catcher vessels delivering to Mothership processors, and catcher vessels delivering to Shore-based processors;
- Five types of key Wild Alaska Pollock products: fillet, surimi, roe, fish oil, and fishmeal.

The goal of this LCA is to cover the entirety of the U.S. Alaska Pollock fishery. GOA covers 11.4% of total catching volume (in which only Shore-based processors operate). In this study, all responses are based on BSAI data and the results are extrapolated to represent the entire production of BSAI and GOA. There are several factors that would influence the relative impacts of GOA and BSAI fisheries including the following: 1) Catching vessels in the GOA tend to have a shorter travel distance especially for the second half of the year, 2) The vast majority of GOA processing uses almost 100% hydropower, and 3) Relative catch per unit effort (CPUE) may be somewhat higher in the Gulf of Alaska. Depending on the relative magnitude of these influences, there could be some over- or underestimation by using BSAI to represent GOA.

To review, the quota setting process in the Bering Sea is as follows:

- From the initial quota, 10% is set aside as Community Development Quota (CDQ). This CDQ is apportioned to regional associations of rural communities in Western Alaska. These associations either partner with a company in the Catcher-processor sector that catches and processes the product, or in the case of one association, owns their own Catcher-processor. In our model, the catch of this quota was apportioned to the appropriate participant in the Catcher-processor sector.
- A small percentage of the initial quota is also set aside to account for bycatch in fisheries other than the Directed Alaska Pollock fishery. After these deductions from the initial quota, the Directed Alaska Pollock Fishery quota is apportioned to the following distinct sectors:
    - Shore-based sector – 50% of the directed fishery quota is apportioned to 71 vessels delivering to processing plants on shore.
    - Catcher-processor sector – 40% of the directed fishery quota is apportioned to vessels that both catch and process that catch into primary products.
    - Mothership sector – 10% of the directed fishery quota is apportioned to 15 vessels that deliver their catch to Mothership processors.
- Overall, BSAI is 88.6% of the total catching volume of Wild Pollock Alaska and GOA covers 11.4%. The overall harvest information is shown in Table 1 below.

When factoring in CDQ harvests by Catcher-processors, the Catcher-processors harvested 46% of the total catch in the Bering Sea from 2016 – 2018. The Shore-based sector accounted for 45% of the catch and the Mothership processors 9%.

Table 1. Harvest information

Fishery location	Sector: Catching & Processing method	Fleet	Number of vessels	Sector's share of total catching volume for location
Bering Sea /Aleutian Islands (BSAI)	Catcher-processors		14	46%
	Mothership processors		3	9%
	Shore-based processors		6	45%
	Catching vessels	To Motherships	15	N/A
		To Shore-based	71	N/A
Gulf of Alaska (GOA)	Shore-based processors	Less than 60 feet	5-7	No data
		Greater than or equal to 60 feet	24	No data
	Catching vessels	Less than 60 feet	8-11	No data
		Greater than or equal to 60 feet	41-45	No data

Based on the guidance of PAS 2050-2, an assessment period of three years is used to take into account biological and environmental variability (BSI, 2012). This study evaluates activities over the three-year period spanning Jan 1, 2016 to Dec 31, 2018. For some members, 2019 data were still being finalized during the data collection phase of this project, and therefore, for data consistency 2019 data are excluded from this study. Results are provided in alignment with the functional units (see Section 3.3.1).

Table 2 presents the combined three-year production totals for 2016, 2017 and 2018 for each of the products and fishery locations.

Table 2. Combined three-year production totals for years 2016-2018 by location, and Wild Alaska Product type

Wild Alaska Pollock product	Total production (MT)	
	Bering Sea /Aleutian Islands (BSAI)	Gulf of Alaska (GOA)
Fillet	485,867	39,840
Surimi	584,076	33,781
Roe	53,316	4,010
Fish oil	80,155	1,434
Fishmeal	192,613	2,498
Head & Gutted	73,775	70,052
Minced	80,996	3,674
Milt	2,934	1,055
Stomach	5,688	39
Bones	29,832	0
Whole fish	1,241	24,381
Belly flap	11	0
Other retained products	31	104

3.2 Data collection and data representativeness

The process to develop the inventory started with the items proposed within PAS 2050-2, which are specific to evaluating potential GHG impacts. Further consideration was given to any supplementary inventory data needed in order to represent all Catching and processing activities, with emphasis on activities that might drive other indicators including those related to ecosystem quality and human health. To identify a more complete set of inventory data, GAPP member companies were consulted and asked to provide input. The external review panel was also consulted to ensure a balance of completeness of inventory and response rate from the surveys.

Data surveys (version 1) were sent by GAPP to all GAPP members, who were pre-notified about the goal of this study in December 2019. However, the initial response was low. To help motivate GAPP members to participate in data collection and to obtain a higher response rate, a simplified data collection file (version 2) was prepared to focus on the expected impact drivers including energy and important consumables. This simplification solution was based on input from the Expert Review Panel Chair, Dr. Tyedmers. The simplified data collection files were sent out in May 2020. Please see associated files for the surveys. Where data was not provided by a GAPP member, the production data from the other members were used to estimate activity for the non-respondent activity. The responses from catchers are used to calculate potential catching impact per kg Wild Alaska Pollock product, and responses from each type of processing are used to calculate the potential impact per kg Wild Alaska Pollock product caused by each type of processing. See Section 4.2.5 for more details.

The response rate is considered in relation to the combined three-year total production volume for years 2016-2018 for each location and for each life cycle stage. The response rate is used to assess the data representativeness and is documented in Table 3. The results calculated from the responses have been used to represent the impact caused by the activities for each sector. The percentage of responses to GAPP total catching volume is used as the response rate and/or data coverage rate in this study.

Table 3. Data representativeness

Fishery location	Life cycle stages	Sector	Catching mass for years 2016-2018 represented in responses (MT)	% of GAPP total catching volume for years 2016-2018 (used as response rate/data coverage rate in this study)
Bering Sea /Aleutian Islands (BSAI)	Catching	Catching vessels to Shore-based processors (*n = 71*)	235,633	11%
		Catching vessels to Mothership processors (*n = 15*)	35,215	10%
	Processing	Catcher-processors (*n = 14*)	1,442,767	79%
		Shore-based processors (*n = 6*)	929,494	54%
		Mothership processors (*n = 3*)	121,330	34%

3.3 Comparative basis

3.3.1 Functions and functional unit

Life cycle assessment relies on a "functional unit" (FU) for comparison of alternative products that may substitute each other in fulfilling a certain function for the user or consumer. The FU describes this function in quantitative terms and serves as an anchor point for the comparison, ensuring that the compared alternatives do indeed fulfill the same function. It is therefore critical that this parameter is clearly defined and measurable. The functional units for this study are:

1) 1 kg of Wild Alaska Pollock fillet, distributed to first-tier customers;

2) 1 kg of Wild Alaska Pollock surimi, distributed to first-tier customers;

3) 1 kg of Wild Alaska Pollock roe, distributed to first-tier customers;

4) 1 kg of average frozen Wild Alaska Pollock product (including fillet, surimi and roe) distributed to first-tier customers.

5) 1 kg of Wild Alaska Pollock fish oil, distributed to first-tier customers;

6) 1 kg of Wild Alaska Pollock fish meal, distributed to first-tier customers;

For each group, we consider three first-tier destinations: East coast US, Asia, and Europe. We provide the results for the three destinations and six functional units.

The results of this study are general for the entire fishery and not specific to any one sector within this fishery.

Functional unit number 4 represents a weighted average product based on the production weight of the three key frozen Wild Alaska Pollock products (fillet, surimi, and roe) and based on the relative contribution of each Catching and processing method. From there, distribution to one of three first-tier customers is included, resulting in three final results.

3.3.2 Reference flows

To fulfill the functional unit, different quantities and types of material are required for Wild Alaska Pollock products. The lists of inputs that provide the functional unit are identified as reference flows. These reference flows are provided in Appendix D alongside the life cycle inventory datasets to which they are mapped.

3.4 System boundaries

The system boundaries identify the life cycle stages, processes, and flows considered in the LCA and should include all activities relevant to attaining the above-mentioned study objectives. The following paragraphs present a general description of the system as well as temporal and geographical boundaries of this study.

3.4.1 General system description

This study evaluates the cradle-to-gate life cycle of Wild Alaska Pollock products (including the catching, processing, and packaging) in addition to distribution to a first-tier business customer, as depicted in Figure 2. An effort is made to define the system boundary and collect data on all activities outlined as key in the PAS 2050-2 standard (BSI, 2012). Fillet, surimi, and roe are considered as Wild Alaska Pollock frozen products.

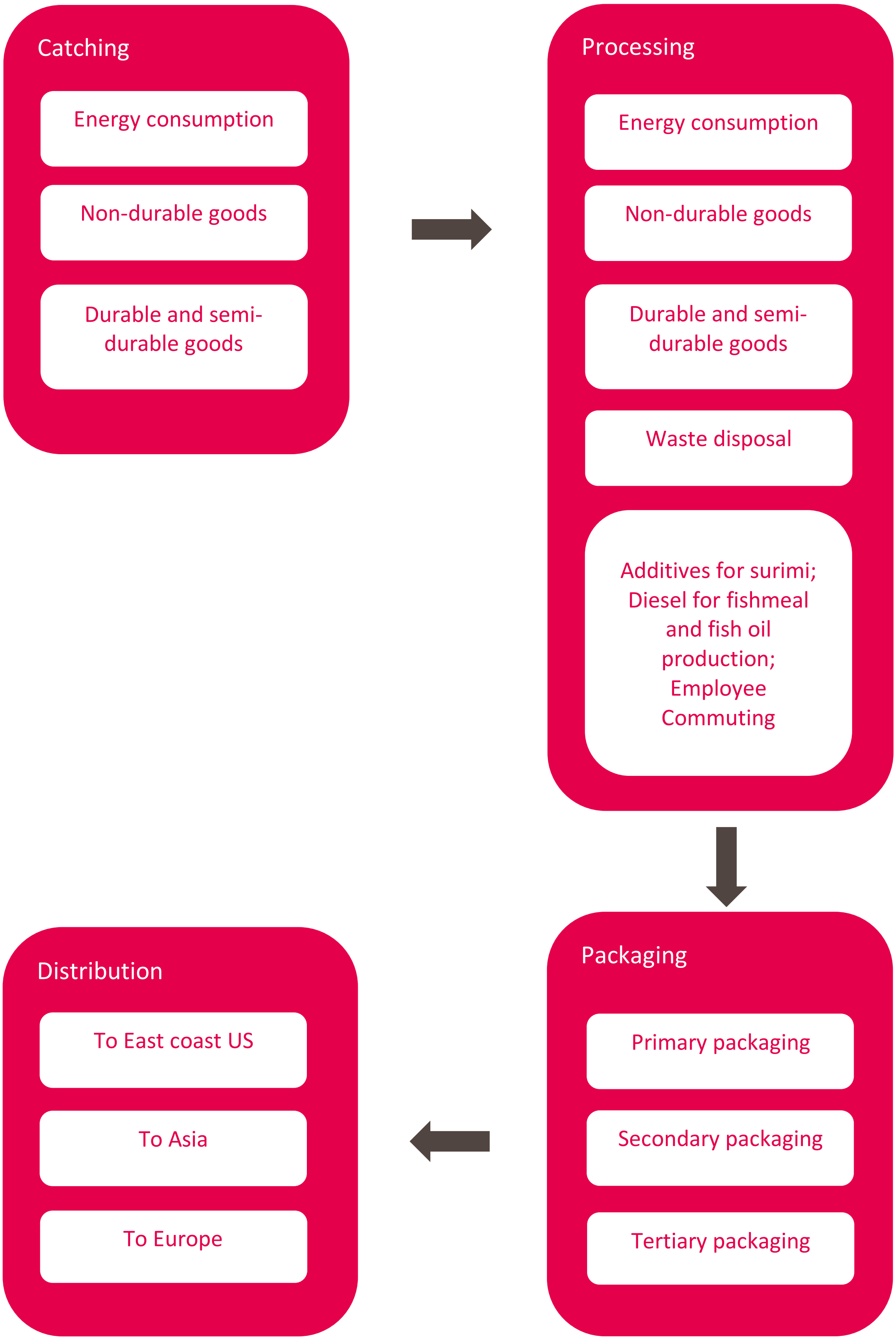


Figure 2. System boundary of Wild Alaska Pollock products evaluated in this study

As is generally done in LCA, within the above shown steps the assessment considers all identifiable "upstream" activities to provide as comprehensive a view as possible of the product's cradle-to-gate life cycle. For example, when considering the environmental impact of transportation, not only are the emissions of the truck or ship considered, but also included are the impacts of additional processes and inputs needed to produce the fuel and the vehicle. In this way, the production chains of all inputs are traced back to the original extraction of raw materials. Per PAS 2050-2 (BSI, 2012) no capital goods (e.g., infrastructure, buildings) of the reporting companies is included. However, capital goods for all material inputs are included in the background life cycle inventory data. Employee commuting from Seattle to Dutch Harbor is also included in this study; however, any commuting that occurs prior to employee arrival in Seattle is not included.

Catching includes:

- Energy consumption
  - Diesel fuel
  - Purchased electricity, 100% diesel based on the regional information
  - Fuel for trucks, if any (e.g., for transport)
  - etc.
- Non-durable goods
  - Refrigerants, including freon, CO_2, ammonia, others
  - Hydraulic fluid
  - Purchased oil or other lubricants
  - Cleaning agents
  - Anti-fouling agents
  - Paint
  - Heated storage (not at Shore-based processors)
  - etc.
- Durable and semi-durable goods
  - Nets
  - Filters
  - Chains
  - Cables
  - Trawl/doors
  - Other steel products
  - Rope/twine
  - Electrical wire
  - Third wire
  - Batteries
  - etc.
- Wastes
  - Solid waste delivered to landfill
  - Waste burned at sea
  - Waste oil delivered to recycling
  - Other waste delivered to recycling
  - etc.

Processing includes:

- Energy consumption
    - Diesel
    - Natural gas
    - LPG
    - Gasoline
    - Purchased electricity
    - etc.
- Non-durable goods
    - Refrigerants, including freon, CO_2, ammonia, others
    - Hydraulic fluid
    - Purchased oil or other lubricants
    - Cleaning agents
    - Glues and other adhesives
    - Adhesive tapes
    - Anti-fouling agents
    - Paint
    - Lubricating oil
    - Fresh water not produced from desalination of sea water
    - etc.
- Durable and semi-durable goods
    - PVC pipe
    - Wood other than wood used in pallets or other packaging
    - Chain and cables
    - Rope/twine
    - Electrical wire
    - Batteries
    - etc.
- Waste generation
    - Waste delivered to landfill
    - Waste delivered to incineration
    - Waste burned at sea
    - Waste recycled
    - Fish waste discharged to sea
    - etc.
- Additives to surimi
    - Sorbitol
    - Sugar
    - Sodium tripolyphosphate
    - Tetrasodium pyrophosphate
- Employee commuting

Any purchased electricity is applied as 100% diesel-sourced, based on regional information.

The Packaging stage considers only materials (and upstream production of the materials) since any assembly of packaging and packing of Wild Alaska Pollock products is mainly done manually. Information taken into consideration is listed below:

- Materials for packaging products together (e.g., box assembly that contains multiple packed items for transport)
- Amount of packaging per kg of specific product (e.g., materials required to pack 1 kg of fillet product)
- Transport of packaging delivery
- Recycled content of packaging materials
- Loss rate during packaging activities
- Lifespan if the packaging is reusable

The Distribution stage includes only the activities from processors to one of three first-tier business customers. The main locations of the first-tier business customers are listed in Figure 2. Information taken into consideration is listed below:

- Transport mode (e.g., ship, truck), all reefer in this study
- Transport distance and mass for each product to each destination

The three first-tier business customer locations chosen for the distribution boundary cumulatively represent the majority of Wild Alaska Pollock product distribution.

3.4.2 Temporal and geographic boundaries

This LCA aims to be representative of Wild Alaska Pollock products produced in BSAI and GOA and sold to Asia, North America and Europe at the time the study is conducted (2019). As described in Section 3.1, the primary data collection to support this work represents the period from January 1, 2016 to December 31, 2018. Data and assumptions are intended to reflect current equipment, processes, and market conditions. It should be noted, however, that some processes within the system boundaries might take place anywhere or anytime. For example, the processes associated with the supply chain and with waste management can take place in Asia, North America or elsewhere in the world. In addition, certain processes may generate emissions over a longer period of time than the reference period. This applies to landfilling, which causes emissions (biogas and leachate) over a period of time whose length (several decades to over a century/millennium) depends on the design and operation parameters of the burial cells and how the emissions are modeled in the environment.

3.4.3 Cut-off criteria

Processes may be excluded if their contributions to the total system's environmental impact are less than 1%. All product components and production processes are included when the necessary information is readily available, or a reasonable estimate can be made. To help us understand which are the most important processes and activities (i.e., >1% of impact), we have carried out a data quality assessment focusing on Climate change impact (see 4.1.2).

The following processes have been excluded from the study due to lack of reliable data and an expected contribution lower than the cut-off criteria. These exclusions are also recommended in PAS2050-2 (BSI, 2012).

- Production and maintenance of capital goods, including buildings, offices, vessels, tractors, fork-lift truck, machinery and other equipment, etc.;
- Production and maintenance of vehicles and aircraft used for transportation;

- Production and maintenance of harbors, roads, pavement and other floor coverings;
- Employee commuting prior to arrival in the Seattle area (as mentioned above, employee commuting between Seattle and Dutch Harbor is included in the study).
- Cold storage in Dutch Harbor prior to shipment is not included in this study, since it tends to be a minor contributor. The 2012 study showed this was only 0.3% of impact (AS SBC report, 2017).

Moreover, the following processes have been excluded from the system boundaries, in conformity to usual practices in attributional LCA: labor, commuting of workers from other states, and administrative work.

It should be noted that the capital equipment and infrastructure available in the *ecoinvent* database (v3.4) is included in the background data for this study in order to be as comprehensive as possible.

4 Approach

4.1 Life cycle inventory

The quality of LCA results depends on the quality of data used in the evaluation. Every effort has been made to implement the most credible and representative information available.

4.1.1 Data sources, assumptions and extrapolation

4.1.1.1 Primary and secondary data

Life cycle inventory (LCI) data collection mainly concerns the materials used, the energy consumed, and the wastes and emissions generated by each process included in the system boundaries. Primary data were collected directly from GAPP's member companies for the materials and energy consumption, primary and secondary packaging materials and weights, as well as data related to transportation distances, modes, and efficiency. These primary data were collected via a survey sent to GAPP member companies in the winter of 2019. See associated files starting with "GAPP_WAP LCA_Data Survey" for all data surveys.

