LCA of King salmon from New Zealand

On behalf of
Fisheries New Zealand

Document Approval and Revision

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Author(s):	Kimberly Robertson | Senior Sustainability Specialist Tor-Anders Waag Strømsvik | Sustainability Specialist
Reviewer(s):	Gustavo Moraga | Senior Sustainability Specialist Jule Scherer | Senior Sustainability Communicator
Approved:	Barbara Nebel | CEO
Sensitivity:	Not confidential
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Contact:

thinkstep ltd
11 Rawhiti Road
Pukerua Bay
Wellington 5026
New Zealand

www.thinkstep-anz.com
anz@thinkstep-anz.com
+64 4 889 2520

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Executive Summary

Why this report was commissioned

Fisheries New Zealand (FNZ), Aquaculture New Zealand and the New Zealand Salmon Farmers Association want to understand the environmental impact of King salmon farmed in New Zealand over its life. They also want to know how salmon's carbon footprint compares to other sources of dietary protein. The data will help the industry to reduce its environmental impacts and promote salmon as a lower-carbon option to suppliers and consumers.

What we did

We used Life Cycle Assessment (LCA), based on international standard ISO 14044 and Fish and Fish Products Product Category Rules (PCR), to:

- measure the environmental performance of salmon for a range of environmental indicators including Global warming, Eutrophication (freshwater, marine and terrestrial) Acidification and Photochemical ozone depletion (summer smog)
- identify where improvements will have the greatest impact
- compare the carbon footprint of salmon with other forms of edible protein.

Our study looked at three phases: (Figure 0-1)

- **Upstream processes:** growing, making and transporting salmon feed
- **Core processes:** hatching, farming, processing and packaging the salmon
- **Downstream processes:** transporting the salmon to the consumer, cooking and disposing of it.

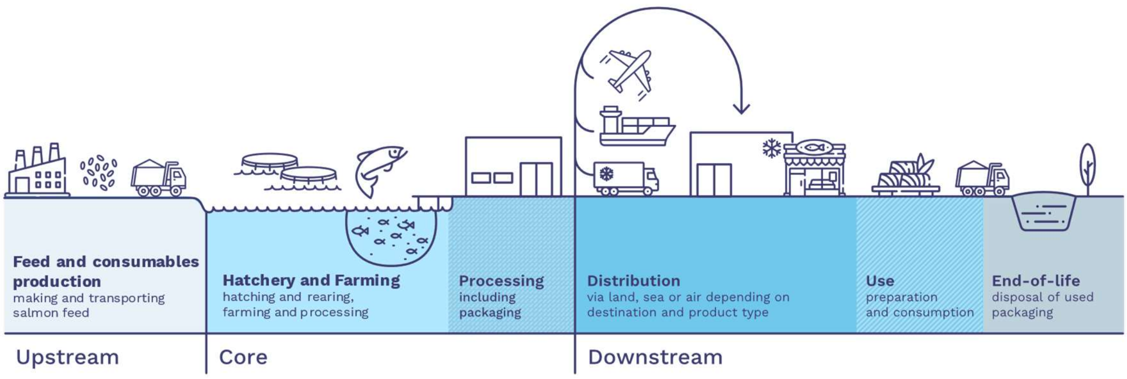

Figure 0-1: Salmon Life Cycle

Our main environmental performance indicators

Carbon footprint:
Measure: climate change – the impact of greenhouse gases emitted

Nutrient losses to waterways
Measure: Eutrophication – adding excessive amounts of nutrients to land and waterways can cause plant and algae growth. This can stem from fertilisers used to produce crops/animals for salmon feed (Eutrophication, terrestrial (EPt)) as well as fertilisers, feed and salmon waste in freshwater ways (Eutrophication aquatic, freshwater (EPf) and the sea (Eutrophication aquatic, marine (EPm))

Acidification
Measure: Acidification Potential – decreasing levels of pH in soils and waterways making them more acidic.

Summer smog
Measure: Photochemical ozone depletion – sunlight reacting with nitrogen oxides and at least one volatile organic compound (VOC) in the atmosphere may affect human health and damage crops.

Table 0-1: Environmental Impacts of salmon, New Zealand distribution (per 1 kg of edible meat)

Indicator	Unit	Upstream	Core	Downstream	Total
Carbon footprint GWPt	kg CO_2 eq.	6.411	1.122	0.695	8.228
Eutrophication aquatic, freshwater EPf	kg P eq.	0.001	0.002	0.000	0.003
Eutrophication aquatic, marine EPm	Kg N eq.	0.035	0.135	0.001	0.170
Eutrophication, terrestrial EPt	Mole of N eq.	0.214	0.041	0.007	0.261
Acidification Potential AP	kg SO_2 eq	0.052	0.009	0.002	0.063
Chemical smog POCP	kg NMVOC-eq	0.028	0.011	0.002	0.040

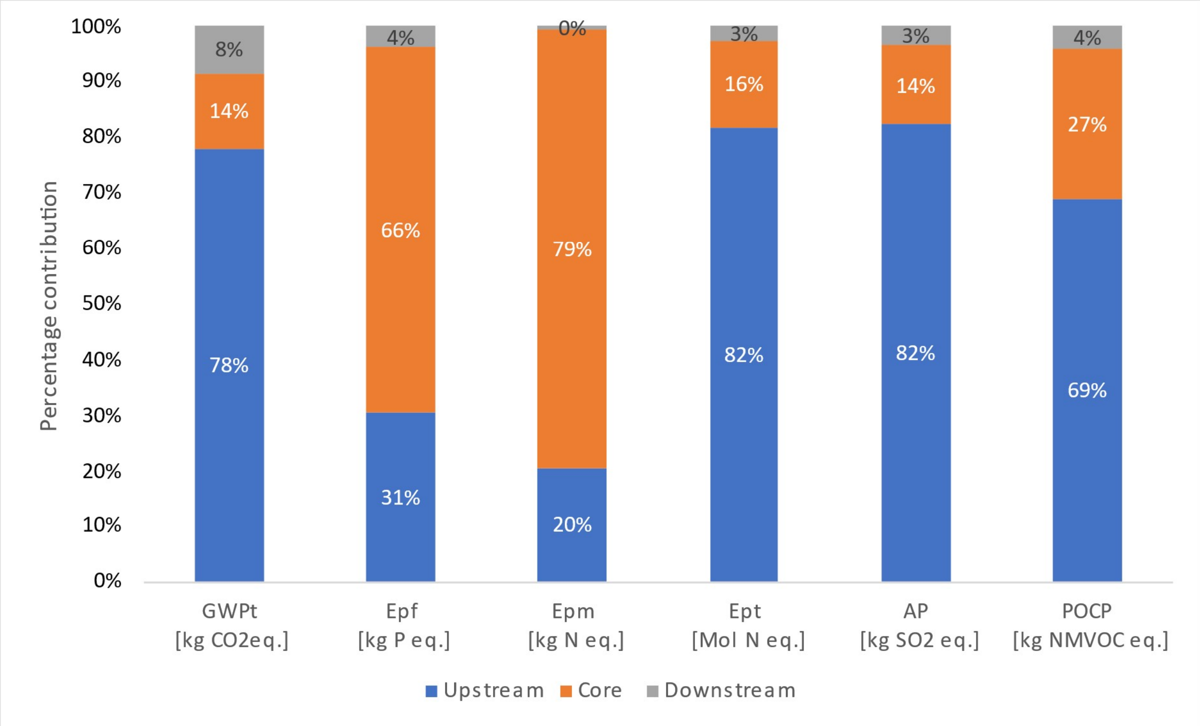

Figure 0-2: Environmental impacts of salmon, New Zealand distribution (per 1 kg of edible meat)

What we found

- In the domestic market, more than 90% of the environmental impacts come from producing salmon feed, hatchery, farming and processing (Table 0-1, Figure 0-2).
- Producing feed (including animal by-products and crops) is by far the largest contributor (78%) to the carbon footprint of salmon sold domestically.
- Feed production also contributes the most to terrestrial eutrophication, acidification and smog formation. Salmon waste entering the water contributes the most to marine and freshwater eutrophication.
- For domestic distribution of salmon, the electricity and fuel the salmon farm uses, contribute the most to the core stage carbon, acidification and chemical smog impacts.
- Customer use (refrigerating and cooking) of the salmon contributes most to the downstream carbon, acidification, freshwater eutrophication and chemical smog impacts.
- Distribution and customer use contribute the most to marine and terrestrial eutrophication downstream impacts.