Certain companies could only provide incomplete data for non-durable goods, durable goods, waste, and/or refrigerant. In these cases, complete data from companies who operate the same type of vessels were used in their place, assuming the same consumption per unit production.

The *ecoinvent* database v3.4 using the cut-off by classification approach (SCLCI, 2017) is prioritized as the default source of background data. Some of these *ecoinvent* datasets may be adapted to improve water balances and enable them to be compatible with the AWARE impact assessment method for estimating water availability impacts (WULCA). *Ecoinvent* 3.6

(SCLCI, 2019) is used in addition to *ecoinvent* 3.4 (AWARE adapted, Quantis modified) where inventory data are only available in the later update.

Ecoinvent is recognized as one of the most complete background LCI databases available, from quantitative (number of included processes) and qualitative (quality of the validation processes, data completeness, etc.) perspectives. Historically focused on European production activities, it has reached a global coverage of thousands of commodities and industrial processes. It is believed that the credibility and transparency of this database make it a preferable option for representing Asian and North and South American conditions relative to other options available. The data's geographic representativeness is one aspect evaluated as part of the data quality assessment.

A full list of data mapping is available in Appendix D.

4.1.1.2 Key assumptions

The following key assumptions are made in the LCA model for Wild Alaska Pollock products:

- Per PAS 2050-2 (BSI, 2012), the impacts that arise from building infrastructure and operations represent less than 1% of final life cycle impacts and on this basis are excluded. In addition, this study includes all flows recommended for inclusion by PAS 2050-2 (BSI, 2012), even if their contributions were less than 1% of final life cycle impacts.
- During the Wild Alaska Pollock catching season there is minimal by-catch of other species. Therefore, we attribute the full impact of catching activities to Wild Alaska Pollock.
- Where one or several pieces of data are missing across catcher/processor responses within the same sector, average data based on the responses from other sectors, normalized by catching volume, is used as a proxy. Specifically, for Mothership catchers and processors some durable and non-durable goods are missing, and therefore normalized data from Shore-based catchers and processors are used.
- Where one or several pieces of data are missing from a portion of the catcher/processor responses within the same sector, we use the available data from other responses in the same sector, normalized by catching volume, to represent the data for the whole group.

Other assumptions are based on the professional judgment of the modelers and are held constant for all Wild Alaska Pollock products under study where a clear basis does not exist to differentiate among systems. All assumptions are documented in Appendix E.

4.1.1.3 Total production data (BSAI)

Production data across the three sectors of Wild Alaska Pollock used the extrapolation method described below.

The following mass balance test was performed:

- Respondents' production of the products listed above were extrapolated by using the percent of catch they represented within their particular sector;

- Next, the results of those extrapolations across all three sectors were compared to the actual cumulative production quantities collected and reported by the National Marine Fisheries Service (NMFS). (NMFS does not report production of processed products by sector due to confidentiality constraints)

The resulting extrapolations were reasonably close to the NMFS production for some products, however, there were notable discrepancies for others (e.g., 20% difference for fillets). Given this, the production of processed products by sector is estimated using extrapolations of survey data for the Catcher-processing and Mothership processing sectors. We used the Mothership processing sector despite an overall lower response rate, as Mothership processors represent 9% of the quota and thus errors would be less impactful to the results. After the extrapolation of the production for the two sectors, the remaining production of each processed product was apportioned to the Shore-based sector. See Table 4 for the total production data.

Table 4. 2016-2018 production by Wild Alaska Pollock product type

Fishery location	Wild Alaska Pollock product	Total production (MT)
Bering Sea /Aleutian Islands (BSAI)	Fillet	485,867
	Surimi	584,076
	Roe	53,316
	Fish oil	80,155
	Fishmeal	192,613
	Head & Gutted	73,775
	Minced	80,996
	Milt	2,901
	Stomach	5,688
	Bones	29,832
	Whole fish	1,241
	Belly flap	11
	Other retained products	31

4.1.2 Data quality assessment

The reliability of the results and conclusions of an LCA depend on the quality of the data used. It is therefore important to ensure that the information is adequate to meet the objectives of the report.

The quality of foreground processes and data used in this study are assessed qualitatively on a 1 to 5 scale, with a score of 5 being most favorable and a score of 1 being least favorable. Quality considerations are based on those outlined by the pedigree matrix, including reliability, completeness, temporal correlation, and geographical correlation (Weidema and Wesnaes 1996) as prescribed in ISO 14044. A complete discussion of this topic can be found in Weidema et al. (2013). The pedigree matrix for rating inventory data appears in Table 4 below.

The full Inventory and Data Quality Assessment results are included in Appendix D, which lists all life cycle processes and ratings for those data that contribute at least 1% to one or more of the most relevant impact indicators. The importance of the data to the total system results may be examined using sensitivity testing and an explanation of influence on the confidence of the results reported. Inventory and Data Quality Assessment results for fillet and fish oil are provided in Table 6 and Table 7, respectively; the full data quality assessment and data quality assessments for other functional units considered also appear in Appendix D and the patterns found across all are very similar.

Table 6 shows a snapshot of the data quality assessment carried out for fillet as an example. Through this data quality assessment, it was identified that diesel consumption for Catching and processing, and refrigerant leakage (especially Freon) are hotspots to the Climate change indicator of fillet production. All the data are primary data, collected from GAPP with a relatively good data coverage rate (see Table 3). For waste and some non-durable goods, the data coverage is relatively low, but their contributions are low as well. Collecting more comprehensive data to have a higher coverage rate in the future would be helpful to improve the data quality. Based on this data quality assessment, considering the extrapolation for diesel consumption (see Section 4.2.6), a sensitivity test on diesel consumption is provided in the study (see Section 5.3.2).

Based on the Inventory and Data Quality Assessment data in Table 6, for every 1 kg of fillet (equivalent to 1 kg of pollock landed):

- 3.5 MJ of diesel fuel are consumed during Catching and processing, contributing 36% to the total Climate change impact, and
- 0.09 grams of leaked refrigerants are associated with Catching and processing. Of this leakage, 0.02 grams are CFC-12, which contributes 31% to the total Climate change impact. (CFC-12 was chosen to represent freon in this study, as it presents a conservative estimate and our data did not specify the gas used in freon systems. In addition, a scenario analysis using ammonia as the only refrigerant was completed in Section 5.3.2.)

The mean fuel use intensity for catching activities across sectors is 16.7 gallons per metric ton of catch; note that this includes fuel used to process fish aboard Catcher-processors, and therefore it overstates the amount of fuel used for catching only. According to Parker and Tyedmers (2014), the median fuel use intensity of global fishery records since 1990 was 639 litres (168.8 gallons) per metric ton of catch. These data suggest that the U.S. Alaska Pollock fishery is among the most fuel-efficient fisheries in the world.

Table 5. Pedigree matrix used for data quality assessment

INDICATOR SCORE	5	4	3	2	1
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant to the market considered, over an adequate period to even out normal fluctuations	Representative data from >50 of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50) relevant for the market considered or >50 of sites but from shorter periods	Representative data from only one sites relevant for the market considered or some sites but from shorter periods	Representativeness unknown or incomplete data from a smaller number of sites and from shorter periods
Temporal correlation	Less than 3 years of difference to the time-period of the dataset	Less than 6 years difference to the time-period of the dataset	Less than 10 years difference to the time-period of the dataset	Less than 15 years difference to the time-period of the dataset	Age of data unknown or more than 15 years of difference to the time-period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

Fillet - Inventory and Data Quality Assessment

Life cycle stages	Activity category	Activity name	Reference flow	unit	Inventory name	RESULT CONTRIBUTION Climate change	Land use	Water consumption	DATA QUALITY
Catching&Processing	Refrigerant leakage	Refrigerant leakage - Freon	2.19E-05	kg	Elementry flow, CFC-12 to air	31%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - R404A	3.31E-11	kg	Elementry flow, R404A to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - R134A	1.38E-11	kg	Elementry flow, R134A to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - Ammonia	4.34E-05	kg	Elementry flow, ammonia to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - CO2	2.52E-05	kg	Elementry flow, COO2 to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage -R507	1.65E-08	kg	Elementry flow, R507 to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - R22	1.50E-06	kg	Elementry flow, R22 to air	0%	0%	0%	4
Catching&Processing	Energy	Diesel	3.54E+00	Mj	Diesel, burned in fishing vessel {GLO}| market for diesel, burned in fishing vessel | Cut-off, U	36%	0%	6%	4
Catching&Processing	Energy	LPG	3.88E-07	kg	Liquefied petroleum gas {RoW}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Energy	Fish oil	8.64E-07	kg	Fish oil, from anchovy {RoW}| fishmeal and fish oil production, 63-65% protein, from fresh anchovy | Cut-off, U	0%	0%	0%	4
Catching&Processing	Energy	Purchased electricity	1.67E-02	kWh	Electricity, high voltage {RoW}| heat and power co-generation, diesel, 200kW electrical, SCR-NOx reduction | Cut-off, U (QLL18.1.0)	1%	0%	3%	4
Catching&Processing	Energy	Gasoline	4.74E-03	MJ	Petrol, unleaded, burned in machinery {GLO}| market for petrol, unleaded, burned in machinery | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Energy	Natural gas	9.25E-07	MJ	Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Durable and Semi-Durable goods	Chain and cables	2.94E-04	kg	Steel, unalloyed {RoW}| steel production, converter, unalloyed | Cut-off, U (QLL18.1.0) + Metal work	0%	0%	0%	4
Catching&Processing	Durable and Semi-Durable goods	Nets	6.15E-04	kg	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U (QLL18.1.0) + Injection moulding {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	1%	4
Catching&Processing	Non-durable goods	Trawl doors	2.92E-05	kg	Steel, unalloyed {RoW}| steel production, converter, unalloyed | Cut-off, U (QLL18.1.0) + Metal working, average for steel product manufacturing {RoW}| processing | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Non-durable goods	Rope	5.44E-05	kg	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U (QLL18.1.0) + Injection moulding	0%	0%	0%	3
Catching&Processing	Non-durable goods	Third wire	2.05E-04	m	Aluminium around steel bi-metal stranded cable, 3x3.67mm external diameter wire {GLO}| market	0%	0%	0%	3
Catching&Processing	Non-durable goods	Battery	1.95E-05	kg	Battery cell, Li-ion {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Non-durable goods	Refrigerant production - Freon	4.07E-05	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - R404A	3.31E-11	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - R134A	1.38E-11	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - Ammoni	1.29E-05	kg	Ammonia, liquid {RoW}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - CO2	3.46E-05	kg	Carbon dioxide, liquid {RoW}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production -R507	1.65E-08	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - R22	1.50E-06	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Hydraulic fluid	5.02E-08	m3	Hydraulic fracturing fluid {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Purchased oil or other lubricants	3.60E-04	kg	Lubricating oil {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Cleaning agents	3.46E-04	kg	Cleaning consumables, without water, in 13.6% solution state {GLO}| market for cleaning consumab	0%	0%	0%	4
Catching&Processing	Non-durable goods	Glues and adhesive tapes	1.45E-06	kg	Solvent glue, at plant/GLO S (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Paint	1.65E-04	kg	Alkyd paint, white, without water, in 60% solution state {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	1%	4
Catching&Processing	Non-durable goods	Filters	4.64E-05	kg	50% Polypropylene, high density, granulate {GLO}| market for | Cut-off, U (QLL18.1.0) + 50% Paper f	0%	0%	6%	4
Catching&Processing	Non-durable goods	Anti-fouling bottom paint	2.19E-05	kg	Alkyd paint, white, without water, in 60% solution state {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Lubricating oil	2.24E-04	kg	Lubricating oil {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Purchased water	3.04E+00	kg	Tap water {GLO}| market group for | Cut-off, U (QLL18.1.0)	0%	0%	213%	4
Catching&Processing	Waste	Mixed MSW to landfill	5.97E-04	kg	Municipal solid waste {RoW}| treatment of, sanitary landfill | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Waste	Fish waste to landfill	6.05E-05	kg	Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Waste	Waste water to WWTP	2.92E-03	m3	Wastewater, average {RoW}| market for wastewater, average | Cut-off, U (QLL18.1.0)	0%	0%	-183%	3
Catching&Processing	Waste	Fish discharged to sea	1.24E-01	kg	Fish discharged to the sea	0%	0%	0%	3
Catching&Processing	Commuting	Employee commuting	3.35E-02	perso	Transport, passengers, aircraft, very short haul {GLO}| market for transport, passengers, aircraft, ver	2%	0%	0%	3
Packaging		Beck liner	1.94E-02	kg	90% Corrugated board box {GLO}| market for corrugated board box | Cut-off, U (QLL18.1.0) + 10% Packaging film, low density polyethylene {GLO}| market for | Cut-off, U (QLL18.1.0)	3%	16%	12%	4
Packaging		LDPE bag	1.67E-03	kg	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U (QLL18.1.0)	1%	0%	5%	4
Packaging		Master case	1.87E-02	kg	Corrugated board box {GLO}| market for corrugated board box | Cut-off, U (QLL18.1.0)	2%	17%	8%	4
Packaging		Pallet	7.13E-04	piece	EUR-flat pallet {GLO}| market for | Cut-off, U (QLL18.1.0)	1%	65%	3%	4
Distribution		East coast US	1.11E+01	tkm	Transport, freight, sea, transoceanic ship with reefer, freezing {GLO}| market for | Cut-off, U (QLL1ε	22%	0%	21%	4

Table 6. Inventory and Data quality Assessment for fillet. The full Inventory and Data Quality Assessment results for all functional units are provided in Appendix D; as noted above, fillet results are very similar to the other frozen product functional units.

Fish oil - Inventory and Data Quality Assessment						RESULT CONTRIBUTION			DATA QUALITY
Life cycle stages	Activity category	Activity name	Reference flow	unit	Inventory name	Climate change	Land use	Water consumption	
Catching&Processing	Refrigerant leakage	Refrigerant leakage - Freon	2.32E-04	kg	Elementry flow, CFC-12 to air	45%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - R404A	2.08E-10	kg	Elementry flow, R404A to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - R134A	8.66E-11	kg	Elementry flow, R134A to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - Ammonia	4.22E-04	kg	Elementry flow, ammonia to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - CO2	1.75E-04	kg	Elementry flow, COO2 to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage -R507	1.84E-07	kg	Elementry flow, R507 to air	0%	0%	0%	4
Catching&Processing	Refrigerant leakage	Refrigerant leakage - R22	1.67E-05	kg	Elementry flow, R22 to air	1%	0%	0%	4
Catching&Processing	Energy	Diesel	3.26E+01	Mj	Diesel, burned in fishing vessel {GLO}| market for diesel, burned in fishing vessel | Cut-off, U	46%	15%	14%	4
Catching&Processing	Energy	LPG	2.43E-06	kg	Liquefied petroleum gas {RoW}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Energy	Fish oil	5.42E-06	kg	Fish oil, from anchovy {RoW}| fishmeal and fish oil production, 63-65% protein, from fresh anchovy	0%	0%	0%	4
Catching&Processing	Energy	Purchased electricity	1.08E-01	kWh	Electricity, high voltage {RoW}| heat and power co-generation, diesel, 200kW electrical, SCR-NOx re	1%	5%	5%	4
Catching&Processing	Energy	Gasoline	2.97E-02	MJ	Petrol, unleaded, burned in machinery {GLO}| market for petrol, unleaded, burned in machinery | Cu	0%	0%	0%	4
Catching&Processing	Energy	Natural gas	5.80E-06	MJ	Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Durable and semi-du	Chain and cables	2.73E-03	kg	Steel, unalloyed {RoW}| steel production, converter, unalloyed | Cut-off, U (QLL18.1.0) + Metal work	0%	2%	1%	4
Catching&Processing	Durable and semi-du	Nets	5.80E-03	kg	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U (QLL18.1.0) + Injection moulding {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	8%	3%	4
Catching&Processing	Non-durable goods	Trawl doors	2.09E-04	kg	Steel, unalloyed {RoW}| steel production, converter, unalloyed | Cut-off, U (QLL18.1.0) + Metal working, average for steel product manufacturing {RoW}| processing | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Non-durable goods	Rope	5.76E-04	kg	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U (QLL18.1.0) + Injection moulding	0%	1%	0%	3
Catching&Processing	Non-durable goods	Third wire	1.47E-03	m	Aluminium around steel bi-metal stranded cable, 3x3.67mm external diameter wire {GLO}| market	0%	1%	0%	3
Catching&Processing	Non-durable goods	Battery	1.80E-04	kg	Battery cell, Li-ion {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Non-durable goods	Refrigerant production - Freon	4.42E-04	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	1%	4
Catching&Processing	Non-durable goods	Refrigerant production - R404A	2.08E-10	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - R134A	8.66E-11	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - Ammoni	8.07E-05	kg	Ammonia, liquid {RoW}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - CO2	2.79E-04	kg	Carbon dioxide, liquid {RoW}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production -R507	1.84E-07	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Refrigerant production - R22	1.67E-05	kg	Refrigerant R134a {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Hydraulic fluid	4.16E-07	m3	Hydraulic fracturing fluid {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Purchased oil or other lubricants	3.30E-03	kg	Lubricating oil {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	1%	1%	4
Catching&Processing	Non-durable goods	Cleaning agents	2.86E-03	kg	Cleaning consumables, without water, in 13.6% solution state {GLO}| market for cleaning consumab	0%	3%	1%	4
Catching&Processing	Non-durable goods	Glues and adhesive tapes	1.12E-05	kg	Solvent glue, at plant/GLO S (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Paint	1.81E-03	kg	Alkyd paint, white, without water, in 60% solution state {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	30%	2%	4
Catching&Processing	Non-durable goods	Filters	3.75E-04	kg	50% Polypropylene, high density, granulate {GLO}| market for | Cut-off, U (QLL18.1.0) + 50% Paper f	0%	14%	13%	4
Catching&Processing	Non-durable goods	Anti-fouling bottom paint	1.57E-04	kg	Alkyd paint, white, without water, in 60% solution state {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	3%	0%	4
Catching&Processing	Non-durable goods	Lubricating oil	1.40E-03	kg	Lubricating oil {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Catching&Processing	Non-durable goods	Purchased water	1.91E+01	kg	Tap water {GLO}| market group for | Cut-off, U (QLL18.1.0)	0%	3%	339%	4
Catching&Processing	Waste	Mixed MSW to landfill	5.15E-03	kg	Municipal solid waste {RoW}| treatment of, sanitary landfill | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Waste	Fish waste to landfill	3.79E-04	kg	Biowaste {RoW}| treatment of biowaste by anaerobic digestion | Cut-off, U (QLL18.1.0)	0%	0%	0%	3
Catching&Processing	Waste	Waste water to WWTP	1.83E-02	m3	Wastewater, average {RoW}| market for wastewater, average | Cut-off, U (QLL18.1.0)	0%	1%	-291%	3
Catching&Processing	Waste	Fish discharged to sea	1.38E+00	kg	Fish discharged to the sea	0%	0%	0%	3
Catching&Processing	Commuting	Employee commuting	2.92E-01	perso	Transport, passengers, aircraft, very short haul {GLO}| market for transport, passengers, aircraft, ver	2%	0%	0%	3
Catching&Processing	Energy	Diesel for fish oil processing	3.53E-02	gal	Diesel, burned in fishing vessel {GLO}| market for diesel, burned in fishing vessel | Cut-off, U	0%	0%	0%	3
Packaging		LDPE bag	3.15E-03	kg	Packaging film, low density polyethylene {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	5%	2%	4
Packaging		Master case	7.88E-04	kg	Corrugated board box {GLO}| market for corrugated board box | Cut-off, U (QLL18.1.0)	0%	6%	0%	4
Packaging		PP bag	3.66E-04	kg	Polypropylene, granulate {GLO}| market for | Cut-off, U (QLL18.1.0)	0%	0%	0%	4
Distribution		East coast US	1.11E+01	tkm	Transport, freight, sea, transoceanic ship with reefer, freezing {GLO}| market for | Cut-off, U (QLL18	3%	1%	5%	4

Table 7. Inventory and Data Quality Assessment for fish oil. The full Inventory and Data Quality Assessment results for all functional units are provided in Appendix D; fish oil results are very similar to fishmeal results.