- Exporting salmon by air freight greatly increases the downstream carbon footprint, terrestrial eutrophication, acidification and chemical smog compared to domestic distribution.

How we calculated the environmental impacts

We used economic allocation to assign the impacts of the feed. This reflects that salmon feed is usually a low-value by-product and assigns the most environmental impact to the high-value product. For example, salmon are fed a variety of animal meals. These are cheap by-products from producing other animal products like meat. The environmental impacts are divided according to the economic value of the animal meal compared to the main product.

Economic allocation is the suggested approach in the EU Commission Product Environmental Footprint Category Rules and the International EPD Programme Fish Product Category Rules and facilitates the discussion about other protein sources. Economic allocation is the least preferred option according to ISO 14044. The choice of feed allocation method has a significant impact on the results. If we allocated the impact according to energy or mass, the environmental impact would increase by 274% and 322% as shown in the sensitivity analysis (section 6.3).

Comparing types of protein

We compared the carbon footprint of producing New Zealand farmed King salmon with producing other protein types. New Zealand-farmed salmon sold domestically has a lower carbon footprint compared to the global average for other animal proteins and is higher than New Zealand mussels and oysters, per 100 g protein. The carbon footprint of New Zealand salmon falls within the range provided by Poore and Nemecek (2018) for global egg, poultry and farmed fish protein. While this study uses protein to compare food types, it doesn't consider that the different protein sources supply the human body with varying amounts of amino acids and are digested differently.

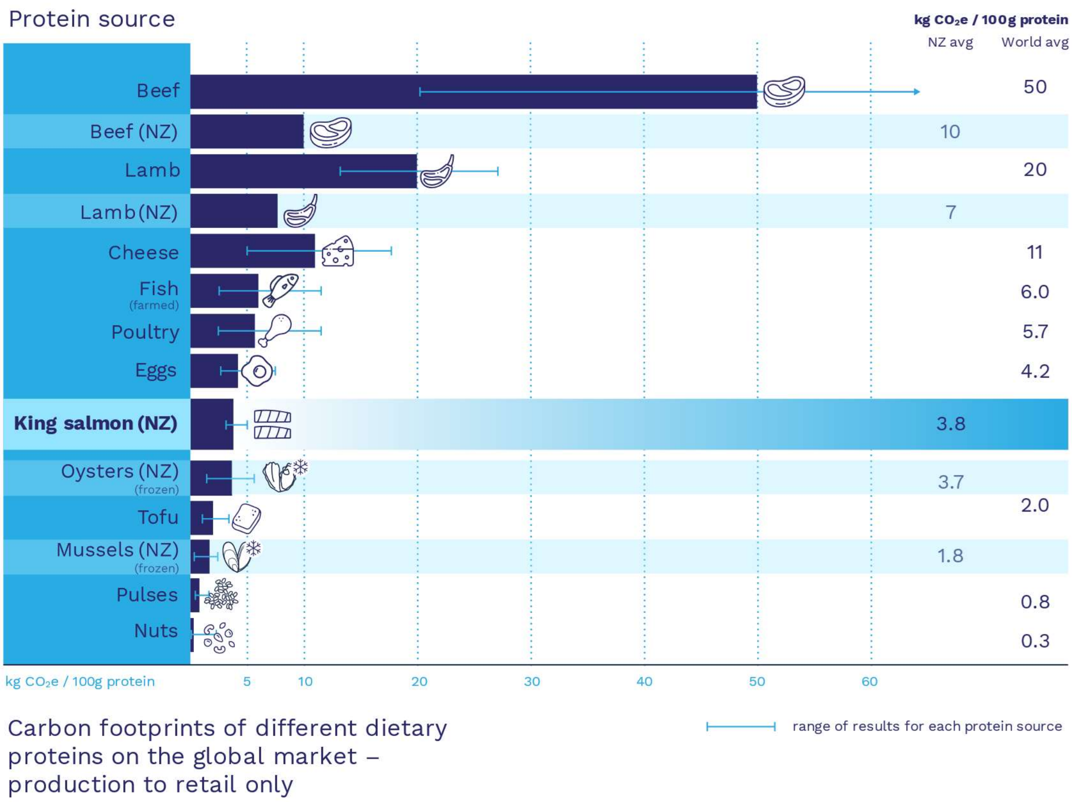

Figure 0-3: Carbon footprints of different dietary proteins on the global market – farming to retail only (per 100g protein) [1]

Our recommendations

Improve salmon feed modelling

The majority of the salmon feed datasets are modelled using geographical proxies. The results would be more accurate if feed input origin and country-specific datasets were available.

Sourcing low-impact feed

Soy protein concentrate and rapeseed oil have a high environmental impact. We recommend working with feed suppliers to identify feed formulations that balance environmental impact, availability, price and nutritional content.

[1] The carbon footprints of the oysters and mussels in Figure 0.3 come from thinkstep (2021). The carbon footprints of New Zealand beef and lamb are from Beef and Lamb NZ (2022), converted to per 100g protein. The other nutritional proteins come from global production data from Poore and Nemecek (2018). All products are shown using a system boundary that spans from farming to retail. The results for salmon are for domestic distribution. The bars in Figure 0.2 are used to show the tenth and ninetieth percentiles (the range within which 80% of producers will fall). These bars indicate the range of results for a particular protein source, due to different production methods, technologies, and locations.

Improving the feed conversion ratio (FCR)

The FCR is the amount of feed needed to produce one kilo of salmon. Reducing the amount of feed lost to the environment, making the feed more nutritious and digestible and using selective breeding could all improve the FCR.

Lowering mortality rate

Making salmon farming more efficient by lowering the mortality rate would lower the environmental impacts.

Reducing transport by air

North America is a large market for the industry. Improving freezing and chilling technology could lead to increased sea freight and lower the transport footprint. Encouraging air freight companies to use lower carbon fuels could also have a significant impact on the carbon footprint of salmon.

Acknowledgements

This report and the underlying Life Cycle Assessments have been funded by Fisheries New Zealand (FNZ). Aquaculture New Zealand (AQNZ) have provided in kind support.

We would also like to acknowledge the contributions from the organisations listed below:

- Biomar Australia
- Skretting Australia
- Salmon Smolt NZ
- New Zealand King Salmon
- Sanford
- Akaroa Salmon
- Mt Cook Alpine Salmon

These organisations either provided data for the Life Cycle Assessment and feedback on earlier versions of this report. Any remaining errors or omissions are those of the authors.

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1. Goal of the Study

This study was commissioned by Fisheries New Zealand and carried out by thinkstep-anz. The study aims to:

- Quantify the environmental performance of farmed salmon produced in New Zealand;
- Identify hotspots for potential future process improvements across the salmon life cycle;
- Discuss the carbon footprint of salmon in the context of existing studies on other forms of edible protein to help put the results into context.

The primary stakeholders for this study are:

- Salmon farmers and processors;
- Salmon feed suppliers;
- Central and local government;
- Community interest groups;
- Environmental groups;
- New Zealand seafood industry companies;
- Salmon consumers.

Life Cycle Assessment (LCA) has been used to evaluate potential environmental impacts of farmed New Zealand salmon. LCA is an established method based on international standards – ISO 14040:2006 (ISO, 2006a) and ISO 14044:2006 (ISO, 2006) – to objectively and scientifically assess the resource requirements of a product, its production of waste and other emissions and its potential impacts on the environment. While this study isn't a comparative assertion, as it doesn't include the modelling of other food protein sources, it is the basis of a comparison with literature LCA carbon footprint results for other protein sources. The report has undergone a critical review by a panel of three experts for compliance with the ISO 14044 standards (not including requirements for comparative assertions. This LCA also follows the Fish and Fish Products Product Category Rules (PCR) (EPD International, 2021).

This LCA report can be used by FNZ, Aquaculture NZ, and the wider New Zealand salmon industries for both business-to-business and business-to-customer communication.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes the identification of specific product systems to be assessed, product function(s), functional unit and reference flows, system boundary, allocation procedures, and cut-off criteria, LCIA methodology and type of impacts, interpretation to be used, limitations, data quality requirements, software and databases uses and critical review.

2.1. Product Information

The product included within this study is King salmon (*Onchorhynchus tshawytscha*) that are farmed, processed, and distributed from New Zealand. Products are primarily sold to New Zealand and North American markets via retail and foodservice sales channels. The most common product is head on gutted (HOG) salmon.

2.2. Functional and Declared Unit

The functional unit for the LCA is 1 kg of edible King salmon meat in HOG salmon, ready for customer purchase, and its packaging. This includes feed input production, transport to feed inputs to manufacturing, feed manufacture, feed transport to smolt and salmon production sites, smolt production, farming, processing, distribution to retail, customer transport, customer use and packaging end of life. The reference flow is defined at the final customer gate (so when the customer purchases it).

To facilitate the comparison with Poore and Nemeck (2018) results for other protein sources the results of this study are presented for a declared unit (a declared unit doesn't cover the whole life cycle) of 100 g of protein, ready for customer purchase, and includes feed input production, transport of feed inputs to manufacturing, feed manufacture, feed transport to smolt and salmon production sites, smolt production, farming, processing, packaging and distribution to retail. It doesn't include customer transport, customer use and packaging end of life. The reference flow for this unit is defined at the retail store. To convert salmon mass to protein the protein content of salmon was taken from the New Zealand Food Composition database (Plant and Food Research & Ministry of Health, 2022).

This study uses protein content to compare different food types. This doesn't take into consideration the complexities of the human dietary requirement for specific amino acids or the digestibility of different protein sources (McAuliffe et al, 2023). Salmon provides a range of nutritional benefits in addition to protein and a nutritional LCA (presenting results for a nutritional declared unit) was considered for this project Nutritional LCA is very complex ((FAO, 2021) and requires nutritionist input to assess the relative nutritional value of different nutrients (x This was beyond the scope of this project. Therefore, the decision was made to present results per kg of edible salmon and 100 g of protein content.

2.3. Content declaration

2.3.1. Product Composition

The composition of the standard salmon is shown below, per kilogram of salmon meat (Table 2-1). The meat yield of the head-on gutted (HOG)[2] salmon is assumed at 70% (New Zealand King Salmon, 2021). Edible yield is calculated by dividing edible meat by HOG body weight.

Table 2-1: Product composition of HOG salmon product

Material	Mass (kg)
Edible meat	1.0
Fish bone	0.4
Polyethylene packaging	0.01
Polystyrene packaging	0.02
Polypropylene glycol packaging	0.03

2.4. System Boundary

The study follows the modular life cycle stage structure outlined by the Product Category Rule (PCR) on Fish and Fish Products (EPD International, 2021). The life cycle is divided into three processes:

- Background upstream processes (from cradle-to-gate);
- Foreground core processes (from gate-to-gate);
- Background Downstream processes (from gate-to-grave).

Upstream processes are associated the production of salmon feed, including the production of raw ingredients, feed ingredient transport, electricity to manufacture the feed and feed packaging and feed transport to smolt and salmon producers. Primary data was collected on the type and amount of feed inputs. Secondary data used for all other background upstream processes.

Foreground core processes include smolt production, salmon farming, processing and packaging. Primary data was collected for all foreground core processes.

Background downstream processes are associated with distribution of product to domestic and international markets, as well as customer use (consumption) and packaging end-of-life (EoL). Secondary data was used for all background downstream processes.

Table 2-2 indicates the modules within each life cycle stage that is reported in this LCA. Each life cycle module is reported separately.

[2] In New Zealand salmon industry the commonly used term is ‘Gilled and Gutted’, which is a fish with head on, skin on, gills and gut removed

Table 2-2: Modules and life cycle stages included in the LCA

Module	Life Cycle Stage	Modules declared
Upstream	Feed production	X
	Packaging material production	X
	Packaging of auxiliary materials	X
Core	Aquaculture	X
	Gutting, scaling and cutting	X
	Refrigeration	X
	Packaging	X
	Transport to retailer/distribution platform	X
Downstream	Customer use	X
	Waste processing of any wasted part of the product	X
	Packaging EoL	X

(X = declared module; ND = module not declared)

Upstream processes (cradle-to-gate):

The following upstream stages are included in the study:

- Production of salmon feed (including feed inputs and transport to feed production facilities, electricity and fuels);
- Manufacturing of primary packaging of feed;
- Waste management processes for upstream agricultural and other processes involved in upstream feed production.
- Transport of feed to New Zealand hatcheries and salmon farms

Core processes (gate-to-gate):

The fishing stage is considered not applicable as this study is based on aquaculture systems.

The following core stages are included in the study:

- Aquaculture which includes
- Smolt production at freshwater facilities, including electricity, fuels, packaging and chemicals used for disinfectant;
- Salmon production at saltwater and freshwater facilities, including electricity, fuels, materials for maintaining facility, packaging and chemicals used for disinfectant;
- Gutting scaling and cutting or salmon processing, (chilled/frozen head on gutted salmon, portions) – includes electricity, fuels, packaging and process chemicals;

- Refrigeration
- Packaging manufacture
- Transport involved with moving product or consumables within core processes – barge vessels, smolt transport, salmon transport from farm gate to processing facilities.

Downstream processes (gate-to-grave):

The following downstream processes are included in the study:

- Transport for distribution of product to market;
- Customer use of product (cooking). Cooking has been modelled following the PCR. See section 3.2.8 for more information.
- End of Life packaging

The system diagram, pictured in Figure 2 1, provides a high-level breakdown of the relevant stages considered in this LCA.