4.2 Allocation methodology

A common methodological decision point in LCA occurs when the system being studied is directly connected to a past or future system or produces co-products. When systems are linked in this manner, the boundaries of the system of interest must be widened to include the adjoining system, or the impacts of the linking items must be distributed—or allocated—across the systems. While there is no clear scientific consensus regarding an optimal method for handling this in all cases (Reap et al. 2008), many possible approaches have been developed, and each may have a greater level of appropriateness in certain circumstances.

ISO 14044 prioritizes the methodologies related to applying allocation. It is best to avoid allocation through system subdivision or expansion. If that is not possible, then one should perform allocation using an underlying physical relationship. If using a physical relationship is not possible or does not make sense, then one can use another relationship. Any allocations made during calculations are stated throughout the report.

4.2.1 Recycled content and end-of-life recycling

When a system donates or receives a material or energy source from an upstream or downstream system, respectively, a decision must be made to assign an amount of impact or benefit to the systems involved.

In this study employs the “cut-off” approach (Ekvall and Tillman 1997), which is represented in Figure 3. In the case of recycled content and recycling at end of life, use of the cut-off approach entails modeling the production of input materials with appropriate virgin production and recycling processes, depending on the average recycled content rate of a material in the relevant market assumed in this study. End-of-life is modeled by including only the portions of disposal that do not result in reclaimed materials or energy. Specifically, landfill and incineration processes are included, but recycling is excluded as it is considered a production process for a subsequent system.

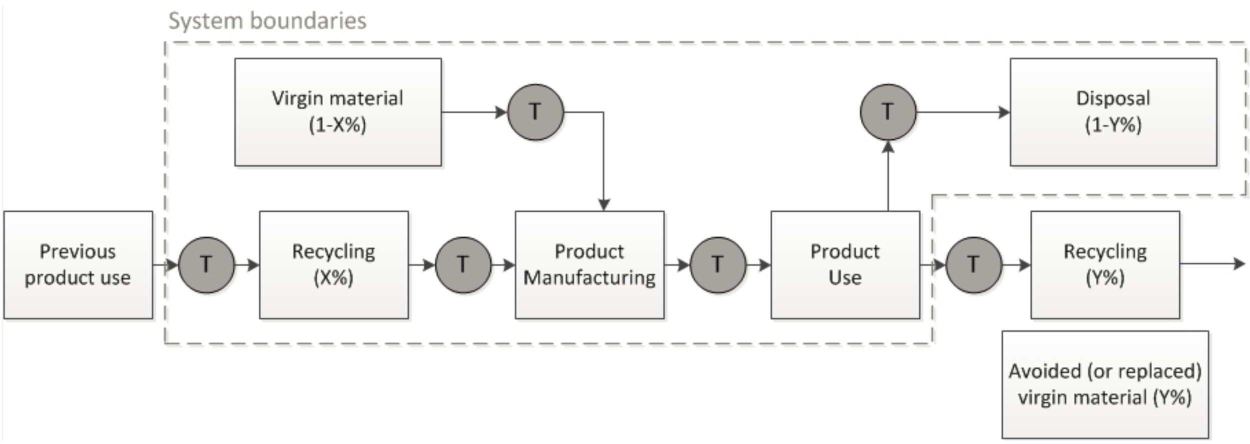


Figure 3. Graphic representation of cut-off allocation methodology (Source: Quantis)

The choice of allocation approach for recycled content and end-of-life recycling is not expected to have a meaningful influence on the results since these activities do not apply to the Wild Alaska Pollock products themselves, only packaging and perhaps other materials to support Wild Alaska Pollock products.

4.2.2 Incineration with Energy Recovery

An allocation decision must also be made regarding the additional functions provided by incineration with energy recovery (or WtE), and landfilling with methane capture, which provide an energy source for use by another system. Following the cut-off methodology for recycling, the energy provided by the end of life (EoL) treatment is credited to a downstream system. For the purposes of this study, end of life figures from the USEPA (Advancing Sustainable Materials Management: 2014 Tables and Figures, December 2016) is used for the distinct types of materials.

4.2.3 Freight transport

In this study, all transport is assumed to be weight-limited and the transportation of the cargo within the vehicle is therefore allocated based on its weight.

Transport vehicles have both a weight capacity and a volume capacity. These are important aspects to consider when allocating the impacts of an entire transportation journey to one product. Vehicles transporting products with a high density (high mass-per-volume ratio) will reach their weight capacity before reaching their volume capacity. Vehicles transporting products with a low density (low mass-per-volume ratio) will reach their volume capacity before reaching their weight capacity. Therefore, the density of the product is critical for determining whether to model transportation as volume-limited or weight-limited.

4.2.4 Ecoinvent processes with allocation

Many of the processes in the *ecoinvent* database also provide multiple functions, and allocation is required to provide inventory data per function (or per process) (Weidema et al. 2013). In this study, the *ecoinvent* database v3.4 using the cut-off by classification allocation model is used (Weidema et al. 2013). Some additional datasets from *ecoinvent* database v3.6 using the cut-off by classification allocation model are also used as a supplement for v3.4. The allocation model is aligned with the cut-off approach used in the foreground modeling (e.g., treatment of recycled content in incoming materials).

4.2.5 Allocation between Wild Alaska Pollock and other species and between key Wild Alaska Pollock products and other (co-product allocation)

This study is specific to five key Wild Alaska Pollock products and excludes activities relating to catching and processing other species, as well as other Wild Alaska Pollock co-products.

Data relating to Catching and processing activities, such as fuel use, tend to be collected and reported by the industry on an annual basis and may account not only for Wild Alaska Pollock activities, but also those for other species. To apportion these activity data to Wild Alaska Pollock, we have asked catchers and processors to separate data based on their best knowledge. Described below are the allocation approaches that have been applied for this work.

- Allocation of catching activities to Wild Alaska Pollock relative to catching of other species was done by each catcher company based on the number of days fished, where needed. If the vessel participated in fisheries other than the directed Alaska Pollock fishery, the catchers apportioned inputs between those other species and Wild Alaska Pollock by having separate meters for Wild Alaska Pollock catching activities or apportioned by number of days fished.
- Allocation of processing activities to Wild Alaska Pollock relative to the processing of other species was done by each processor company by the amount of production, where needed. If other species were processed and stored at the facility, the processors apportioned inputs and energy consumption between those other species and Wild Alaska Pollock by having separate meters for Wild Alaska Pollock processing facilities, or apportioned by product volume/mass, etc. based on data availability.

With regard to Wild Alaska Pollock-specific product-related activity data versus that for excluded co-products: Allocation for processing different Wild Alaska Pollock products which are not included in the system boundary of this study are done by mass where needed. During Wild Alaska Pollock processing, various Wild Alaska Pollock products are produced simultaneously. The mass of each Wild Alaska Pollock product is reported by each company and the catching amount needed to produce each Wild Alaska Pollock product is estimated by GAPP, using a conversion rate for each product. These conversion rates are expressed as yields (percent recovered from fresh pollock biomass in final product mass) in Table 8. The potential impacts from Catching and processing activities are apportioned to each product based on its relative catching mass.

Given that the choice of allocation factors among Wild Alaska Pollock products is likely to be influential to the results, a sensitivity analysis using an economic allocation metric (wholesale price, see Table 8) has been carried out. The economic values are for sold pollock products in their final form; since the pollock parts before transformation are not products and never get sold, the price for pre-transformation pollock is not available. The three-year weighted average price is used in this study. The economic value of the entire production of each Wild Alaska Pollock product is applied to allocate the impact from fishing and processing.

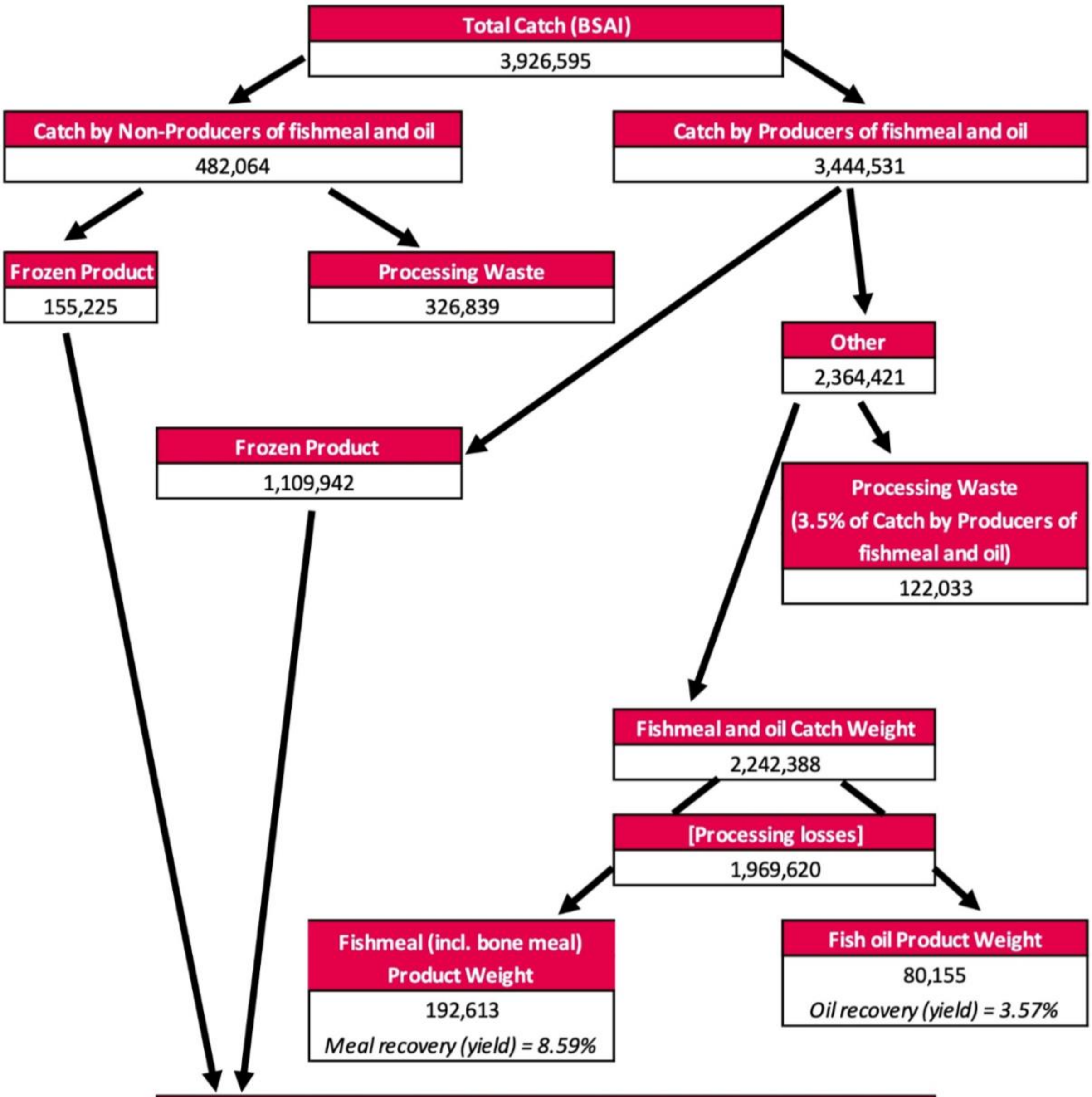
A production flowchart representing the distribution of total catch through to final product form is represented in Figure 4. To reconcile total production to total catch weight equivalents in our mass balance exercise, the fresh pollock biomass to final product mass ratios for all frozen products are used for this study. 1:1 ratios (100% yield rate) are applied to all frozen products other than surimi. Since surimi has non-fish additives, a 0.91:1 ratio (109.9% yield rate) is used to convert production to catch weight.

As represented in Figure 4, fishmeal and fish oil are co-products through recovery plants. Based on industry interviews, the estimated overall processing waste rate for fishmeal and oil producers is 3.5%. Therefore, the remaining catch weight (total catch weight sent to fishmeal and oil producers, minus a 3.5% processing waste rate, minus the amount used to produce frozen products) are the raw materials to produce fishmeal and fish oil. The production processes for fishmeal and fish oil cannot be divided, therefore mass allocation between fishmeal and fish oil is performed based on the production volume (Product Weight).

For those processors that do not produce fishmeal or fish oil, the amount of catch weight that would have gone into fishmeal and fish oil production had they had that capability is assumed to be processing waste returned to the sea. Waste does not carry any Catching and processing environmental impact. All impacts are attributed to Wild Alaska Pollock products.

Table 8. Yield rates and economic values (wholesale price) for Wild Alaska Pollock products

Fishery location	Wild Alaska Pollock product	Yield rates (percent recovered from fresh pollock biomass in final product mass)	Economic value (wholesale price)
		Average of all sectors	$ per MT
Bering Sea /Aleutian Islands (BSAI)	Fillet	100%	$2,580.39
	Surimi	109.9%	$2,412.27
	Roe	100%	$6,756.11
	Fish oil	3.57%	$1,316.67
	Fishmeal	8.59%	$1,893.33
	Head & Gutted	100%	$2,055.95
	Minced	100%	$2,553.05
	Milt	100%	$1,316.67
	Stomach	100%	$2,403.33
	Bones	100%	$1,316.67
	Whole fish	100%	$1,316.67
	Belly flap	100%	$1,316.67
	Other retained products	100%	$1,316.67



Frozen Product	Catch Weight	Product Weight	Percent of Total Catch
Fillet	485,867	485,867	12.37%
Surimi	531,509	584,076	13.54%
Roe	53,316	53,316	1.36%
Headed & Gutted	73,775	73,775	1.88%
Minced	80,996	80,996	2.06%
Milt	2,901	2,901	0.07%
Stomach	5,688	5,688	0.14%
Bones (not bone meal)	29,832	29,832	0.76%
Whole fish	1,241	1,241	0.03%
Belly flap	11	11	0.00%
Other retained products	31	31	0.00%
Totals	1,265,167	1,317,734	32.22%

NOTE: The only frozen products assigned a functional unit in this study are fillet, surimi, and roe.

Figure 4. Production Flow Chart of BSAI Fishery in metric tons (MT), all catches 2016 to 2018

4.2.6 Diesel energy apportions for fish oil and fishmeal processing

The energy data collected from each respondent represent aggregate consumption, including cutting and dividing the fish, as well as the processing of fish oil (cooking, pressing, decantation, and centrifugation) and fishmeal (cooking, pressing, drying, and grinding). To be able to apportion energy between dividing whole fish and processing fish oil and fishmeal, a survey of the industry to identify the incremental energy (in the form of diesel fuel) consumed to produce fishmeal and fish oil has been done. We identified participants in each sector that produce fishmeal and fish oil to include in the survey.

1) Shore-based: All Shore-based processors produce fishmeal and oil;
2) Catcher-processors: 8 of the 11 Catcher-processors produce fishmeal and fish oil; and
3) Motherships: 2 of the 3 Motherships produce fishmeal and fish oil.

Using the responses, mass allocation between fishmeal and fish oil (based on production volume) is used to determine energy consumption per kg of fishmeal and fish oil production. We deducted the energy consumed to produce fishmeal and fish oil from the aggregated consumption to determine the amount of energy consumed to produce the other primary products for each company.

4.3 Impact Assessment

4.3.1 Impact assessment method and indicators

Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment. The method to be used here to evaluate environmental impact is the Product Environmental Footprint (PEF) method (JRC-IES 2017). This method assesses 16 different potential impact categories (midpoint). It is the result of a project for the European Commission that analyzed several life cycle impact assessment (LCIA) methodologies to reach consensus. It is the official method to be used in the Product Environmental Footprint (PEF) context of the Single Market for Green Products (SMGP) initiative (European Commission 2013).

Table 9 describes the models used for each of the 16 indicators considered in the present study. More detailed description is listed in Appendix 1, included at the end of this report.

The European Commission Joint Research Centre (JRC) classifies every impact category according to the maturity and reliability of its underlying model:

- Level I: recommended and satisfactory
- Level II: recommended, but in need of some improvements
- Level III: recommended, but to be applied with caution

Models classified at Level III are likely to evolve in the near future.

Table 9. Indicators and related assessment models used

IMPACT CATEGORY OR LCI INDICATOR	MODEL	UNIT	SOURCE	CLASS
Climate change	Bern model – Global Warming potentials (GWP) over a 100-year time horizon	kg CO_2 eq	IPCC, 2013	I
Ozone depletion	EDIP model based on the ODPs of the WMO w/ infinite time horizon	kg CFC-11 eq	WMO, 1999	I
Human toxicity – non-cancer effects	USEtox® model	CTUh	Rosenbaum et al., 2008	III (interim)
Human toxicity – cancer effects	USEtox® model	CTUh	Rosenbaum et al., 2008	III (interim)
Particulate matter	PM method recom-mended by UNEP	Deaths/kg $PM_{2.5}$emitted	UNEP 2016	I
Ionising radiation	Human Health effect model	kg U^{235} eq	Dreicer et al., 1995	II
Photochemical ozone formation	LOTOS-EUROS model	kg NMVOC eq	van Zelm et al., 2008	II
Acidification	Accumulated Exceedance model	mol H+ eq	Seppälä et al.,2006; Posch et al., 2008	II
Terrestrial eutrophication	Accumulated Exceedance model	mol N eq	Seppälä et al.,2006; Posch et al., 2008	II
Freshwater eutrophication	EUTREND model	kg P eq	Struijs et al., 2009	II
Marine eutrophication	EUTREND model	kg N eq	Struijs et al., 2009	II
Freshwater ecotoxicity	USEtox® model	CTUe	Rosenbaum et al., 2008	III (interim)
Mineral & metal resource depletion	CML 2002 model (abiotic depletion – ultimate reserves)	kg Sb eq	Guinée et al., 2002 and van Oers et al. 2002	III
Non-renewable energy resource depletion	CML 2002 model (abiotic depletion – fossil)	MJ	Guinée et al., 2002 and van Oers et al. 2002	III

Land use	Soil Quality Index (based on the LANCA model)	points	Beck et al. 2010 and Bos et al. 2016	III
Water scarcity footprint	AWARE 100 model	m^3 water deprived eq	Boulay et al. 2016	III
Water consumption (W-R)	Impact 2002+	m^3	Jolliet et al. 2003	I

No normalization of the results against an external reference is carried out, but an internal normalization is performed presenting results on a relative basis (%) compared to the reference for each system. No weighting of the impact categories is done; they are presented individually and not as a single score, as there is no objective method by which to achieve this.

We expect to focus on Climate change, Land use and Water consumption because these are the most relevant ones to GAPP's industry. All results for all indicators are provided in Appendix A, B and C.

4.3.2 Limitations of LCIA

Life cycle impact assessment results present potential and not actual environmental impacts. Additionally, these categories do not cover all the environmental impacts associated with human activities. Impacts such as noise, odors, electromagnetic fields and others are not included in the present assessment. The methodological developments regarding such impacts are not sufficient to allow for their consideration within life cycle assessment. Other impacts, such as potential benefits or adverse effects on biodiversity, are also only partly covered by current impact categories.

4.4 Calculation tool

SimaPro 8.6 software, developed by PRé Consultants (www.pre.nl) has been used to assist the LCA modelling and link the reference flows with the LCI database and link the LCI flows to the relevant characterization factors. The final LCI results are calculated combining foreground data (intermediate products and elementary flows) with generic datasets providing cradle-to-gate background elementary flows to create a complete inventory of the Wild Alaska Pollock systems.

4.5 Contribution analysis

A contribution analysis has been performed to determine the extent to which each process modeled contributes to the overall impact of the system under study. Lower quality data may be suitable in the case of a process whose contribution is minimal. Similarly, processes with a great influence on the study results should be characterized by high-quality information. In this study, the contribution analysis is a simple observation of the relative importance of the different processes to the overall potential impact.

4.6 Uncertainty in LCI and LCIA

There are two types of uncertainty related to the LCA model:

- Inventory data uncertainty; and
- Characterization models uncertainty, which translate the inventory into environmental impacts.

4.6.1 Inventory data uncertainty analysis

To quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the input uncertainty and data variability, data quality assessment results are included in Appendix D, listing each indicator score for processes and flows that contribute at least 1% to one or more of the impact indicators. See more details in Section 4.1.2.

4.6.2 Characterization models uncertainty analysis

In addition to the inventory data uncertainty described above, there is also uncertainty related to the LCIA method, which is about the characterization of the LCI results into mid-point indicators. The accuracy of characterization factors depends on the ongoing research in the many scientific fields behind life cycle impact modeling, as well as on the integration of current findings within operational LCIA methods.

There are presently no systematic methods available for quantifying or evaluating the influence of the uncertainty in these characterization models within the assessments made here. Without consideration of the uncertainty in LCIA characterization factors, the uncertainty assessment results derived here should be seen as something like a lower bound on the level of uncertainty in the systems and the uncertainty would be higher if also considering the uncertainty in these characterization factors.

4.7 Sensitivity and scenario analysis

The parameters, methodological choices and assumptions used when modeling the systems present a certain degree of uncertainty and variability. It is important to evaluate whether the choice of parameters, methods, and assumptions significantly influences the study’s conclusions and to what extent the findings are dependent upon certain sets of conditions. Following the ISO 14044 standard, a series of sensitivity analyses are used to study the influence of the uncertainty and variability of modeling assumptions and data on the results and conclusions, thereby evaluating their robustness and reliability. Sensitivity analyses help in the interpretation phase to understand the uncertainty of results and identify limitations. The following parameters and choices are subjects for sensitivity analyses due to their high potential impacts or uncertainty:

- Energy consumption data, including fuels (used in Catching and processing) and electricity (used in processing, if there is any);
- Co-product allocation assumptions (e.g., economic metric);
- Refrigerant type (e.g., using ammonia as the only refrigerant).

4.8 Critical Review

A critical review has been conducted by a review panel, including Dr. Peter Tyedmers, a university-based food system LCA expert and the chairman of the review panel; Dr. Friederike Ziegler; and Dr. Ray Hilborn. This review process is instrumental in confirming that the study has followed the stipulations set forth in the ISO 14040 and 14044 standards (ISO 2006a, 2006b), as well as PAS 2050-2 (BSI, 2012).

The critical review process was carried out in several steps:

1) Goal and scope report review (June 2020);
2) Full report review (June 2021);
3) Clarification of and response to points raised by the reviewers (June/July 2021);
4) Review of response in Step 3 and final comments by reviewers (July 2021).

The external critical review verification letter, as well as Quantis' comments and responses to the review report are presented in Appendix 2.

5 Results

5.1 Baseline results

This section provides baseline indicator results profiles per 1 kg of Wild Alaska Pollock product evaluated in this study: fillet, surimi, roe, an average frozen Wild Alaska Pollock product (i.e., combination of fillet, surimi, and roe), fish oil and fishmeal. For the purposes of this results summary, the Distribution stage reflects the East coast US as the first-tier destination, although full results for all three destinations (including Asia and Europe) can be accessed in Appendix A. Similarly, while only three indicators are highlighted in this discussion (Climate change, Land use, and Water consumption) based on GAPP's interests, the full set of indicator results can be accessed in Appendix A.

5.1.1 Climate change indicator results - Overall

Figure 5 shows the Climate change indicator results for each functional unit. Among the life cycle stages considered, the Catching and processing stage dominates the potential impact. The Packaging and Distribution stages contribute much less to the life cycle potential impacts. The potential Climate change impacts span 0.83 to 6.38 kg CO2 eq per kg of distributed product, with roe and fillet on the low end and fish oil and fishmeal on the high end. The relatively high impact of fish oil and fishmeal relative to the other products is a result of the use of a mass metric for the allocation of co-products resulting from Wild Alaska Pollock processing into usable products. Due to the high pollock mass requirements to produce a unit of fish oil and fishmeal (see Section 4.2.5 for additional discussion), fish oil and fishmeal are apportioned much of the impacts from Catching and processing. Additionally, the energy that is utilized during the processing of fishmeal and fish oil is another contributor to the Climate change indicator results for these two products.

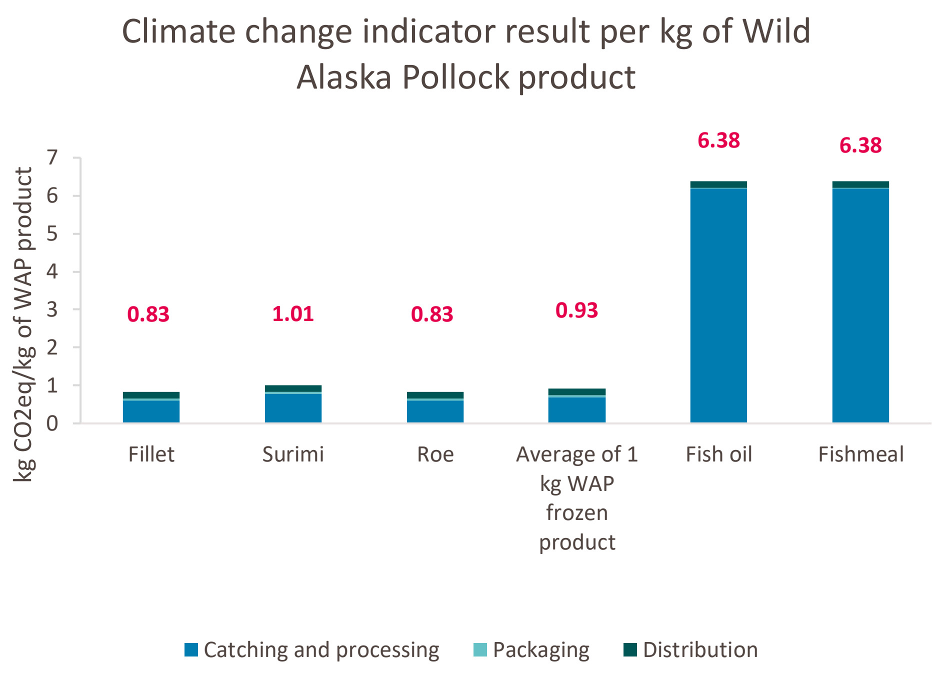


Figure 5. Climate change indicator results for the six Wild Alaska Pollock functional units (based on PEF methodology v1.4 (JRC-IES 2017))

The Catching and processing life cycle stage contributes to more than 70% of the fillet, surimi, roe and average frozen product Climate change indicator. Catching and processing contributes 97% to the fish oil and fishmeal Climate change indicator.
The Distribution stage contributes to about 20% of the fillet, surimi, roe and average frozen product Climate change indicator, and 3% to the fish oil and fishmeal Climate change indicator results.

Figure 6 presents close-up profile results specifically for the four frozen product functional units. The main differences seen among frozen products are due to differences in Catching and processing. Surimi has higher results for Catching and processing (0.78 kg CO2eq/kg), mainly because of the production of additives and non-fish ingredients that supplement the pollock to make the surimi product. There are also differences in the Packaging life-cycle stage, but these are not significant.

The fish oil and fishmeal functional units have identical indicator results in this study because, due to the use of mass allocation, they are allocated the exact same Catching and processing impact (including energy use at the recovery plant) per unit of production (kg of final product). Packaging results do differ between fish oil and fishmeal but the difference is relatively small.

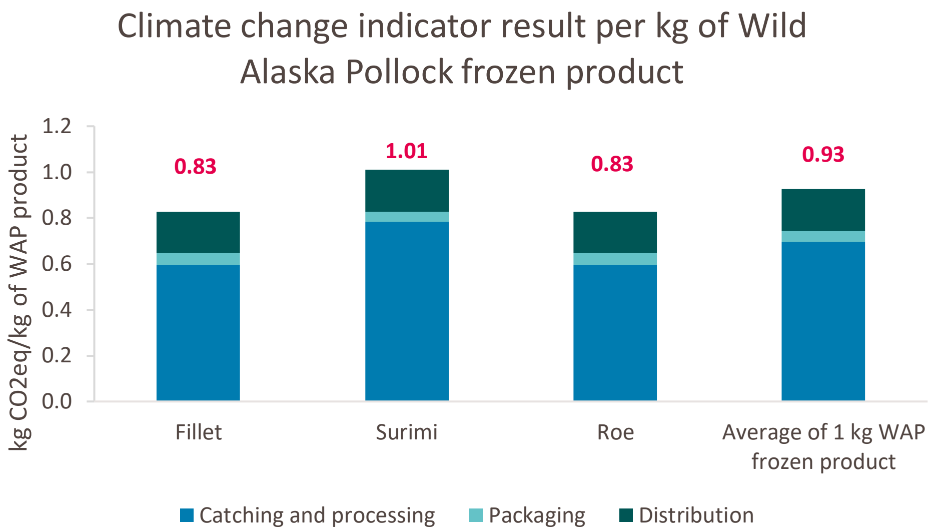


Figure 6. Climate change indicator results for the four frozen product functional units (based on IPCC 2013)

Supporting data for Figure 5 and Figure 6 can be found in Appendix A.

5.1.2 Land use indicator results - Overall

Figure 7 shows the Land use indicator results for the six Wild Alaska Pollock functional units. Packaging is the top contributing life cycle stage to the Land use indicator overall. For fillet and roe, Packaging contributes 99% of the total Land use result. For surimi, average frozen product, fish oil and fishmeal, Packaging contributes 66%, 77%, 10%, and 0.5% respectively. The majority comes from the wood-based packaging, including pallets and cardboard boxes. For fish oil and fishmeal, Catching and processing dominates the result.

Relative to the other frozen products, surimi has a large contribution from Catching and processing stage. The driver of this impact is from the additives and non-fish ingredients that supplement the pollock to make the surimi product.

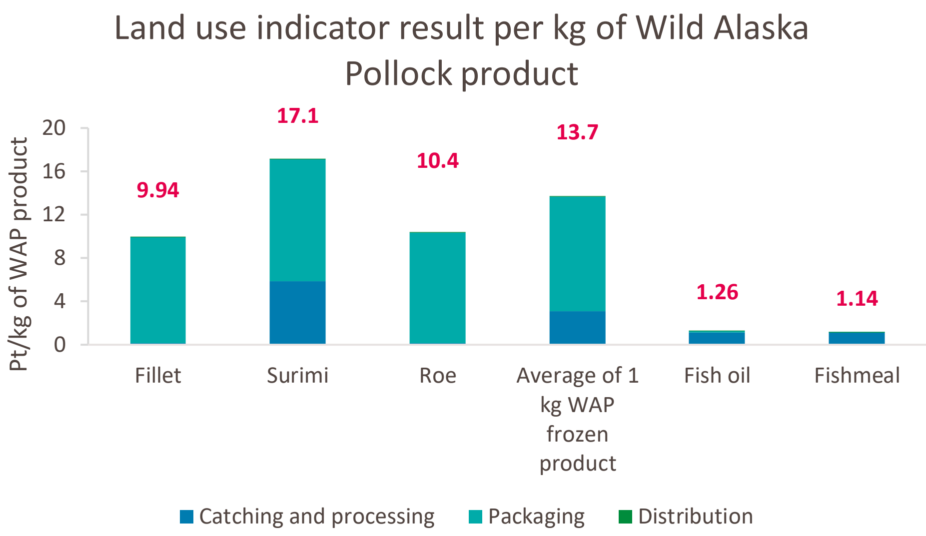


Figure 7. Land use indicator results for the six Wild Alaska Pollock functional units (based on Beck et al. 2010 and Bos et al. 2016)

Supporting data for Figure 7 can be found in Appendix A.

5.1.3 Water consumption indicator results - Overall

Shown in Figure 8 are the Water consumption indicator results for the six Wild Alaska Pollock functional units. Most of the Water consumption indicator impact comes from the Catching and processing stage. Surimi has the highest Water consumption (14.0 L/kg), and 95% of it is from Catching and processing. Fish oil and fishmeal have the next largest Water consumption indicator (5.89 L/kg and 5.82 L/kg), of which 92% and 94% is from Catching and processing.

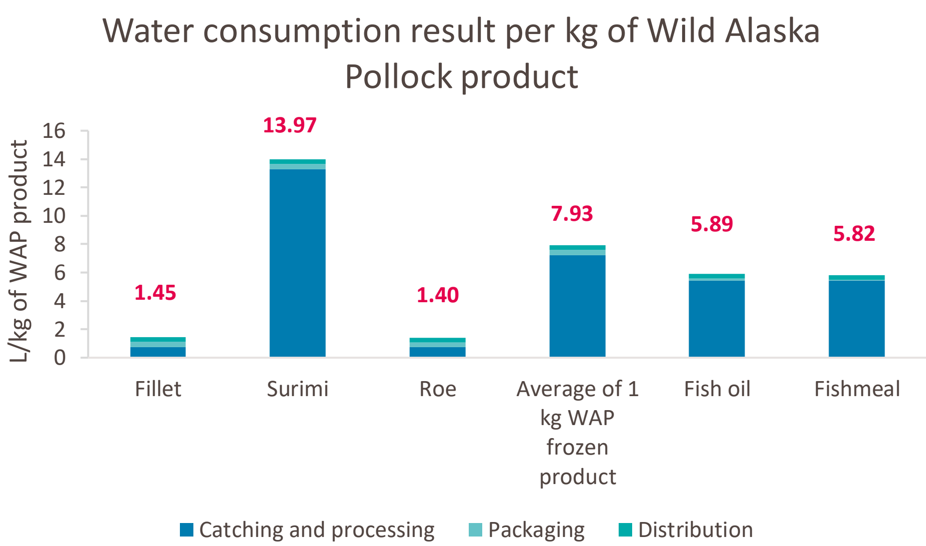


Figure 8. Water consumption indicator results for the six Wild Alaska Pollock functional units (based on Impact 2002+)

Supporting data for Figure 8 can be found in Appendix A.

5.1.4 Additional indicator results - Overall

To demonstrate the life cycle contributions across the full set of indicators evaluated in this study, Figure 9, Figure 10, and Figure 11 show the life cycle stage contributions normalized to each indicator's total, for an average frozen Wild Alaska Pollock product, fish oil, and fishmeal, respectively. The Distribution indicator result shown is specific to distribution to the East coast US. Results for other destinations can be find in Appendix A.
For the average frozen Wild Alaska Pollock product, Catching and processing contributes more than 60% to all indicators except Land use. Ozone depletion is driven primarily by refrigerant leakage. Other than Land use, most of the indicator results follow the patterns of the Climate change indicator results.