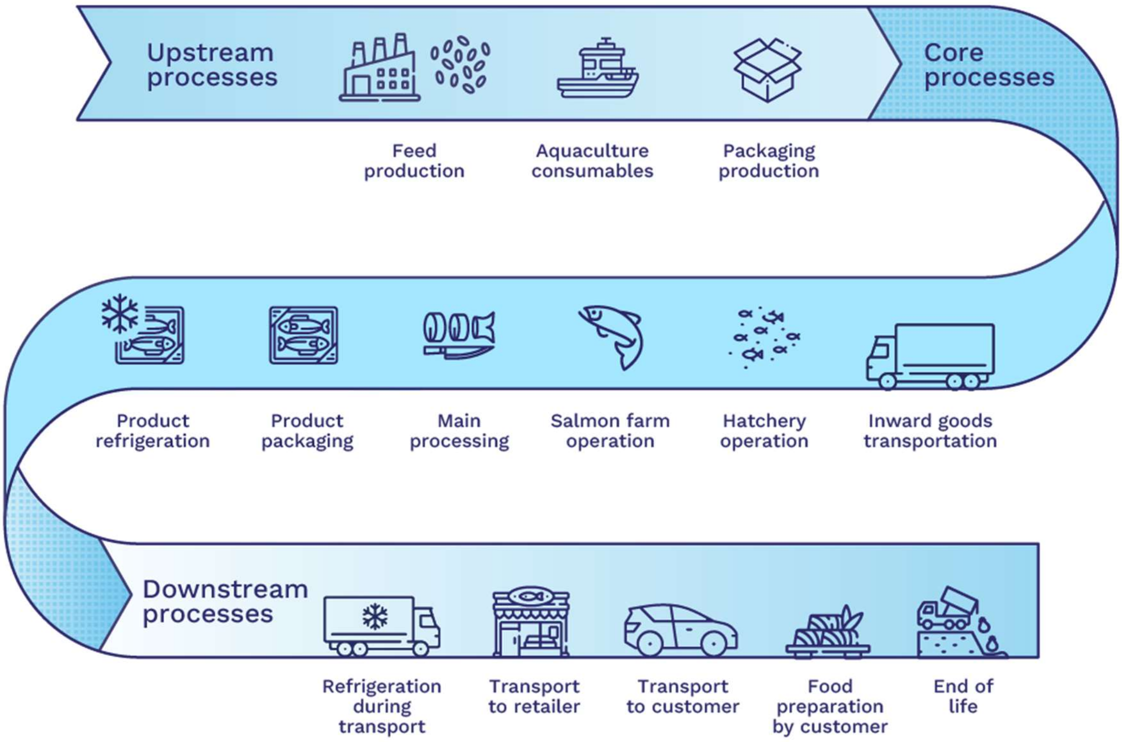

Figure 2-1: New Zealand King salmon lifecycle stages

2.4.1. Exclusions

The following processes are not included in the study:

- Manufacture of capital goods (buildings, boats, trucks, other product equipment);
- Business travel of personnel;
- Travel to and from work by personnel;
- Research and development activities.

- Wastewater treatment required after digestion and excretion by people consuming the salmon

2.4.2. Time Coverage

Primary data was collected for feed input formulations, smolt production, salmon farming and processing is for the annual operation for the calendar year 2021.This data may change in the future as salmon farmers are considering land-based, recirculating aquaculture systems and open ocean farming.

Secondary data from the Agri-footprint database is used for salmon feed inputs and in some cases may be based on data more than 10 years old as noted in Table 3-10.

2.4.3. Technology Coverage

The LCA is intended to represent the current technology used in salmon production operations in New Zealand. The study includes three sea-based farming company and one fresh water farming company. The study participants produced 97% of the salmon in New Zealand in 2021 (Aquaculture New Zealand pers comm). For some processes (nylon, plastics, cardboard, steel, ethanol, hydrogen peroxide, liquid nitrogen, Sodium hypochlorite, oxygen, Hydrogen peroxide, Virkon s, diesel burned in electric generation, petrol burned in machinery, truck, sea and passenger transport), background data represents European or global technology where no primary information is available for a given process.

2.4.4. Geographical Coverage

The LCA is intended to represent an average of salmon production across all salmon production sites in New Zealand. All salmon farms in New Zealand are located in the Marlborough sounds, Canterbury (sea and freshwater systems) and Stewart Island. Feed input data was provided by feed suppliers specific to New Zealand. Geographical coverage for this data is high.

The background data for feed ingredients is country specific for 32% of feed inputs. A Netherlands proxy was used for all other feed ingredients. The geographical coverage for feed ingredient background data is considered low.

2.5. Allocation

2.5.1. Feed Allocation

Most feed datasets use economic allocation as feeds are usually low value co-products of another system (e.g., animal meal, blood meal, fish meal). This aligns with the Product Environmental Footprint Category Rules, from the EU Commission and International EPD Programmes PCR for fish and fish products but it corresponds to the third (i.e. lowest tier) of the ISO 14044 allocation hierarchy. Feed impacts can also be modelled using mass and energy allocation, and the allocation method has a large impact on results. ISO 14044 requires that where several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted. See section 6.3 for the sensitivity analysis of economic, mass and energy allocation methods.

2.5.2. Co-Product Allocation

Co-product allocation follows the requirements of ISO 14044, section 4.3.4.2. It wasn't possible to split the salmon processing input information into sub-process for each product type. For example, the electricity used for salmon processing couldn't be split up by product type (e.g. HOG salmon, portions, fillets). These products are deemed to be allocated equal impact, based on mass.

The only co-product produced directly from HOG salmon during processing is offal, some of which is sold as inputs to other systems. This was modelled using the three allocation options used in the feed sensitivity analysis. This results in 1.4~2.9% of inputs and outputs arising from Core and Upstream processes being attributed to offal sold as a co-product, (depending on the allocation method).

2.5.3. End-of-Life Allocation

End-of-Life allocation follows the requirements of ISO 14044, section 4.3.4.3.

Allocation of recycled material is reported in the Life Cycle Inventory (LCI) as an input or output flow when such materials leave or enter the specific product system. The boundary between the current and the next product system is defined by the willingness to pay for the recycled material. This implies that from the moment the user of a secondary material pays for the material, this (secondary) product system will also be responsible for its environmental burdens from that point onward.

Consequently, if there is an inflow of recycled material to the production system, the recycling process and transportation of the recycled material to site are both included. If there is an outflow of material to recycling, both dismantling and transportation of the material to a sorting/recycling facility are included. The material intended for recycling is then an outflow from the production system.

Material recycling (cut-off approach): The system boundary at EoL is drawn after scrap collection to account for the collection rate, which generates an open scrap output for the product system. The processing and recycling of the scrap is associated with the subsequent product system and is not considered in this study. Material sent to recycling in this study include some cardboard, polyethylene, mixed plastics, paper and metals.

Energy recovery & landfilling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary includes the waste incineration and landfilling processes following the polluter-pays-principle. In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilisation rates (flaring vs. power production). No credits for power or heat production are assigned. Landfilled material includes some smolt and salmon farm mortalities, mixed plastics and general waste.

2.6. Cut-off Criteria

Some material flows have been excluded from the analysis due to their very small/insignificant nature. These are listed in Table *2-3*. All other material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts. The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Chapter 5.

Table 2-3: Excluded flows

Exclusions	Use	Average use/kg salmon	Reason for exclusion	Density	Mass/kg salmon	Mass % of total inputs
Aqui-S	Aquatic anaesthetic	0.0000004	Insignificant mass	1.09	0.000000444	<0.001%
Disinfectant/Biozyme cleaner	Disinfectant	0.0000704l	Insignificant mass	1.017	0.0000206	<0.001%
Hydraulic oil	In machinery	0.0000017l	Insignificant mass	0.86	0.0000015	<0.001%

2.7. Selection of LCIA Methodology and Impact Categories

The following environmental indicators have been used in this study (Table 2-4). These indicators are a subset of all indicators required by the Fish and Fish product PCR and are considered the most relevant as they are either of global/national concern (eg GWP, EU) or metrics commonly used in LCA (eg AP, POCP)

Table 2-4: Impact category descriptions

Impact Category	Description	Unit	Reference
Global Warming Potential, total (GWPt)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	(IPCC, 2013)
Eutrophication aquatic, freshwater (EPf)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and	kg P eq.	(Struijs, 2009)
Eutrophication aquatic, marine (EPm)		kg N eq.	(Struijs, 2009)

Eutrophication, terrestrial (EPt)	terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	Mole of N eq.	(Seppälä, 2016; Posch, 2008)
Acidification Potential (AP)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	mol H+ equivalent	(Seppälä, 2016; Posch, 2008)
Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg NMVOC equivalent	(van Zelm R, 2008)

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the declared unit. LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.

2.8. Interpretation to be used

The results of the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results;
- Evaluation of completeness, sensitivity of results to feed allocation; feed background data; distribution and transport, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data;
- Conclusions, limitations, and recommendations.

2.9. Limitations

A limitation of this study is the use of non-country specific feed datasets for 68% of the feed inputs. A sensitivity analysis was undertaken to assess the worst-case scenario in which all datasets with the incorrect geography have a larger impact.

2.10. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes (hatchery, farming and processing) using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties can approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed. An evaluation of the data quality regarding these requirements is provided in Chapter 5 of this report.

2.11. Software and Database

The LCA model was created using Microsoft Excel. The ecoinvent v3.8 (Wernet, et al., 2016) and Agri-footprint 5 ((Blonk Consultants, 2019) databases provide the life cycle inventory data for the raw and process materials for the background system. Ecoinvent processes were accessed via Simapro using the cut-off by classification model.

2.12. Critical Review

As this study is intended to be made available to the public it has undergone a critical review. This critical review has been conducted by a panel of three experts:

- Sarah McLaren (Chair), Professor of Life Cycle Management at Massey University, New Zealand;
- Nathan Pelletier, NSERC/Egg Farmers of Canada Industrial Research Chair in Sustainability, University of British Columbia, Canada;
- Gaspard Philis, LCA.no (Consultancy), Dokka 6B, 1671 Fredrikstad, Norway.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

3.1.1. Primary data collection

Primary data was sourced from one New Zealand smolt producer, and three salmon producers that also produce smolt, two aquaculture feed producers, one freshwater salmon producer and three marine salmon producers for the calendar year 2021. Data collection sheets with system inputs/outputs were sent to each producer and followed up with interviews to clarify any data gaps. Seasonal variations were balanced out by using yearly averages. The LCA model calculates the results for each salmon producer and the production weighted average results are presented in this report. The study participants produced 97% of the salmon in New Zealand in 2021 (Aquaculture New Zealand pers comm).

Primary data includes total production by year; mortalities destined for rendering and other by-products by year, feed use and supplier; average annual inputs of materials and chemicals; and annual water use by source.

Most salmon producers have their own smolt production and also source smolt from the salmon smolt producer. The LCI associated with smolt production is production weighted average.

3.2. Product System

3.2.1. Overview of Product System

The system diagram, pictured in Figure 3 1, provides a high-level breakdown of the relevant stages considered in this LCA.

Upstream Processes

The New Zealand salmon product life cycle begins with the production of salmon feed. Raw ingredients are sourced from multiple locations, which is detailed in section 3.2.3 of this report. The feed inputs are transported to a feed production site and once assembled, the ingredients are consolidated in large mills in Tasmania Australia. Feed is packaged and transported to hatchery and salmon production sites in New Zealand.

Core Processes

Salmon farmers grow juvenile salmon, known as smolts, using the imported feed in freshwater enclosures in hatcheries. Once the smolts have matured, they are transported to open freshwater or seawater pens to be farmed into fully grown salmon.

When salmon are ready for market consumption, they are removed from the pens and sent for processing and packaging. One processing path is considered in this LCA – the processing and packaging of head-on gutted salmon.

Downstream Processes

Once packaged, salmon are distributed into various sales channels, depending on the product type.

3.2.2. Upstream: Feed production

Feed composition and milling data was collected from two feed suppliers used by New Zealand salmon producers. These suppliers accounted for more than 90% of feed consumed by the salmon hatchery and farms in 2021. The data from feed suppliers is confidential so it is only presented to reviewers (Annex B). The data shows the inputs used to produce salmon feed, averaged across all suppliers for each year, based on the feed supplied to the hatchery and four salmon farm companies as well as an average annual total per tonne of feed produced. Feed ingredients, milling energy inputs, packaging production and transport inputs are included. Feed contributions from the remaining suppliers (less than 10%) was assumed to be the same composition as the average feed supply.

Specific feed inputs are modelled for most of the feed inputs. A small amount of 'Other/technical" feed (4%) was modelled as being the same composition as the rest of the feed. In reality, this is made up of a proprietary mix of minerals, vitamins and pigments. A sensitivity analysis was carried out, the results for which can be seen in Section 6.3.

The electricity used to mill the feed ingredients together is assumed to be Tasmanian electricity grid mix as the majority of the feed is sourced from mills located there.

Feed datasets use economic allocation as feeds are usually the co-products of another system. This aligns with the Product Environmental Footprint Category Rules, from the EU Commission and International EPD Programmes PCR for fish and fish products but corresponds to the lowest tier of the ISO 14044 allocation hierarchy. ISO 14044 requires that where several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted. Scenario analysis was undertaken using feed energetic and mass allocation. Fava bean only had economic allocation emission factors available and the same emission factor has been used for all three allocation methods for these inputs.

Biogenic carbon in feed inputs is is released over a short time period and is therefore not accounted for.

3.2.3. Core: Hatchery operation

Salmon Smolt NZ operates freshwater hatcheries in Kaiapoi and provides smolt to all salmon farms included in this study. Three of the four salmon farms also have their own smolt hatcheries and supplement with smolt from Salmon Smolt NZ. Data was collected for all smolt production sites and production weighted average inputs and outputs calculated. Table 3-1 provides the inputs and outputs used to produce smolts, including feed, material, chemical and water inputs. The hatcheries also produce salmon eggs used as an input to smolt production. As the output product is salmon smolt all inputs to the hatchery are assigned to salmon smolt.

Table 3-1: Inputs to hatchery sites for production of one tonne of smolt

Input/Output	Units	Production-weighted average	Standard deviation
Feed	kg	1255.2	394.9
Energy			
Diesel	L	72.9	48.6
Electricity	kWh	8065.3	4160.7
Petrol	L	45.1	31.6
LPG	kg	0.3	0.4
Materials			
Polyethylene	kg	7.1	5.9
Mixed plastics	kg	3.5	4.1
Cardboard cartons/boxes	kg	3.5	3.1
Chemicals			
Ethanol	L	1.8	2.5
Hydrogen peroxide	L	1.1	1.5
Liquid nitrogen	L	2.1	1.8
Sodium hypochlorite	L	0.1	0.2
Liquid oxygen	kg	8.1	15.7
Hydrogen peroxide	kg	1.1	1.5
Virkon s	kg	0.4	0.3
Chlorine	kg	0.02	0.02
Water	ML	382.3	132.8
Outputs			
Smolts	kg	1000	0
Mortalities for landfill	kg	22.7	19.1
Mortalities for petfood	kg	20.5	74.3
Mortalities for composting	kg	63.7	81.3
Water	ML	382.3	132.8
Waste			

Polyethylene to recycling	kg	7.3	5.7
Cardboard to recycling	kg	3.5	3.2
Polyethylene to landfill	kg	1.7	2.0
Mixed plastics to landfill	kg	3.5	4.1
General waste to landfill	kg	5.1	13.1
Smolt waste to composting	kg	1.3	4.3
Transport to EoL	km	5.2	2.8
Feed transport			
Sea	km	4133	1879
Road	km	669	431

3.2.4. Core: Salmon farm operation

Four salmon producers provided data for this LCA:

- New Zealand King Salmon: farmed in the Marlborough Sounds;
- Sanford: farmed in Big Glory Bay, Stewart Island;
- Akaroa Salmon: farmed in the Akaroa Harbour, Canterbury;
- Mt Cook Alpine Salmon: farmed in freshwater hydro-electric races, Canterbury.