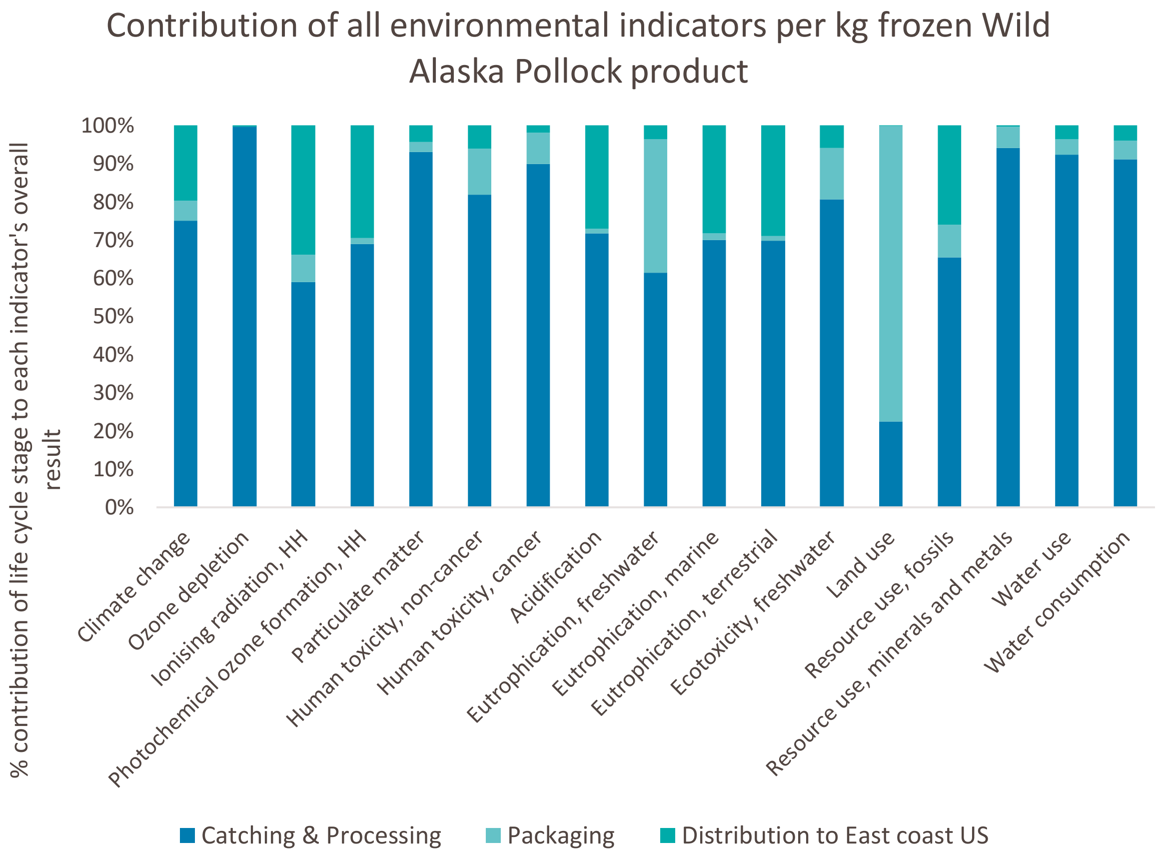


Figure 9. Full suite of normalized indicator results for 1 kg of average frozen Wild Alaska Pollock product distributed to East coast US (based on PEF v1.4)

For fish oil distributed to East coast US, the Catching and processing stage contributes at least 85% across all indicators evaluated.

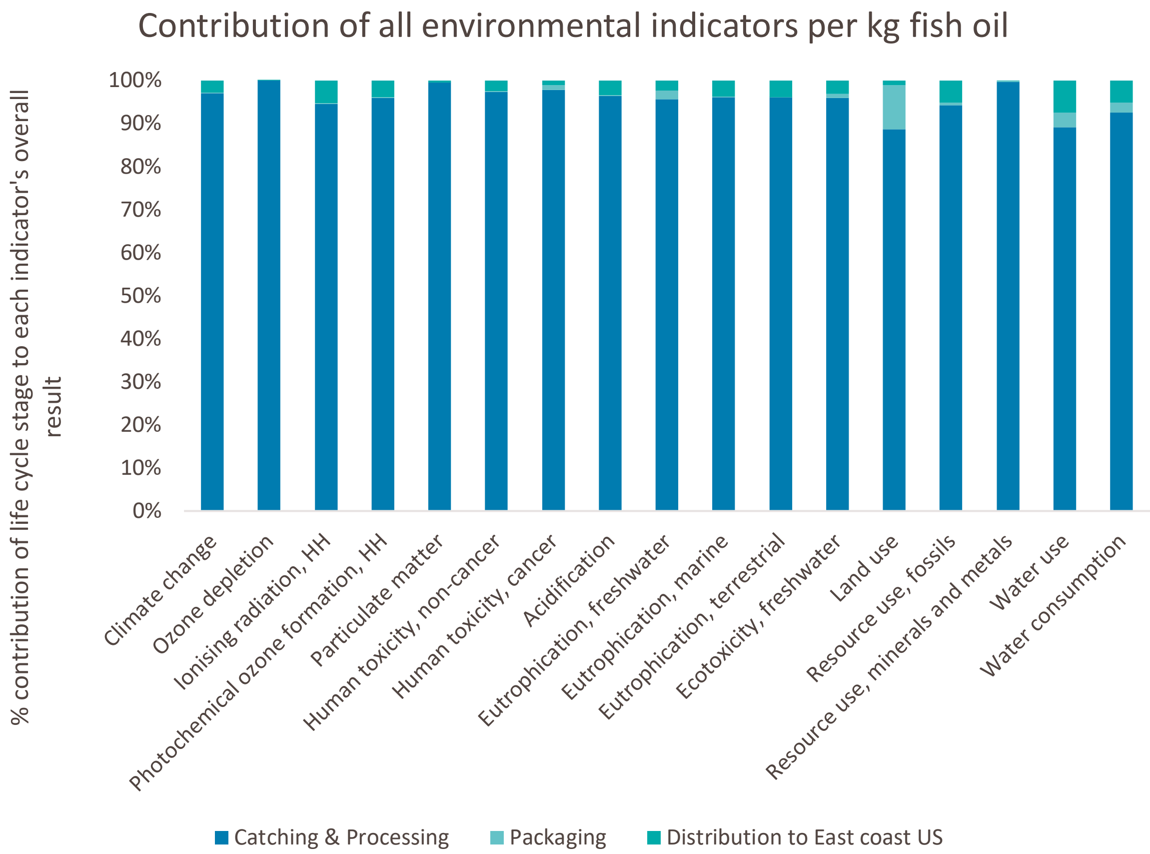


Figure 10. Full suite of normalized indicator results for 1 kg of fish oil distributed to East coast US (based on PEF v1.4)

For fishmeal distributed to the East coast US, the same pattern is more pronounced—Catching and processing contributes to over 90% of potential indicator results. The contribution of Catching and processing is slightly more pronounced compared with fish oil due to the lower impact from Packaging.

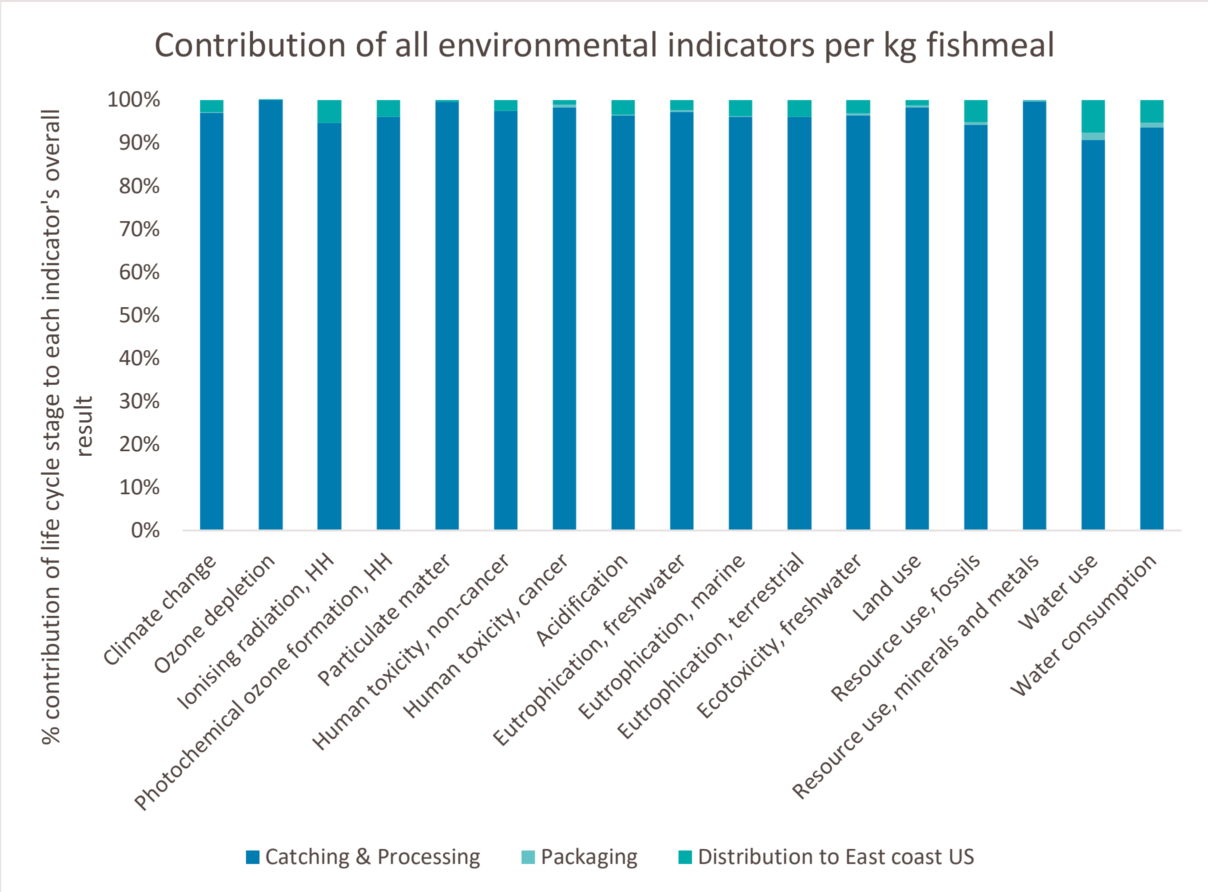


Figure 11. Full suite of indicator results for 1 kg of fishmeal distributed to East coast US (based on PEF v1.4)

Supporting data for Figure 9, Figure 10 and Figure 11 can be found in Appendix A.

5.2 Contribution analysis – Catching and processing stage

Given the dominance of the Catching and processing stage to the indicator results of these Wild Alaska Pollock products, a contribution analysis of this life cycle stage is discussed below.

5.2.1 Climate change indicator results – Catching and processing stage

Across all functional units except surimi, energy-related activities tend to contribute to about half of the Catching and processing stage Climate change indicator results. The other half tends to be driven by refrigerant leakage, and for surimi only, a portion is due to the upstream impacts of producing surimi product additives and ingredients. Activities like commuting and waste disposal tend to be negligible to the Climate change indicator results.

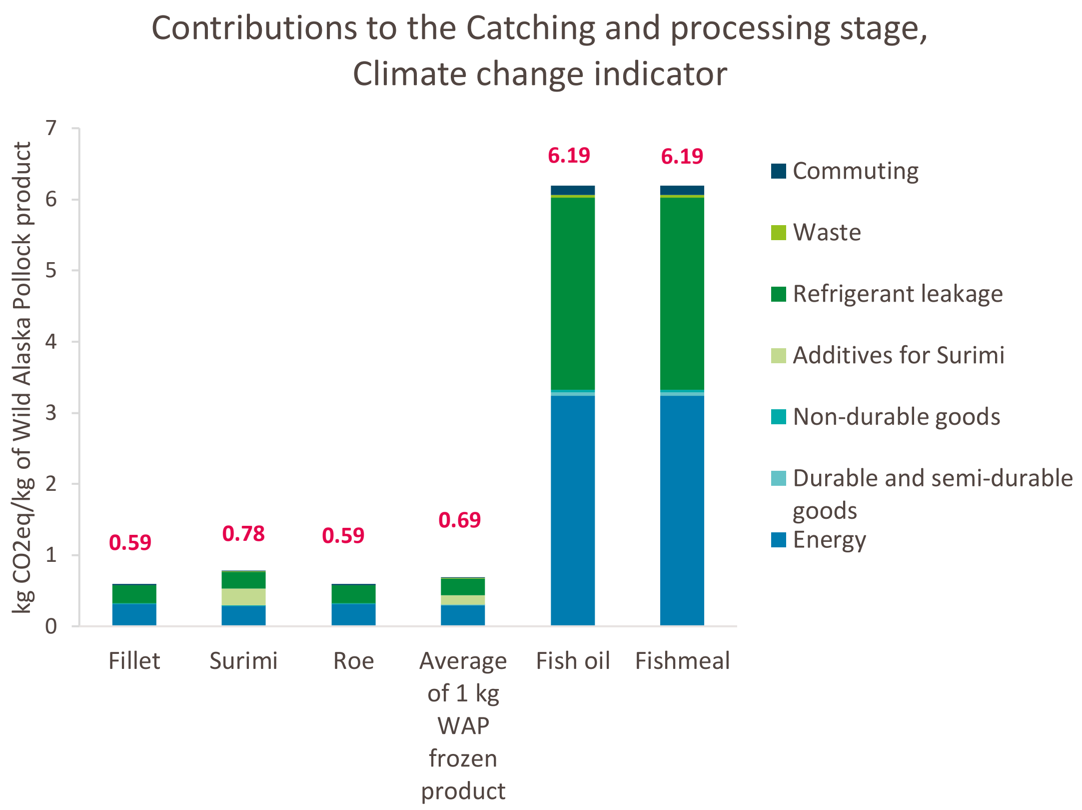


Figure 12. Catching and processing stage contribution analysis to the Climate change indicator for the six Wild Alaska Pollock products (based on IPCC, 2013)

5.2.2 Land use indicator results – Catching and processing stage

The Land use indicator results are highest for surimi, which is driven by the upstream impacts of additives and ingredients incorporated into the surimi product. Thus, these impacts are unrelated to the Wild Alaska Pollock, and are attributed to the additives. Additives with high Land use results tend to be agricultural products, especially sugar, that require either land occupation or land transformation during their cultivation.

For other products, the impact mainly comes from the production of paint as a maintenance material, and the production of water filters, which are used to desalinize the sea water.

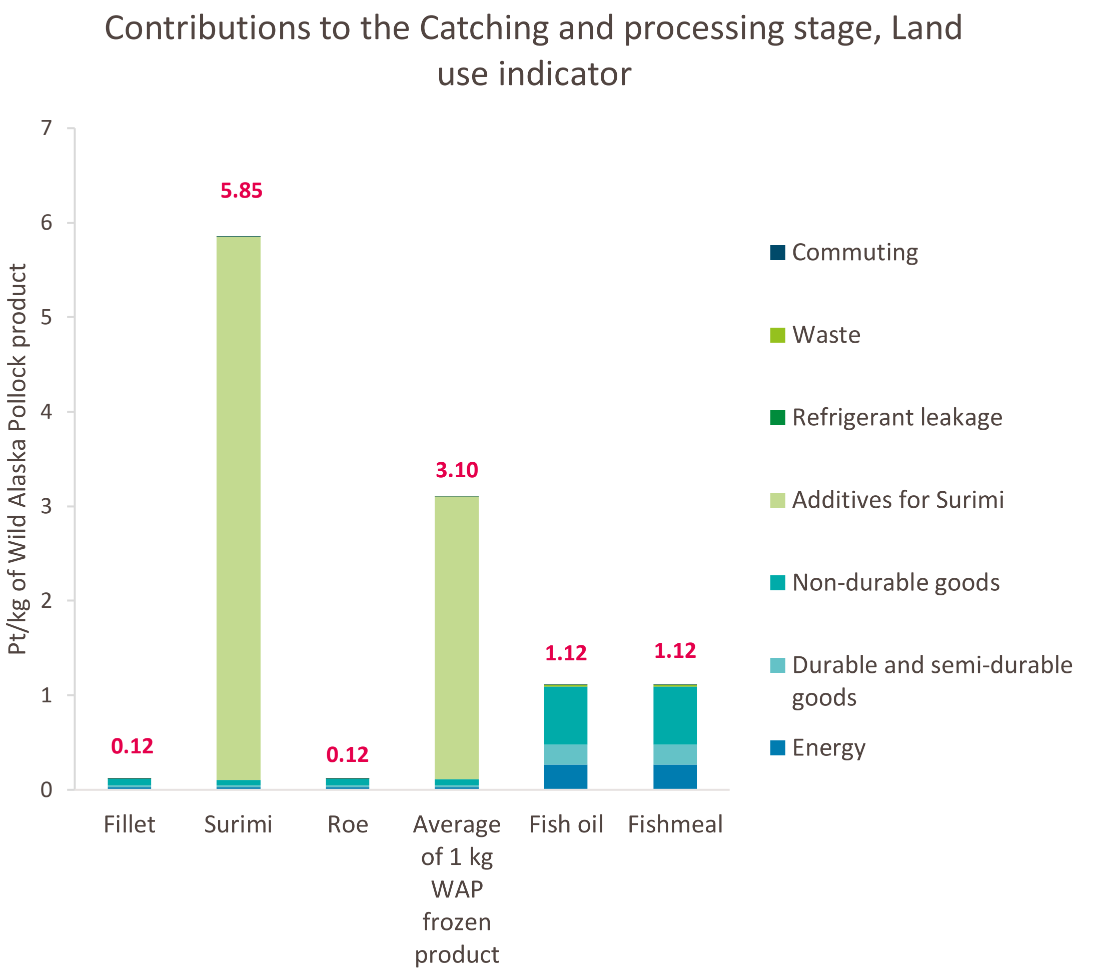


Figure 13. Catching and processing stage contribution analysis to the Land use indicator for the six Wild Alaska Pollock products (based on Beck et al. 2010 and Bos et al. 2016)

5.2.3 Water consumption indicator results – Catching and processing stage

Figure 14 presents the Water consumption indicator results for the six functional units. Because some activities within the Catching and processing stage are net positive water consumers and others are net negative, the red dot indicates the overall net Water consumption value for this stage. The main contributor under non-durable goods is purchased tap water. The negative Water consumption values result from wastewater sent to a wastewater treatment plant, which means during the wastewater treatment process there is water sent back to the environment. Notably, the Additives for surimi are relatively large consumers of water, likely due to the agricultural origins of the additive ingredients and the water demands of cultivation. Otherwise, Non-durable goods are a meaningful contributor to Water consumption, mainly due to the purchased water used during processing for cleaning.