Table 3-2 provides the 2021 production weighted average feed, energy and material inputs to farms to produce salmon at the farm gate.

Table 3-2: Inputs to farm sites for production of one tonne of salmon at farm

Input/Output	Units	Production-weighted average	Standard deviation
Inputs			
Feed	kg	2,219.4	96.6
Smolts	kg	29.9	11.4
Energy			
Electricity	kWh	0.03	0.28
Diesel	L	104.9	49.7
Petrol	L	3.2	9.3
LPG	kg	0.1	0.4

Coal	kg	0.1	0.2
Materials			
Nylon	kg	0.03	0.29
Polyethylene	kg	0.2	2.0
Mixed plastics	kg	6.6	9.3
Cardboard	kg	0.03	0.05
Chemicals			
Virkon	kg	0.0003	0.0004
Water	L	32.1	3.9
Transport			
Smolt transport to farm (truck)	km	324.9	106.3
Smolt transport to farm (boat)	km	16.2	14.7
Outputs			
Salmon at farm-gate	kg	1,000.0	0.0
Mortalities to landfill	kg	144.4	109.8
Mortalities for composting	kg	63.0	39.0
Ammonium	kg	102.8	4.5
Phosphate	kg	16.2	0.7
Water	L	32.1	3.9
Polyethylene to landfill	kg	0.2	2.0
Mixed plastics to landfill	kg	0.03	0.29
Polyethylene to recycling	kg	0.01	0.01
Mixed plastics to recycling	kg	6.6	9.3
Cardboard to recycling	kg	0.03	0.05
Transport to eol	tkm[3]	2.3	2.4
Feed transport from feed supplier			
Sea	km	1,504	1495
Road	km	81	251

Ammonium and Phosphate modelling

There are direct interactions with the environment: some feed is lost when it goes into the water, and the excretions of the fish. These have been modelled using stoichiometry to estimate the amount of nitrogen and phosphorus in the feed, and then calculating the amount released to the environment from the fish faeces and feed loss (Table 3-3) according to Wang et. al. (2012). The total dissolve nitrogen and phosphorus is then converted to Ammonium (NH4) and Phosphate (PO4) using atomic weights and emissions are shown in Table 3-4. Table 3-4 values were used in the modelling. In the absence of site information,

[3] tkm: tonne kilometers

this LCA has assumed the worst case that all dissolved organic nitrogen is released to the environment as ammonium. This affects the structure and function of the aquatic foodweb and eutrophication indicators.

Eutrophication impacts calculated with ReCiPe 2008 (Struijs et al. 2009) assess aquatic eutrophication through two impact indicators: marine eutrophication and freshwater eutrophication. This method accounts for the sensitivity of the receiving water body: marine water is considered to be sensitive to N (i.e. N is the limiting nutrient for marine biomass growth), whereas freshwater is considered to be sensitive to P (i.e.:P is the limiting nutrient for freshwater biomass growth (Struijs et al. 2009).

Table 3-3: Nitrogen and Phosphorus calculations (per 1000 kg of feed)

Direct Emission	Nitrogen	Phosphorus	Unit
Feed % content	8.0	1.0	
Nutrient mass	80.00	13.3	kg
Feed loss rate	0.03	0.03	kg
Mass loss	2.40	0.40	kg
Mass consumed by salmon	77.60	12.9	kg
Consumed mass used in salmon biomass	39	31	%
Mass to salmon biomass	30.4	3.99	kg
Consumed mass excreted as dissolved inorganic NH3/PO4	46	19	%
Consumed mass excreted as dissolved inorganic NH3/PO4 (in kg N or P)	36	2.39	kg
Consumed mass lost as a particulate through defecation	15	50	%
Mass of consumed food released as a particulate through defecation	11.6	6.45	kg
Total particulate (no dissolving)	14	6.85	kg
% particulate organic dissolved into dissolved organic	15	15	%
Food released as a particulate through defecation: Dissolved organic matter (after dissolving, kg N or P)	2.1	1.0	kg
Total dissolved N or P	38.1	3.4	kg

Table 3-4: Direct emissions to environment

Direct Emission	Mass per tonne of feed (kg/t)
Ammonium	49.0
Phosphate	10.5

Feed Methane emissions

The potential for methane emissions due to the accumulation of unconsumed feed was considered. Poore and Nemecek (2018) calculated 0% methane mineralisation for both freshwater fast flowing and marine flow through systems. These are the systems applicable to this study and therefore methane emissions are not included.

3.2.5. Core: Processing and packaging

Table 3-5 provides inputs for processing and packaging for 1 tonne of Head-on gutted salmon.

Table 3-5: Inputs to processing and packaging of salmon, per tonne of head-on gutted salmon packaged

Input/Output	Units	Production-weighted average	Standard deviation
Salmon input	kg	9469.4	9839.2
Energy			
Electricity	kWh	553.3	173.0
Diesel	L	3.3	4.3
Petrol	L	0.1	0.4
Materials			
Polyethylene	kg	12.1	4.5
Polystyrene	kg	24.8	6.1
Propylene glycol	kg	15.0	11.0
Chemicals			
Sodium hydroxide	L	0.02	0.06
Sodium hypochlorite	L	0.1	0.3
Disinfectant	L	0.3	0.4
Water	L	12921.8	3753.8
Refrigerants			
R410A	kg	0.000279	0.000235
R404A	kg	0.014030	0.011825
R449	kg	0.000325	0.000274
R134A	kg	0.000005	0.000043
R507	kg	0.002180	0.007255

R407F	kg	0.001203	0.001690
Outputs			
Head-on gutted salmon	kg	1000.0	0.0
Frozen HOG salmon	kg	184.7	190.4
Fresh gilled and gutted	kg	3990.0	5582.1
Frozen gilled and gutted	kg	59.1	36.8
Portions	kg	201.3	316.7
Fillets	kg	3818.9	4340.9
Smoked	kg	75.8	202.8
Waste			
Polyethylene to recycling	kg	1.8	2.0
Mixed plastics to recycling	kg	0.1	0.1
Wooden pallets to reuse	kg	0.9	1.2
Cardboard to recycling	kg	2.0	4.1
Paper to recycling	kg	0.2	0.3
Metal to recycling	kg	0.7	1.0
General waste to landfill	kg	2.5	3.5
Transport to landfill	km	44.8	17.3
Transport to recycling	km	44.8	17.3
Wastewater	L	12921.8	3753.8
Salmon offal	kg	139.5	176.7

3.2.6. Downstream: Distribution

The distribution distance for three distribution scenarios can be seen in Table 3-6. As salmon is a relatively high value product with low shelf life, it is often air freighted. In 2021 most exported salmon from NZ was transported to North America (Aquaculture New Zealand, 2022). The international scenarios are based on transport to Los Angeles, United States.