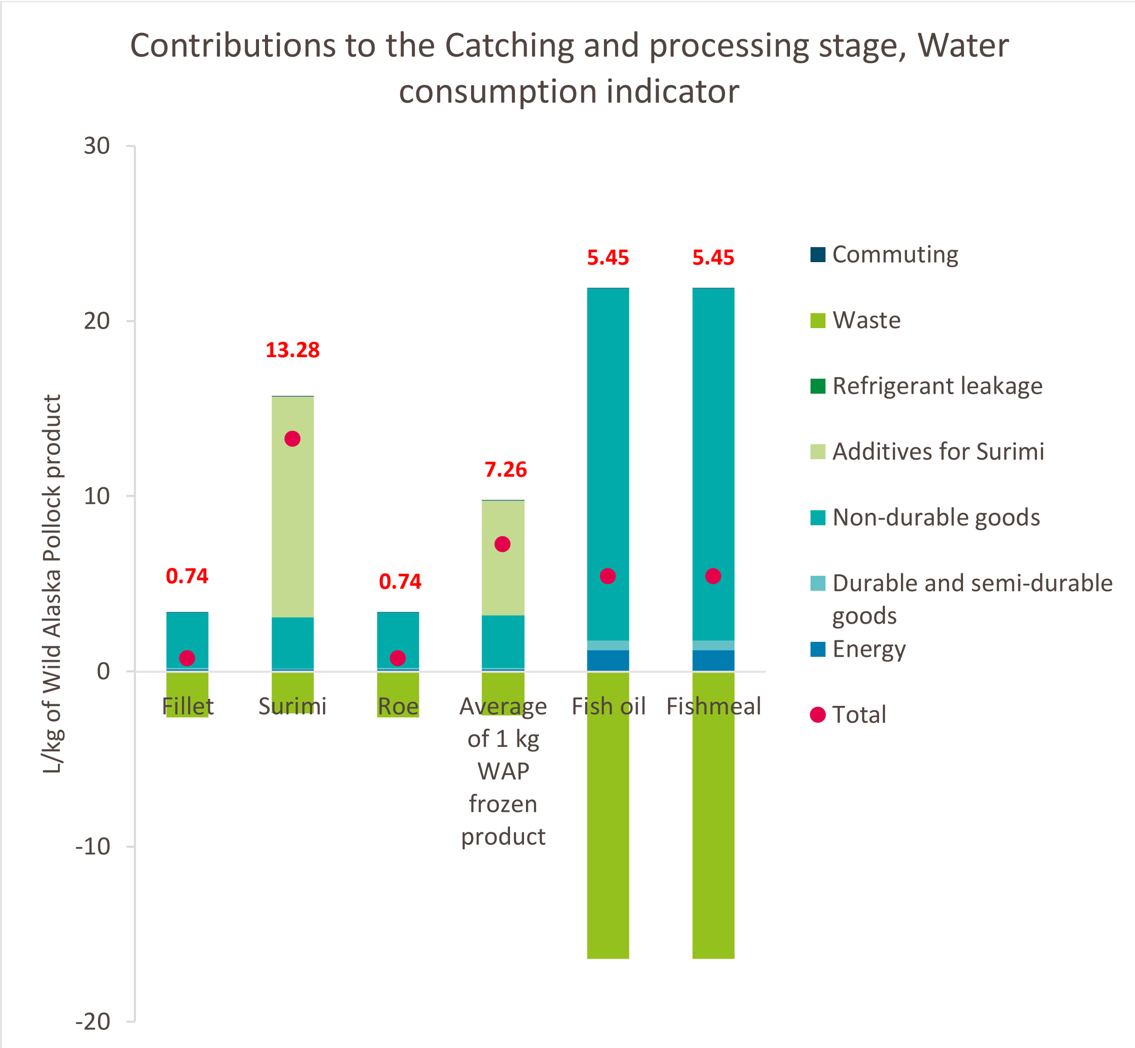


Figure 14. Catching and processing stage contribution analysis to the Water consumption indicator for the six Wild Alaska Pollock products (based on Impact 2002+)

5.3 Scenario and Sensitivity analysis

5.3.1 Scenario analysis with economic allocation

Allocation among co-products from the processing of Wild Alaska Pollock plays a significant role in this study. To test the sensitivity of the results to the choice of allocation methodology, results with an economic allocation metric among co-products are provided below.

Shown in Figure 15 are the Climate change indicator results for the six functional units for both the mass allocation and the economic allocation. Overall, the use of a mass metric results in a relatively lower impact (as compared to economic allocation) for the frozen Wild Alaska Pollock products (fillet, surimi, and roe), by pushing more of the Catching and processing impact to fishmeal and fish oil, which have a relatively low unit economic value but consume a higher volume of fish parts per unit of final product.

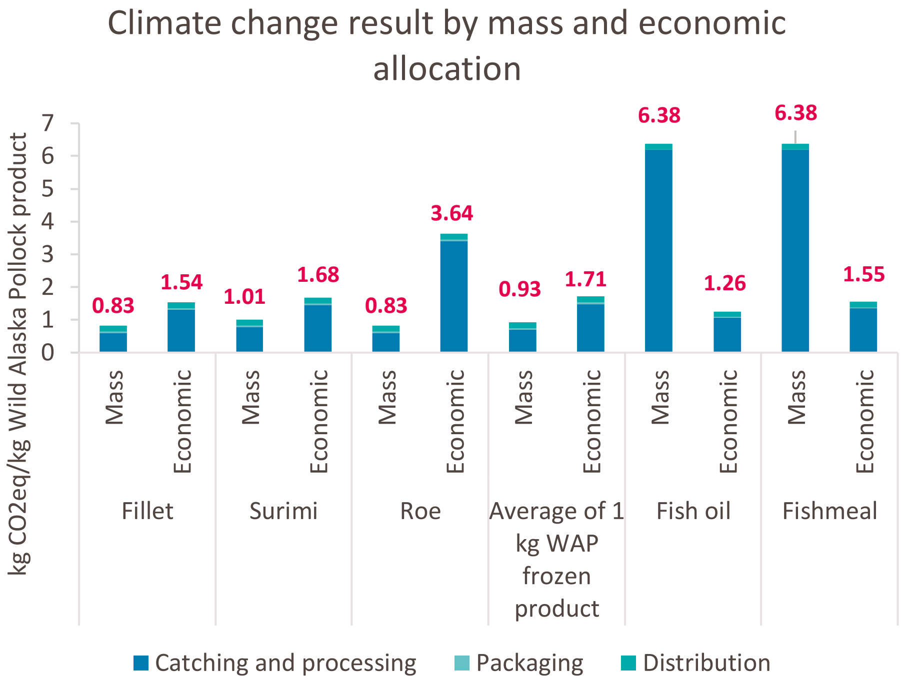


Figure 15. Sensitivity test using an economic co-product allocation metric (based on IPCC 2013)

- Fillet – 186% of mass allocation/baseline result
- Surimi – 166%
- Roe – 439%
- Average frozen product – 185%
- Fish oil – 20%
- Fishmeal – 24%

The underlying mass and economic metrics, as well as the results data to support these charts, can be found in Appendix B. In this study, 3-year weighted average prices are applied to take into account price variability, using economic values from the years 2016, 2017, and 2018. When the relative economic values change significantly within these co-products, the result would be expected to change as well, due to the use of economic allocation.

5.3.2 Scenario analysis with using ammonia as the only refrigerant

Refrigerant leakage is another big contributor to the total Climate change result, mainly because of the consumption of freon. As noted above, CFC-12, which has a high global warming potential, is used to represent freon refrigerants in this study. There are several different types of refrigerant consumed in this industry, including freon, R507, CO2, R22, R134A, R404A, and ammonia. To test the potential impact of substituting refrigerants with low global warming potential, a scenario analysis using ammonia as the only refrigerant is carried out in this study.

Due to the relatively low global warming potential of ammonia, and the relatively low impact during the production stage, the total Climate change result goes down about 30% compared with the baseline result.

- Fillet – 69% of using ammonia as the only refrigerant/baseline result
- Surimi – 77%
- Roe – 69%
- Average frozen product – 73%
- Fish oil – 58%
- Fishmeal – 58%

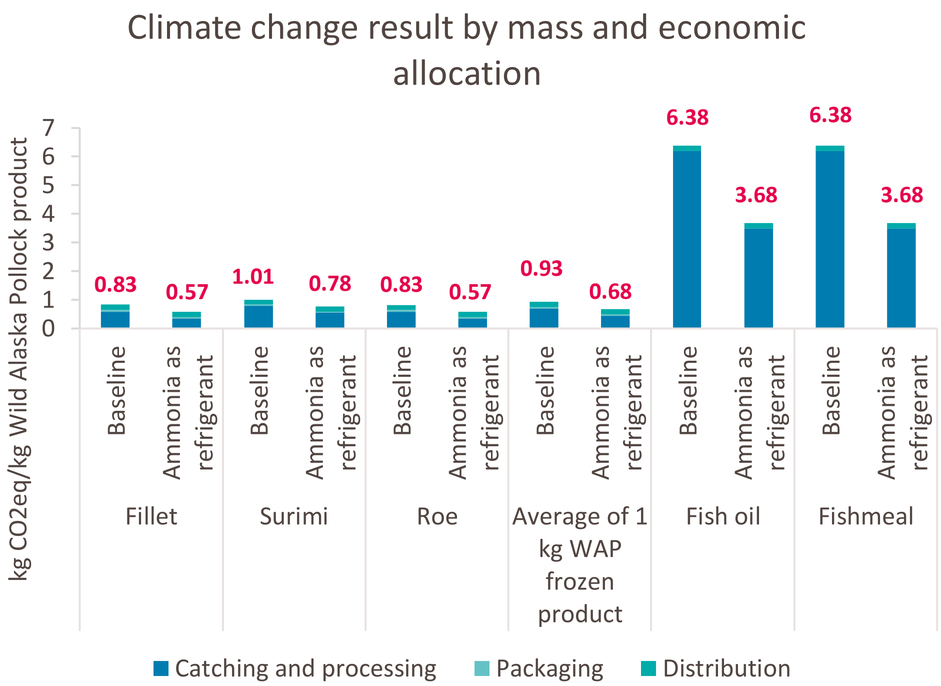


Figure 16. Scenario results for using ammonia as the only refrigerant (IPCC 2013)

5.3.3 Sensitivity analysis for diesel consumption

Given the importance of energy-related activities (i.e., fuel and electricity use) to the indicator results across the Wild Alaska Pollock products, a sensitivity test has been carried out on the quantity of diesel consumption during Catching and processing (this excludes diesel consumption used to process fishmeal and oil). Diesel is the top contributor to the Climate change indicator, and given that some data extrapolation has been done to apportion the total diesel consumption to processing fishmeal and fish oil (see Section 4.2.6 for more details), there is a degree of uncertainty in data quality.

Shown in Figure 17 are the results under the baseline scenario as well as plus and minus 10% (+/-10) diesel consumption quantity. The choice of +/-10 was based on consideration of the data quality.

With diesel consumption fluctuating 10%, Climate change indicator results for surimi and average frozen product rise or fall 3%, while for fillet, roe, fish oil, and fishmeal it would rise or fall 4%. From this analysis, it can be concluded that the results across the six Wild Alaska Pollock products would not change substantially. It should be recommended, however, that in future work, diesel data collection be emphasized for its importance.

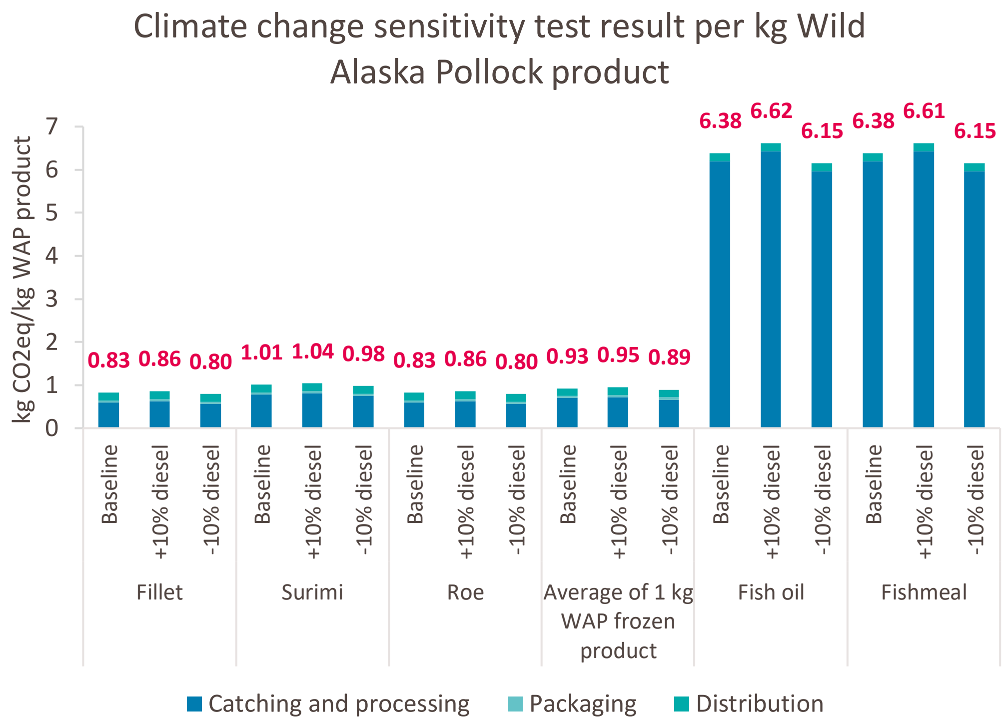


Figure 17. Sensitivity results for diesel fuel consumption (IPCC 2013)

6 Key Findings

The results of this cradle-to-distributor life cycle assessment of various Wild Alaska Pollock products reveal that per kg of distributed product (to the East coast of the US):

- Climate change indicator results may vary from 0.83 to 6.38 kg CO2eq (for roe to fish oil and fishmeal, respectively);
- Land use indicator results may vary from 1.14 to 17.1 Pt (for fishmeal to surimi, respectively);
- Water consumption indicator results may vary from 1.40 to 13.97 L (for roe to surimi, respectively).

Within the Climate change indicator results, Catching and Processing dominates the impact of the product. Energy, mainly diesel, is the top contributor to the Climate change indicator. Focusing on reducing diesel consumption, or seeking low-carbon alternatives, would help reduce the impact. Refrigerant leakage is another big contributor to the Climate change indicator. Focusing on reducing leakage and seeking low-carbon alternatives would help reduce the impact.

Within Land use, Packaging is the top contributor to the impact of the product. The majority of the Land use indicator results comes from wood pallets. Improving the reuse rate and introducing recycled content would help reduce the impact.

Within Water consumption, the Catching and processing life cycle stage dominates the impact of the product. Surimi has a significant higher Water consumption results due to the production of additives. Water consumption for other products is mainly from the purchased tap water used for cleaning.

These results are highly sensitive to the choice of co-product allocation metric. In the baseline results of this study, a mass allocation metric was used to apportion the impacts of Catching and processing across the various useful outputs of processing. When an economic allocation with wholesale price metric is used, the results of all frozen products significantly increase. For 1 kg of average frozen product, the Climate change indicator result shifts from 0.93 to 1.71 kg CO2eq, and for roe it shifts dramatically from 0.83 to 3.64 kg CO2eq. For fish oil and fishmeal, results go down with economic allocation. For fish oil, the Climate change indicator result shifts from 6.38 to 1.26 kg CO2eq, and for fishmeal it shifts from 6.38 to 1.55 kg CO2eq.

The results of this work are on the same order of magnitude as work Fulton (2010) carried out to estimate the Climate change potential of Wild Alaska Pollock fillets (0.59 kg CO2eq per kg fillet product). Care must be taken when comparing results of LCAs carried out with potentially different scopes, system boundaries, and data quality; however, it helps to validate, in broad strokes, that the orders of magnitude are similar, as one would expect.

7 Recommendations

Future environmental footprinting of Wild Alaska Pollock can be improved through the following activities:

- Obtaining a higher data collection / survey response rate, and obtaining product-specific activity data to minimize the need for allocation-, apportionment- and extrapolation-related modeling decisions.
- Obtaining survey data from a more deliberately representative sampling of companies, e.g., from companies operating in the Gulf of Alaska.
- Consider including a plastic leakage indicator among the metrics evaluated to evaluate the potential impact of lost nets in the sea.
- Consider bolstering the evaluation of impacts on biodiversity, both direct and indirect. Over-fishing might be a consideration for wild caught species.

Improvement of Wild Alaska Pollock's environmental footprint can be made by:

- Focusing on reducing diesel consumption, or seeking low-GWP alternatives, would help reduce the impact.
- Focusing on reducing refrigerant leakage and seeking low-GWP alternatives, e.g., ammonia, for refrigerant would help reduce the impact.
- Focusing on packaging innovation to reduce the Land use impact, e.g., improving recycled content, improving reuse rate, exploring low-wood content alternatives.

It is not our intention to make competitive or derogatory claims about other forms of seafood or land-based animal protein, however if any audience would like to gain a deeper understanding of where Wild Alaska Pollock products fall on the animal protein continuum in terms of environmental impacts, please acknowledge the following:

- The scope of studies comparing different animal proteins can be different. This study is a cradle-to-gate study. Distribution after the first-tier customer, consumer use phase, and end-of-life of food waste impacts are excluded. Other studies may have a different scope.
- Wild Alaska Pollock are wild caught fish. There is no cultivation impact associated with the fish catch. Other cultivated proteins (e.g., beef) could have a cultivation impact, including land use and land use change.
- The methodologies used in different studies can vary, including impact calculation methods, data year, allocation method among co-products, and functional unit definitions.

8 Limitations

When using the information provided by this study, the following limitations should be considered along with the context described in earlier sections of this report:

- The direct comparison of this study to other studies may not be meaningful unless the functional unit and goal and scope assumptions are aligned, such as assumptions around the life cycle stages considered and the co-product allocation metric.
- Notable extrapolation has been done to fill data gaps. It is recommended to update the study when data are more representative of the overall GAPP population, especially for key activity data such as energy consumption and refrigerant use.
- This study uses BSAI data to represent both BSAI and GOA. There could potentially be some over- or underestimation, as the catching vessels in GOA tend to have a shorter route than those of BSAI. However, the vessel catching efficiency (catch per unit of effort) might be different, so there is no clear conclusion on whether there is any

overestimation. It is recommended to revisit the study with data from GOA to better represent the fishing information geographically.

- The natural fisheries system results in Wild Alaska Pollock's lower contributions to resource depletion and environmental concerns, from an LCA perspective, and in order to sustain this natural capital the ecosystem enabling this system to function must be protected. Although the health of ecosystem in which the Wild Alaska Pollock are caught was not directly assessed in this study due to the limitations of our methodologies, the relatively low environmental footprint of Wild Alaska Pollock depends greatly on the health of its ecosystem and the services it provides.
- This is a cradle to gate LCA. Downstream activity is not included, including use stage and potentially influential consumer behaviors.
- LCIA results present potential and not actual environmental impacts. They are relative expressions, which are not intended to predict the final impact or risk on the natural media or whether standards or safety margins are exceeded. Additionally, these categories do not cover all the environmental impacts associated with human activities. Impacts such as noise, odors, electromagnetic fields and others are not included in the present assessment. The methodological developments regarding such impacts are not sufficient to allow for their consideration within LCA.
- In the impact assessment models and life cycle inventory data underlying LCA, there are different types of uncertainty, such as parameter uncertainty, model uncertainty, or value choices (Huijbregts 1998; Hertwich and Hammitt 2001a,b). Although it is clear that uncertainties in models and data exist, LCIA methods rarely report uncertainties for their characterization factors. Spatial variability, and the limitations within methods to be spatially explicit regarding emissions that have location-dependent impacts, is an important source of uncertainty to consider in the context of LCA. Further discussion of spatial aspects, as well as other considerations in life cycle impact assessment, can be found in Verones et al. (2017). In the context of the indicators evaluated in this study, some have low spatial uncertainty, namely, GWP, and therefore the reported indicator results can safely be considered representative for any geographic region where emissions might take place. For other indicators, there is high regional variability that is not carried through in the average data considered by the method. Examples of this include the Water consumption inventory, which does not consider variable local scarcity, and acidification, which is highly dependent on the buffer capacity of soils to neutralize acid rain, which is a regional issue. For other LCIA indicators, uncertainty in the results is driven by limitations in the inventory. For instance, for ozone formation and the effect on terrestrial ecosystems, much uncertainty stems from the type of diesel fuel used and emissions controls around the use, which may be correlated to geographic regions due to regulations.

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10 Appendices

For Appendices A, B, C, D, and E, see file “GAPP_WAP LCA_Appendix.xlsx”.

10.1 Appendix 1 – Description of impact categories

Climate change

Model: Bern model – Global Warming potentials (GWP) over a 100-year time horizon (IPCC 2013)

Unit: kg CO_2 eq

Impact category that accounts for radiative forcing caused by greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4) or nitrous oxide (N_2O). The capacity of a greenhouse gas to influence radiative forcing is expressed in terms of a reference substance (carbon dioxide equivalents) and considers a time horizon of 100 years following the guidelines from the Intergovernmental Panel on Climate Change (IPCC 2013). Radiative forcing is the mechanism responsible for global warming.

Ozone depletion

Model: EDIP model based on the ODPs of the WMO with infinite time horizon (WMO 1999)

Unit: kg CFC-11 eq

Impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons). The emission factors are calculated using Ozone Depletion Potentials (ODP) reported by the World Meteorological Organization. The ODP is a relative measure for the potency of a substance to destroy the ozone layer. Stratospheric ozone filters out most of the sun's potentially harmful shortwave ultraviolet (UV) radiation. When this ozone becomes depleted, more UV rays reach the earth. Exposure to higher amounts of UV radiation can causes damages to human health such as skin cancer, cataract and weakened immune system. The impact metric is expressed in kg CFC-11-eq (CFC-11 to air equivalents).

Human toxicity, non- cancer effects

USEtox model (Rosenbaum et al. 2008)

Unit: CTUh

Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter or ionizing radiation. The impact metric is expressed in CTUh (i.e. comparative toxic units for humans in terms of cases, the estimated increase in morbidity in the total human population).

Human toxicity, cancer effects

USEtox model (Rosenbaum et al. 2008)

Unit: CTUh

Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer. The impact metric is expressed in CTUh (i.e. comparative toxic units for humans in terms of cases, the estimated increase in morbidity in the total human population).

Particulate matter

Model: PM method recommended by UNEP (UNEP 2016)

Unit: deaths per kg $PM_{2.5}$-emitted

Sometimes named respiratory effects, respiratory inorganics or winter smog, this impact category measures the potential impact on human health (such as acute and chronic respiratory diseases and asthma attacks) caused by emissions of inorganic particles. It takes into account the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NO_x, SO_x, NH_3) into the air. The impact metric is expressed in deaths per kg $PM_{2.5}$-emitted ($PM_{2.5}$ covers all particles < 2.5 µm).

Ionising radiation

Model: Human Health effect model (Dreicer et al. 1995)

Unit: kg U_{235}-eq

Impact category that accounts for the adverse health effects on human health caused by the routine releases of radioactive material into air and water. The model describes the routine 14 atmospheric and liquid discharges in the French nuclear fuel cycle. The impact metric is expressed in kg U_{235}-eq (Uranium 235 to air equivalents).

Photochemical ozone formation

Model: LOTOS-EUROS model (van Zelm et al., 2008)

Unit: kg NMVOC-eq

Impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials. The impact metric is expressed in kg NMVOC-eq (non-methane volatile organic carbon to air equivalents).

Acidification

Model: Accumulated Exceedance model (Seppälä et al.2006; Posch et al. 2008)

Unit: mol H+ -eq

Impact category that addresses impacts due to acidifying substances in the environment. Emissions of nitrogen oxides (NO_x), ammonia (NH_3) and sulphur oxides (SO_x) lead to releases of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification. The impact metric is expressed in mole H+-eq (hydrogen ions to soil and water equivalents).

Terrestrial eutrophication

Model: Accumulated Exceedance model (Seppälä et al.2006; Posch et al. 2008)

Unit: mol N-eq

Impact category that addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of vegetation in soil. The degradation of organic material consumes oxygen resulting in oxygen deficiency. With respect to terrestrial eutrophication, only the concentration of nitrogen is the limiting factor and hence important. The impact metric is expressed in mole N-eq (nitrogen equivalents).

Freshwater eutrophication

Model: EUTREND model (Struijs et al. 2009)

Unit: kg P-eq

Impact category that addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of algae and other vegetation in freshwater. The degradation of organic material consumes oxygen resulting in oxygen deficiency. In freshwater environments, phosphorus is considered the limiting factor. The impact metric is expressed in kg P-eq (kg phosphorous to freshwater equivalents).

Marine eutrophication

Model: EUTREND model (Struijs et al. 2009)

Unit: kg N-eq

Impact category that addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of algae and other vegetation in marine water. The degradation of organic material consumes oxygen resulting in oxygen deficiency. In marine environments, nitrate (NO_3) is considered the limiting factor. The impact metric is expressed in kg N-eq (kg nitrogen to water equivalents).

Freshwater ecotoxicity

USEtox model (Rosenbaum et al. 2008)

Unit: CTUe

Impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem. The impact metric is expressed in CTUe (i.e. comparative toxic unit for ecosystems in terms of the estimated potentially affected fraction of species (PAF) integrated over volume and time, i.e. PAF*m^3*y).

Resource use, minerals and metals

Model: CML 2002 model (Guinée et al., 2002 and van Oers et al. 2002)

Unit: kg Sb eq

Category that measures the potential impact on resource depletion from mineral and metals resource use. The emission factors are determined on an ultimate reserves and rate of de-accumulation approach. The impact metric is expressed in kg Sb-eq (kg antimony equivalents).

Resource use, energy carriers

Model: CML 2002 model (Guinée et al., 2002 and van Oers et al. 2002)

Unit: MJ

Category that measures the potential impact on non-renewable resource depletion from energy carriers (i.e., fossil fuels and uranium). The impact metric is expressed in MJ (megajoules).

Land use

Model: Soil quality index based on LANCA model (Beck et al. 2010 and Bos et al. 2016)

Unit: points (dimensionless)

The LANCA® (Land Use Indicator Value Calculation in Life Cycle Assessment) model assesses the environmental impact from land occupation and land transformation through four indicators: biotic production, erosion resistance, mechanical filtration and groundwater replenishment. The European Commission Joint Research Centre (JRC) aggregated these into a single Soil Quality Index. The LANCA®

Water scarcity footprint

Model: AWARE 100 (Boulay et al., 2016)

Unit: m^3 water deprived-eq

This impact indicator assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. It is based on the AWARE 100 model, the recommended method from WULCA for water consumption impact assessment in LCA.

10.2 Appendix 2 – External Critical Review Verification Letter

Appended below is the final critical review verification letter from the expert panel, dated July 16, 2021, followed by the panel's earlier comments and Quantis' responses.

Prior to finalization of the report, Quantis made the following additional changes in an attempt to, in part, address the residual issues identified in the panel's letter:

1. Added text to clarify that the primary data used in this study only record when freon was used but do not specify CFC-12 vs. other options. Therefore, Quantis chose to model using CFC-12 for freon as a conservative assumption. Quantis also added additional mention of the scenario analysis using ammonia as the sole refrigerant.
2. Expanded Table 6 to include all Inventory results (beyond just refrigerants and energy), and added Table 7 to show Inventory results for fish oil.
3. Added text to further explain the approach used to model employee commuting (Section 3.4.1).

Ms. Sarah Beaubien
Director, Quantis US
240 Commercial Street #3B
Boston, MA 02109

July 16, 2021

Dear Ms. Beaubien,

We write as the three-member Review Panel commissioned to: 1) provide guidance to the process of completing, and 2) undertake a final critical review of Quantis' Life Cycle Assessment of Wild Alaska Pollock: Final ISO LCA Report, dated July 15, 2021, to assure it conforms with International Organization for Standardization (ISO) 14040 and 14044 guidance documents for conducting life cycle assessment (LCA). This letter communicates the overall assessment of our review and provides a final short list of additional details that could be addressed as the report is finalized. Completion of these would be ideal but are not mandatory.

Members of the Review Panel and signatories of this letter are:

- Ray Hilborn, Professor, School of Aquatic and Fishery Sciences, University of Washington
- Friederike Ziegler, Senior scientist, Research Institutes of Sweden, and
- Peter Tyedmers, Professor, School for Resource and Environmental Studies, Dalhousie University (chair of the Review Panel).

The Review Panel was established and initiated work in April, 2020. As a panel we have reviewed and provided detailed feedback on an initial Goal and Scope document provided by the Quantis analysts leading this work in June of 2020. In June of 2021, we reviewed and provided detailed feedback on a Draft final report that was accompanied by a set of Appendices and related files. Then on July 15, 2021 we were provided with a revised version of the final report that we have all now reviewed. Before and between these major review activities, members of the Review Panel were also frequently consulted and provided advice related to a wide range of data acquisition and handling issues that the Quantis team encountered in undertaking this LCA.

Overall, we concur that the LCA study described above meets ISO 14040 and 14044 requirements for the public disclosure of comparative statements.

There are residual issues that we have identified in our review of the revised final report that have been previously communicated to the Quantis team via e-mail but are briefly reproduced below. In our view, addressing these issues in the report would be ideal but are not essential for the report to meet ISO standards. The issues that would ideally be addressed are:

- In the report it appears that it is an assumption that the main Freon refrigerant lost on fishing boats is CFC-12. If it is an assumption this would be good to make clear. If it is based on data provided by one or more firms then this should be indicated. This is an important issue as refrigerant loss has been found to represent a substantial source of life cycle greenhouse gas emissions from the Alaska pollock supply chain and there are many Freon refrigerants also in wide usage and some have much lower global warming potentials than CFC-12.

- In our feedback on the draft final report, we'd urged inclusion of detailed life cycle inventory (LCI) data in the body of the final report itself. Though some important LCI data have now been included in the report (related to fuel use and refrigerant loss when fishing), these reported LCI data are limited. If more detailed LCI data are being withheld purposefully to limit disclosure of sensitive business operational details this should be stated. If they are not being withheld for these reasons, we would urge greater inclusion of a wider set of LCA data related to at least some of the major sub-systems.
- The revised final report has substantially improved the transparency around key issues, like the mass flows through pollock processing stages, that had been previously difficult to follow. However, other details of data analysis steps and assumptions employed to quantify other inputs to the system being modelled, but that often make smaller contributions to overall results, remain obscure. Some of these can be discerned from a careful read of some of the supporting materials but others can not. In the interests of greater methodological transparency, it would be ideal if more of the analytical steps and assumptions made were evident in the body of the final report or in an appendix.

This has been an interesting project to have been part of. We applaud the entire team that has been central to seeing this project through to completion, particularly given the unusual challenges that everyone has encountered along the way. Well done Xinyue, Ron, Adam and Melissa.

Sincerely,

Ray Hillborn, PhD

Friederike Ziegler, PhD

Peter Tyedmers, PhD

Review of the study "Life cycle assessment of Wild Alaska Pollock"

Compilation of Reviewer Comments and Quantis Updates

Commissioner: GAPP; Author: Quantis team

Reviewers: Prof. Peter Tyedmers (Dalhousie University), Dr. Friederike Ziegler (RISE Research Institutes of Sweden), Prof. Ray Hilborn (University of Washington)

Date: July 8, 2021

1. General/overall comments

Nr.	Integrated Comments from all Reviewers	Decision	Updates
1.1	Fourth Key objective does not seem to be addressed in the report	Yes	**Added some language in the recommendations section about important considerations when comparing to other proteins.**
1.2	too bad that ultimately no GoA data were either forthcoming or useable. But the share of total catch is small and as such overall results would not likely be affected much.	-	**No action needed.**
1.3	In the discussion of cut offs, you indicate that a test was undertaken to try and identify those inputs which make trivial (<1%) contributions to LCIA results. It's unclear though what came of this effort. I don't want to overly complicate things but it would also be useful to know if the <1% was only in relation to GHG emissions or did you also look at the relative contributions of detailed inputs across other imapct categories included? In additon, please specify if single processes were excluded if estimated to represent <1% or if all processes excluded together should represent less than 1%.	Yes	**Modified this language to clarify that we collected all data points based on PAS2050-2, included all data when available or able to be estimated (even some data points with <1% contribution).**
1.4	Not exactly sure where this should appear but after reading all the way through the inventory section, I realsed I saw no details on the non-fish inputs to surimi other then they only account for 9% of the mass of the final surimi product. I'm hoping that these inputs have been characterized in the modeling and if so, they need to be described somewhere and ideally included in an inventory table	Yes	**The non-fish inputs to surimi are characterized in the modeling (see Appendix D_Data Quality line 100-103). Added a paragrah/bullet points in 3.4.1, Processing inventory data, on non-fish inputs to surimi.**
1.5	the description of the mass balance test that was performed and how data from one sub-sector were used to characterize another was quite opaque. This could be argued as a writing sytle issue and there be beyond our purview but I would encourage effort to be a straightforward transparent with your methods descriptoin as very useful for all readers.	Yes	**Updated language to clarify.**

1.6	re the yield rate of fish oil. The ratio is really unclear. Moreover, we're all very concerned with the implied yield rate of oil from fresh material mass. A 1:2.5 ratio implies a yield of oil from live weight mass of fish tissue of 40% - or are we completely misreading this ratio?? Such a high yield rate of oil from mass of fresh fish tissue is simply impossibe. The highest fish oil yield rate from whole fish biomass we have come across is ~20% - this would equate to a ratio of 1:5. But that is in menhaden. In whitefish species like AK pollock, fish oil yield rates from whole fish tends to be in the mid single digit range (say 5-6%) while oil yield rates from trimmings from whitefish tends to be lower still and can be as low as 2%- this latter value would be a ratio of 1:50	Yes	**The mass allocation approach and corresponding results have been modified to reflect fishmeal and fish oil as co-products, following approval for our modified approach from the panel via email. The discussion of yield rates has been updated and clarified in Sec 4.2.5, Table 3, and Figure 5 of the report.**
1.7	Re Table 6. this will be a very useful Table but the column heading "catch weight to wild Ak Pollock weight ratio" is very cryptic and I think an incorrect statement of what is represented. I think what you are trying to report in the column below is the ratio of the final product form mass to fresh pollock biomass ratio but what is described is something else. Separately, in addition to the very serious problem with the fish oil to fresh pollock biomass ratio (1:2.5) as noted above, the ratio you report for fishmeal is also very confusing to verging on the highly unlikely. In most reduction plants that process round fish, you see a fish meal yield rate of 20 to 22% - this would equate to a ratio of 1:5. The ratio that you report (1:10.5) implies a yield rate of 9.5% which is very low.	Yes	**Renamed column to reflect percentage yields rather than ratios and updated yields based on revised approach (see comment above).**
1.8	Re the wholesale prices in Table 6. Great that these are available as they are often not but there might be a challenge with the use of the wholesale prices for fishmeal and oil in the context of allocation. What is ideally needed in any subsequent economic allocation undertaken is the value of the pollock processing co-products at the point of initial processing - where the portions of the pollock that are destined for different products separate, and before their further transformation (e.g. reduction to meal and oil) happens. Using the wholesale prices of meal and oil will I suspect overrepresent the value of these co-products in an economic allocaiton model	Yes	**Since the pollock parts before transformation are not products and never get sold, the price for pre-transformation pollock is not available. The best data available is the price of final products. We updated the language in 4.2.5 to be clear.**
1.9	I'm on the fence as to whether to raise this but here goes. First I think it very good that more than just GHG emissions are being modeled and reported. But choice of additional impact categories to include seems automatic and non-specific or tailored to the product and related concerns. So on the one hand, great that you've adopted the suite of IC used in the PEF but some seem highly irrelevant in the case of a set of fisheries products. The most obvious ICs that seem less than useful are Land Use and perhaps water consumption. There is no need I think to remove these from the results but an aspect of good practice that seems to be increasingly skipped over is the throughtful identificaiton and motivation of the specific IC of concern to be addressed	Yes	**Added that these ICs were chosen 'based on GAPP's interests…' in 5.1**