Table 3-6: Inputs to the distribution of salmon products to market

Input/output	Units	New Zealand	International Sea freight	International Air Freight
Packaged product	kg	1,120	1,120	1,120
Transport				
Air	tkm			11,090
Ferry	tkm	60		
Road	tkm	500	500	500
Sea	tkm		11,070	

Outputs				
Product to market	kg	1,000	1,000	1,000

3.2.7. Downstream: Cold storage

The cold store impacts have been modelled following "9. Appendix: Cold Storage" of the PCR (EPD International, 2021).

The method used is as follows:

Formula: Ep = Es * (100%)/u * Vp * t

Where:

- Ep is the electricity consumption due to cold/frozen storage;
- Es is the specific energy consumption of the cooling room (kWh per m^3 per day);
- u is the utilisation degree of the storage room (%);
- Vp is the volume of the considered product (m^3);
- t is the storage time (days).

Values are set as (per kg of edible meat):

- Es = 0.59 kWh per m^3 per day that the product is stored in a cold place (5°C);
- u = 50%;
- Vp = 0.075 m^3;
- t = 7 days.

3.2.8. Downstream: Losses at retailer

To consider loss of product at the retailer (e.g., due to un-sold products reaching their expiry dates and being disposed of), an 8.7% loss rate (Buzby, Wells, Axtman, & Mickey, 2009) was applied to the modelling. The 8.7% of lost product is assumed sent to landfill,without methane recovery.

3.2.9. Downstream: Use

Transport to customer

The distance travelled by the product from the market outlet to the consumer is modelled as five kilometres as per PCR guidelines (EPD International, 2021) which recommends 62% of the product is transported by car (for 5 km, round trip), 5% by van (5 km, round trip), and 33% having no impact from transport (European Commission, 2018). It is assumed that transport of the salmon is allocated 10% of the total trip impact.

Cooking

Following the recommendation of the PCR (which uses assumptions from the Barilla Centre for Food & Nutrition (2016)), salmon is modelled as being cooked in a pan for 10 minutes using 0.5 kWh electricity. For the domestic scenario New Zealand grid electricity is used and for the international scenarios it is assumed that 61% is cooked with heat from electricity (US

Grid) and 39% from natural gas, resulting in 0.30 kWh electricity and 0.20 kWh of natural gas used (0.70 MJ).

3.2.10. Downstream: End-of-Life

All fish meat is modelled as being eaten by the consumer and is thereafter considered to be outside the system boundary, as seen in

Table 3-7. Inedible fish waste (bones) is assumed to go to biowaste (industrial composting). All other waste (packaging) is assumed to be landfilled. The location of end-of-life for salmon packaging is modelled as the world average. Product and packaging composition at end-of-life is shown in section 3.2.6. Waste to landfill is modelled as being transported by truck for 50 km.

Table 3-7: End of life fate of salmon product and packaging

Flow	EoL fate
Salmon meat	Cut-off (consumed)
Inedible waste (for standard salmon)	Landfill
Polyethylene packaging	Landfill

3.3. Background Data

The LCI datasets used in modelling the product systems are detailed below. Background datasets were obtained from two life cycle inventory databases: ecoinvent v3.8 (Wernet, et al., 2016) and Agri-footprint 5.0 from Blonk Consultants (Blonk Consultants, 2014). Datasets from ecoinvent v3.8 include data from varying years, but most have data extrapolated to 2019. Agri-footprint 5.0 is the updated version of Agri-footprint, which was first released in 2014.

The proxy column is used to indicate whether a dataset accurately represents the desired material or process; “No*” indicates the use of a geographical proxy for a correct dataset where the region of manufacture is expected to have little influence on its environmental profile; and “Yes*” indicates the use of a geographical proxy for a correct dataset where the region of manufacture is expected to materially influence its environmental profile.

3.3.1. Fuels and Energy

Electricity consumption used for feed production was modelled using the Australian Hydro process. Electricity as an energy supply used by the fish processing sites and domestic cooking was modelled using the NZ grid mix. Electricity use for cooking in the international scenarios was modelled as US grid electricity as detailed in Table 3-8:. Energy datasets used are outlined in Table 3-9:

Table 3-8: Electricity used for feed production hatchery, processing and cooking

Location	Dataset	Data Provider	Reference Year	Proxy?
NZ	Electricity, high voltage {NZ}| market for electricity, high voltage | Cut-off, S	Ecoinvent	2021	No
AU	Electricity, high voltage {AU}| electricity production, hydro, run-of-river | Cut-off, S	Ecoinvent	2021	No
US	Electricity, low voltage {US-WECC}| market for electricity, low voltage | Cut-off, S	Ecoinvent	2021	No

Table 3-9: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Natural gas	NL	Combustion of natural gas, consumption mix, at plant Economic	Ecoinvent	2019	No
Diesel	GLO	diesel, burned in diesel-electric generating set, 18.5kW {GLO}| diesel, burned in diesel-electric generating set, 18.5kW | Cut-off, S	Ecoinvent	2021	No
Diesel	GLO	Diesel, burned in fishing vessel {GLO}| market for diesel, burned in fishing vessel | Cut-off, S	Ecoinvent	2021	No
Petrol	GLO	Petrol, unleaded, burned in machinery {GLO}| market for petrol, unleaded, burned in machinery | Cut-off, S	Ecoinvent	2021	No

3.3.2. Raw Materials and Processes

Feed

As feed inputs were sourced from many different countries, a geographical proxy dataset from the Netherlands was used for most feeds. The country of origin of Fish meal, fish oil and Soy protein concentrate are identified and country specific datasets used for these inputs. These country specific feed data sets cover 32% of the feed inputs. A Swiss dataset was used as a proxy for fava bean meal as it is the only fava bean dataset available. All other feeds used the Netherlands feed datasets as a proxy Most of the NL datasets used have higher GWP impacts compared to the same feed ingredients produced in other countries. As the actual feed source was unknown for 68% of the feed inputsa sensitivity analysis of feed inputs is provided in 6.3.

Table 3-10 shows the LCI datasets used in modelling the salmon feed raw ingredients. The Agri-footprint datasets marked as “NL” (Netherlands) are originally “RER” (Europe) datasets, regionalised to the Netherlands. “CH” relates to Swiss datasets, “BR” relates to Brazilian datasets, “PE” relates to Peruvian datasets.