	In order to interpret the characterised results, there is a clear need for a table of key inventory results per tonne of WAP landed in the text (I can find the LCI table hidden in Appendix D "Data quality"), either for each type of fishery and year or just a merged one that at least shows the average and range in fuel use intensity and the amount of refrigerant leaking per tonne of fish landed, since these two data points determine so much of the results. For each data point it would also be good to know how much data was available, just assuming that data on fuel use was easier to get than refrigerant use. One or two well constructed inventory tables, or if easier one inventory table per individual FU would substantially improve transparency and facilitate easier interpretation of the characterized results	Yes	**1. Added a sentence in 4.1.2. Per ton of WAP landed (fish caught), 3.5 MJ of diesel fuel and 0.09 grams of refrigerant leakage. 2. Data coverage rate for each sector breakdown by categories (e.g. energy, non-durable goods) is added as confidential appendix E**
1.1	Intimately related to the issues identified above re to the apparent yields of fishmeal and oil are then the results of the GHG emissions associated with these two products. If in what are typical situations where the yield of fishmeal is in the range of 20% from wet weight biomass and oil is in the range of say 5% then we would expect that the biomass required to provide 1 kg of oil is substantially larger (actually 4x larger) than that required to provide 1 kg of meal. Consequently, the GHG emissions associated with catching the greater fish biomass would also be substantially higher (4x) for oil then for fishmeal. But this is not what we see in Fig 5. So either the yield rates are truly very unusual (oil yield rate is much higher than fishmeal yield rate for the first time in all reduction fisheries) OR you have got things very mixed up/confused in the modeling of yields and hence GHG emissions. To provide some context for the relative scale of typcial oil and meal GHG emission intensities for fishmeal and oil (including when derived form AK pollock) see Cashion Parker and Tyedmers 2017 Global reduction fisheries and their products in the context of sustainable limits. in Fish and Fisheries. Though we raise this in the context of GHG emissions, the effect of odd/incorrect yield rates for meal and oil will also affect results for the other IC considered, particulalry when the catching and processing phase is a hotspot (as it seems to be for most if not all)	Yes	**The mass allocation approach and corresponding results have been modified to reflect fishmeal and fish oil as co-products, following approval for our modified approach from the panel via email. In this case the mass allocation approach generates identical results for fishmeal and fish oil functional units. Added discussion on this throughout, particularly Sec 4.2.5 and Sec 5.1.1.**
1.11	setting aside here the concern re the relative scale of the emissions associated with fishmeal and oil, in this Figure, we're all struck by the enormous role that refrigerant losses play in overall GHG emisiosns from these products. This is a very unusual finding - but not completely unheard of, particularly when the fishery is a low fuel intensive fishery. Would you do us a favour though, please double check the refrigerant loss data and associated calculations. and then the simapro model to confirm the numbers. It's just product to undertake a double check like this when there is such an anomolous hotspot in a system like this. If the data stand up, this is definitely an important finding to frame recommendaitons around given the scope of emission reduction potentials that appear possible. FZ adds to this comment: It seems that the importance of the refrigerants is entirely due to the modelling as emission of CFC-12. Do you actually have information this is a refrigerant used or was it an assumption for the general "freon" category? It would also be good to understand if you got data on this from all respondents or from fewer than those that provided fuel use data e.g.	Yes	**1. The data we collected from each company includes the Freon consumption. A conservative assumption on CFC-12 is used in this project. The calculation has been checked. 2. A scenario analysis using Ammonia as the only refrigerent has been added in the report.**
1.12	Also related to Figure 12 (and 13) is the appearance of commuting amongst the sub-system activities/inputs modeled. I don't recall anything about this being described. What was the scope of this input?	Yes	**Added a paragrah/bullet points in 3.4.1, Catching/Processing inventory data, on employee commuting**

1.13	Regarding the economic allocation modelling. We want to check whether you used just the relative value of the co-products or the relative value of the co-product revenue stream (wholesale price times mass of each co-product produced in a year)? When the scale of the co-product streams are very different as are here, and their unit wholesale prices are also different, the difference in these two approaches can be very significant! I've just now read page 49 lines 11-12 where you indicate that you used wholesale prices without first multiplying them to the size of the co-product streams. If this is indeed the case, this needs to be re-visited.	Yes	**Thanks for raising this. We used wholesale price * production to allocate the catching and processing impact across wild alaska products, then normalized the results to per kg product. Reworded language in 4.2.5 and section 6(page 49 lines 11-12) and make it clear.**
	We don't understand the negative water use from waste. It needs to be explained in text and in the caption.	Yes	**Added a sentence to 5.2.3, The negative water consumption values result from wastewater sent to a wastewater treatment plant, which means during the wastewater treatment process there is water sent back to the environment.**
1.14	great that you looked at the effect of an increase or decrease in the fuel use intensity of the fishery on LCIA results but I'm surprised that you didn't also consider modelling a scenario in which a different refrigerant is used as the consequences of say a straight substiution of a refrigerant is poteniallly much more achievable and results potentially much more dramatic and would likely result in variable effects between impact categories	Yes	**See 5.3.2. We added a scenario analysis using ammonia as the only refrigerant to the report.**
1.15	The entire recommendations section seems to be surprisingly brief. Separately, the final bulleted recommendation regardign the potential effect of reducing loss of refrigerants or substiution with those with a low or zero GWP would ideally be supported with a scenario analysis as noted above. Improvements are only suggested for climate.	Yes	**Added 5.3.2 to support the refrigerant recomendation. Added a bullet point for Land use recommendation.**
1.16	Re the references. It may have been intentional but it is interesting that you've choosen to not try and compare, despite the cautions needed, to make any sort of comparison with previously published results. In addiiton to the GHG emisison estimates for fishmeal and oil derived from AK pollock reported in Cashion Parker and Tyedmers 2017 Global reduction fisheries and their products in the context of sustainable limits. in Fish and Fisheries, there is a paper by McKuin 2019 (Climate forcing by battered and breaded fillets and crab-flavoured sticks form Alaska pollock. Elementa) that could provide a pre-existing source of GHG emisiosn numbers for surimi that could be used as a basis of comparison. But this context making or comparison might be beyond the scope of what you agreed to do.	Yes	**Indeed we have deliberately avoided comparisons as being beyond scope here but we have added a reference to Fulton (2010), along with a caution about making comparisons between studies.**

2. Specific comments

Nr.	Integrated Comments from all Reviewers	Decision	Updates
2.1	Peter Tyedmers home department name is School for Resource and Environmental Studies	Yes	**Typo fixed**
	perhaps refer to estimated impacts rather than potential impacts	Yes	**Language changed**

2.2	as noted later in the report, you aren't assessing environmental impacts when using mid-point indicators but contributions to prenomena of concern. This is admittedly a very nuanced observation and you can address it or not.	No	**For clarity of purpose to the lay reader, we will keep as is here, but have nuanced the language at several other places in the report.**
	Not sure what "leading" means in this context	Yes	**Removed the word 'leading'**
2.3	PAS 2050-2 applies to seafood and other aquatic food products generally not just those from fisheries	Yes	**Specified using the title of the standard**
2.4	As a comment above, mid-point indicators don't tell us what the environmental impacts are. Better phrasing might be: Understand the contributions that produciton of Wild Alaska Pollock products make to resource depletion (e.g. energy use, water use etc0 and environmental concerns (e.g. climate change, etc). ...	Yes	**Substituted in the suggested language**
2.5	Sorry if I'm a pedant (this is PT) but again, not measuring environmental impacts - a point that you do make later in the report.	Yes	**Nuanced the language here in response to comment**
	when referring to catch-processor and shore based processors would it not be better to say catcher processor companies and shore based companies	Yes	**Added 'companies'.**
2.6	again, not evaluating environmental impacts - but again, I may be being pedantic	No	**Kept as is in this case, but point taken.**
2.7	looks like you have an extra 'and' in the sentence. Should be '… catcher vessels delivering to mothership processors, ...	Yes	**Typo fixed**
2.8	this is a confusing paragraph as it starts out as if it is describing the fishery and it's breakdown into sub-fleets but it is really describing the data coverage that you have (data from 6 of 14 catcher-processors etc).. Perhaps better to first in one paragraph describe the compisiiton of the fleets (total number of units, % of total catch etc) and then separately describe your data coverage from those secors in the BSAI. When you state "total" here, do you mean total BSAI?	Yes	**It appears as though the reviewer has misunderstood the percentages - they refer to the % of total catch that is processed by each sector. We have made some minor text adjustments to help clarify.**
2.9	The bulleted breakdown of the sub-sectors in BSAI, the fractions of the total quota sum to 110% of the total. Revisit and make the total quota sum to 100 but then indicate within each how they are harvested. The issue here may be that you are conflating who owns quota (one set of percentages) and who fishes available quota (another set of percentages)	Yes	**The 'extra' 10% is due to the Community Development Quota. We have re-written this section to clarify.**
2.1	Pollock and Alaska are reversed.	Yes	**Typo fixed**
2.11	Table 1 is very useful but the data represented in the far right column is confusing. The description suggests it's a % of the catch in each region - essentially describing the % of the regionally available catch by each sector. But then the NA make no sense. OR are you actually representing say the % of where you received data from? I don't thinnk that it is the latter but it's confusing.	Yes	**Changed table headings and lead-in sentence to clarify.**
	Table 1: very confusing re Gulf of Alaska – why are there no catching volumes and what is the split in vessels??	Yes	**Specified 'no data' instead of N/A. GOA was not used in the analysis.**
2.12	the sentence that starts "The three-year period data are used…" doesn't seem to add anything	Yes	**We have removed this sentence.**
2.13	functional units should be plural	Yes	**Typo fixed**
2.14	Data in table 2 are unclear. Are these sums of the total three year produciotn voluems or averages of the three years. Either way, a bit more detail in the Table caption would be useful.	Yes	**Clarified with lead-in sentence and table caption.**
	"External" review panel rather than "peer"	Yes	**Substituted 'external' for 'peer'**

2.15	In this first paragraph on this page there is frequent reference to supporting materials. Some are referenced as Appendices and others are not (like the versions of the surveys) If they are also to be made available, perhaps ideal to also place them into an Appendix	No	**Confirmed that Appendices are referenced consistently and accurately throughout, and Associated Files are as delineated under 'Project Information'.**
2.16	Table 3. Really good to have these data reported but the Landed 'volumes' (really masses) represented are unclear. Are they tonnes of live weight landings across the three years being characterized or in just one year	Yes	**Changed table headings and lead-in sentences to clarify that it's three years of data together**
	Table 3 number of plants/vessels would be useful	Yes	**This info is covered in Table 1 but we added in the # of vessels per sector for ease of reference**
	Related to the above: If the data originally was provided per year for three years, it is much more interesting to present annual results and then calculate an average than to aggregate the data first.	No	**The info is from 3 years combined, which is the basis for the analysis. PAS 2050-2 calls for an assessment period of three years to take into account biological and environmetnal variability.**
	which three functional units are going to be considered or does that depend on markets?	Yes	**Fixed - this was a holdover from a previous draft when there were only three functional units.**
2.17	you indicate three functional unitis but there are now six. Text looks like a carry over from the scope document and wasn't fully updated. It should be specified that some of the products are frozen in the FU definition	Yes	**See response to Comment 2.17. Added 'frozen' to the description of FU #4.**
2.18	a minor point but it's unclear how trucks are used in the catching of pollock. Is it transport of catch to shore-based processor location?	Yes	**This is a required data point based on PAS 2050-2, which means we should consider this data point during data collection. Added some text to the description to the item description, for clarification.**
2.20	one too many packaging. Did you mean something else?	Yes	**Changed this language to clarify the two types of packaging included in the analysis.**
	how spatially disaggregated is the WECC grid mix for energy – A lot of Alaska has hydropower but I suspect all the shore based processors are 100% diesel generated	Yes	**Thanks that is correct, the updated results will reflect 100% diesel for purchased electricity.**
2.21	re transport mode do you mean that regardless of mode (ship, truck etc0 all containers are refrigerated?	Yes	**Yes, updated**

2.22	you indicate here that commuting of workers was excluded but I think somewhere in the results you have indicated contributions from labour travel by air from homes in the lower 48 states. This was something that had been discussed/encouraged earlier but so far it's not been mentioned. You mention here attributional LCA, but have not stated the type of LCA done here or explained the term and the difference to alternative ways of LCA modelling.	No	**Based on PAS2050-2, there is no indication that the commuting should be included. We've included the air travel from Seattle to Dutch Habor to represent the employee commuting, as virtually all of the company-arranged travel to and from Dutch Harbor is from Seattle. Commuting from other states is not included.**
2.23	instead of saying see associated files starting with xxxxx would it not be better if these materials were in an Appendix as are other supporting materials?	No	**The survey files etc. are supplementary materials and we feel they are best kept separate from Appendices for ease of reference.**
	Should all excluded processes together represent less than 1% or each one? Please specify	Yes	**Updated**
2.24	In the lower part of Table 4, Belly flip shouold be Belly flap	Yes	**fixed (in table)**
2.25	in the space of three sentences, you describe the pedigree matrix scale twice and actually then also reverse the direction in one of them. Is a score of 5 best as initially suggested and in line with table 5 or is 5 worst as described at the top of page 28??	Yes	**fixed the language for clarity and accuracy here.**
2.26	Trends are patterns that occur over time. You are not describing a trend but a simple pattern of resutls. More generally can you make the meaning of the sentence a bit clearer? Something like The data quality assessment for other functional units considered also appear in Appendix D and the patterns found across all are very similar.	Yes	**substituted in the suggested sentence.**
2.27	data are plural. You've previously recognized that data are plural but here you use is instead of are.	Yes	**fixed**
2.28	We like that you've included part of the data quality assessment result for one product as an illustrative item in the report but it's simply unreadable at the scale it is.		**We will enlarge the image and flip this page horizontal once we've made other edits.**
2.29	a great Figure but the source is not indicated	Yes	**Source = quantis. Added to caption.**
2.3	to what does the 1:1 ratio refer? Similarly in the next sentence, to what does the 1:0.91 ratio refer? In the first case (1:1) I think it's fresh product mass to frozen product mass (not additions of glazing water etc) In the second (1:0.91), I think it's surimi mass to skinless boneless fresh pollock meat. But please make it clear for the reader.	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.31	Unclear why you have not reported the apparent fish meal to live weight ratio when you have for oil (which seems problematically high) and it's seemingly reported in Table 6.	Yes	**See comments above about changes to yield discussion and mass allocation approach.**

2.32	It is not clear to me if the proportion of by-products that us wasted was quantified and if this affected the calculations or if it was assumed that all was processed to fish meal/oil. So that the WAP products from the plants without fish meal factory is higher than from others.	Yes	**Language updated. Yes you are right that the WAP products from the companies without meal plant is higher than those with meal plants (if all other inputs are the same), since waste does not carry any enviromental impact. In this study we report the results as an average industry results so the result for companies with or without meal plants won't be reported separately.**
2.32	Regarding the sentence that reflects on the reason behind the relatively high GHG emission intensity of fishmeal. You indicate that it is due to the use of mass allocation and indeed given that 1 kg of fishmeal typically requires 5 kg of wet fish biomass to produce, right away you are going to have higher emission intensities compared to those resulting from fillets when using mass allocation, however, it is also a function of the additional energy invested in the dewatering, cooking and grinding of the meal. Finally, if the yield rate used is incorrectly low - as we suspect it is here given the 1:10.5 product to wet fish biomass ratio that you reported, then you are going to be over-reporting the energy use and ultimately the GHG emisison intensity of the fishmeal production. This highlights why it's REALLY important to get the fishmeal and oil yield rates right.	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.33	Re the data reported in Fig 5. Just as I think that the fishmeal GHG emission values may be being overestimated (perhaps by 2x) I suspect that the fish oil emisiosn intensity may be being underestimated as the seeming yield rate that you have used (1:2.5 or 40%) is crazy high.	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.34	Re the sources of land use impacts of fishmeal and oil. Can you indicate what the source of the land use that arises from fish catching and processing? On it's face, it will be hard for the average reader to imagine how there is any sort of land use dependency, let alone impact that arises from fishing.	Yes	**Added language here. See 5.2.2**
2.35	Re results of the land use modeling, setting aside if this is even a useful IC to report, I think that the 3x higher land use for meal over oil is suspect given the seeming role of catching and processing in both and the issues identified with yield rates	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.36	Re results of the water consumption modeling, setting aside if this is even a useful IC to report, I think that the 3x higher water use for meal over oil is suspect given the seeming role of catching and processing in both and the issues identified with yield rates	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.37	And specifically in relation to the data reported in Fig 10 at the top of p 42, I think that once the fish oil yield rate concern is addressed (from above we are concerned that you are using a yield rate value that is far too high) that the catching and processing hotspot will increas in importance across all of the ICs that you are reporting for.	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.38	this is minor but the pattern that you are seeing in the contribution analysis is not a trend as it does not vary over time. I know that in common parlance everything is now a 'trend', and indeed many things are (like the popularity of a meme over time) but patterns as you are describing in Figs 10, 11 etc are simply patterns and not trends.	Yes	**Trend' has been changed to 'pattern' throughout the document.**

2.39	And specifically in relation to the data reported in Fig 11 at the top of p 43, I think that once the fishmel yield rate concern is addressed (from above we are concerned that you are using a yield rate value that is far too low) that the catching and processing hotspot will will decrease in importance across all of the ICs that you are reporting for. However, it is likely to remain the hotspot but just not account for 90+ % of total contributions.	Yes	**See comments above about changes to yield discussion and mass allocation approach.**
2.4	The presumption re the role of land occupation and land use change as the drivers underpinning the high land use values arising from agricultural inputs to surimi should not be necessary. If you dig into the underying sources of land use for the ingredients used in the background data you have drawn upon you should be able to confirm that this is the case or not	Yes	**Language added in 5.2.2 that discusses the sources of land use impacts.**
2.41	The use of the word 'benefits' in relation to the relative emisison intensity of frozen products in relation to fishmeal and oil seems inappropriate as it seems to be ascribing a preference or desirability for a specific outcome. Ultimately we are attempting to model as far as possible an objective understanding of the world. This is hard enough without introducing the sense that the results can be shaped to accomodate certain desired outcomes.	Yes	**We have changed the language in this paragraph to remove the use of 'benefit', as well as to clarify the meaning of this paragraph overall.**
2.42	re the description of the impact of economic allocation. We're surprised that there is no discussion of the highly unstable nature of the econ allocation results. Wholesale prices of the co-products are going to vary of time and in particualr with respect to each other. These changes would have immediate affect on the econ allocaiotn-based results. Indeed, it is likely that they are no longer valid given the time between when the wholesale unit price data were collected/reported and when the report finally is released.	Yes	**Added discussion of the impact of price variability and relative economic values when using economic allocation.**
2.43	describing refrigerants as low-carbon is problematic as most contain zero carbon. This is the result of using 'low-carbon' to mean low GHG emission intense. Sometimes this verbal conflation is OK but here's an instance where its misleading. So substitute the phrase low-carbon with another that conveys the idea of low GWP or low GHG emission source of refrigerant.	Yes	**Substituted low GWP for low carbon in both the fuel and refrigeration bullet points**
2.44	definitely no cultivation going on with AK pollock	Yes	**Removed 'cultivation' and also removed 'benefits' (and substituted in some additional language).**