Table 3-10:Salmon feed LCI datasets

Ingredient	Location	Dataset	Data Provider	Reference Year	Proxy?
Animal meal	NL	Animal meal, at processing Economic - NL	Agri-footprint	database2019 data: 2012	Yes, geographic
Blood meal	NL	Blood meal, at processing Economic - NL	Agri-footprint	database2019 data: 2012	Yes, geographic
Feather meal	NL	Animal meal, at processing Economic - NL	Agri-footprint	database2019 data: 2013	Yes, geographic and ingredient
Poultry meal	NL	Animal meal, at processing Economic - NL	Agri-footprint	database2019 data: 2013	Yes, geographic and ingredient
Poultry oil	NL	Animal meal, at processing Economic - NL	Agri-footprint	database2019 data: 2013	Yes, geographic and ingredient
Corn protein concentrate	NL	Pea protein-concentrate, at processing/NL Economic	Agri-footprint	database2019 data: 2017	Yes, geographic and ingredient
Fava bean meal	CH	Market for fava bean, feed, Swiss integrated production | fava bean, feed, Swiss integrated production | Cutoff, S - CH	Ecoinvent	2019	Yes, geographic
Lupin meal	NL	Lupins meal, at processing Economic - NL	Agri-footprint	database2019 data: 2017	Yes, geographic
Soy protein concentrate	BR	Soybean protein-concentrate, at processing Economic - BR	Agri-footprint	database2019 data: 2012	No
Wheat feed	NL	Wheat flour, at processing Economic - NL	Agri-footprint	database2019 data: 2012	Yes, geographic
Wheat gluten meal	NL	Wheat gluten meal, consumption mix, at feed compound plant Economic - NL	Agri-footprint	database2019 data: 2012	Yes, geographic
Other crop meals	NL	Lupins meal, at processing/NL Economic	Agri-footprint	database2019 data: 2017	Yes, geographic

Rapeseed oil	NL	Crude rapeseed oil (pressing), at processing Economic - NL	Agri-footprint	database2019 data: 2012	Yes, geographic
Other crop oils	NL	Crude sunflower oil (pressing), at processing Economic - NL	Agri-footprint	database2019 data: 2012	Yes, geographic and ingredient
Fish meals	PE	Fish meal, at processing Economic – PE	Agri-footprint	database2019 data: 2012	No
Other fish oils	PE	Fish oil, at processing Economic - PE	Agri-footprint	database2019 data: 2012	No
Water	RoW	Tap water production, conventional with biological treatment | tap water | Cutoff, S – RoW (Rest of World)	Ecoinvent	2019	No*

Materials

Raw materials and chemical datasets used in the modelling of feed, smolt farming, salmon farming, and salmon processing were modelled using secondary data are presented in Table 3-11 and Table 3-12.

Table 3-11: Hatcheries and farms LCI datasets

Material	Location	Dataset	Data Provider	Reference Year	Proxy?
Nylon	RER	Nylon 6 production | nylon 6 | Cutoff, S - RER	Ecoinvent	2021	No*
Polyethylene	RER	packaging film, low density polyethylene| packaging film production, low density polyethylene | Cut-off, S	Ecoinvent	2021	No*
Polypropylene	EU	Polypropylene fibres (PP), crude oil based, production mix, at plant, PP granulate without additives S System -	Ecoinvent	2021	No*

Processing chemicals

Table 3-12: Processing materials LCI datasets

Material	Location	Dataset	Data Provider	Reference Year	Proxy?
Sodium hydroxide	GLO	Market for sodium hydroxide, without water, in 50% solution state | sodium hydroxide, without water, in 50% solution state | Cutoff,	Ecoinvent	2021	No*
Sodium hypochlorite	RoW	Sodium hypochlorite production, product in 15% solution state | sodium hypochlorite, without water, in 15% solution state | Cutoff,	Ecoinvent	2021	No*
Ethanol	RER	Ethanol (ethene), at plant Economic - RER	Ecoinvent	2021	No*
Hydrogen peroxide	RoW	Market for hydrogen peroxide, without water, in 50% solution state | hydrogen peroxide, without water, in 50% solution state | Cutoff,	Ecoinvent	2021	No*
Chlorine	RoW	Chlorine dioxide production | Cut-off, S	Ecoinvent	2021	No*
Liquid nitrogen	RoW	Market for nitrogen, liquid | nitrogen, liquid | Cutoff, S - RoW	Ecoinvent	2021	No*
Liquid oxygen	RoW	Oxygen, liquid {RoW}| air separation, cryogenic | Cut-off,	Ecoinvent	2021	No*
Weed Spray/Virkon	RoW	glyphosate {RoW}| glyphosate production | Cut-off, S	Ecoinvent	2021	No*

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials and auxiliary materials to production and assembly facilities.

Transportation was modelled using the global transportation datasets from ecoinvent 3.8 Table 3-13.

Table 3-13: Transportation and cold storage datasets

Mode / fuels	Location	Dataset	Data Provider	Reference Year	Proxy?
Sea (feed)	GLO	Transport, freight, sea, container ship transport, freight, sea, container ship	Ecoinvent	2021	No
Lorry	RoW	Transport, freight, lorry 7.5-16 metric ton, EURO4 | transport, freight, lorry 7.5-16 metric ton, EURO4 | Cutoff, S -	Ecoinvent	2021	No
Rail		transport, freight train {RoW}| market for transport, freight train | Cut-off, S	Ecoinvent	2021	No
Air (refrigerated)	GLO	transport, freight, aircraft with reefer, cooling {GLO}| transport, freight, aircraft with reefer, cooling | Cut-off, S	Ecoinvent	2021	No
Lorry (refrigerated)	GLO	transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, R134a refrigerant, freezing {GLO}| transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, R134a refrigerant, freezing | Cut-off, S	Ecoinvent	2021	No
Ferry (refrigerated)	GLO	transport, freight, sea, container ship with reefer, freezing {GLO}| market for transport, freight, sea, container ship with reefer, freezing | Cut-off, S	Ecoinvent	2021	No
Sea (freezer)	GLO	transport, freight, sea, container ship with reefer, freezing {GLO}| market for transport, freight, sea, container ship with reefer, freezing | Cut-off, S	Ecoinvent	2021	No
Consumer vehicle - car	GLO	transport, passenger car, medium size, petrol, EURO 5 {GLO}| market for transport, passenger car, medium size, petrol, EURO 5 | Cut-off, S	Ecoinvent	2021	No
Consumer vehicle - van	GLO	transport, passenger car, large size, diesel, EURO 3 {GLO}| market for transport, passenger car, large size, diesel, EURO 3 | Cut-off, S	Ecoinvent	2021	No

3.3.4. Packaging

The datasets used for modelling product packaging materials are provided in Table 3-14.

Table 3-14: Key material and process datasets used in packaging

Material	Location	Dataset	Data Provider	Reference Year	Proxy?
Polyethylene	RER	packaging film, low density polyethylene | packaging film production, low density polyethylene | Cut-off, S	Ecoinvent	2021	No*
Polypropylene	EU	Polypropylene fibres (PP), crude oil based, production mix, at plant, PP granulate without additives S System - Copied from ELCD - EU-27	Ecoinvent	2021	No*
Cardboard	RER	Market for corrugated board box | corrugated board box | Cutoff, S - RER	Ecoinvent	2021	No*
Propylene glycol	RoW	Propylene glycol production, liquid | propylene glycol, liquid | Cutoff, U	Ecoinvent	2021	No
Polystyrene	RoW	Polystyrene production, general purpose | polystyrene, general purpose | Cutoff, S - RoW	Ecoinvent	2021	No

3.3.5. Waste processes

The general waste dataset was used for salmon smolt and farm mortalities, and general waste going to landfill. General waste also captured the end-of-life processing for propylene glycol, nylon, cardboard and polyester (Table 3-15).

Table 3-15: Waste treatment processes

Treatment/ Process	Location	Dataset	Data Provider	Reference Year	Proxy?
Salmon bones /guts / mortalities	RoW	Market for biowaste | biowaste | Cutoff, U	Ecoinvent	2021	No
Polyethylene	RoW	Treatment of waste polyethylene, sanitary landfill | waste polyethylene | Cutoff, U	Ecoinvent	2021	No
Polypropylene	RoW	Treatment of waste polypropylene, sanitary landfill | waste polypropylene | Cutoff, U	Ecoinvent	2021	No
Polystyrene	RoW	Treatment of waste polystyrene, sanitary landfill | waste polystyrene | Cutoff, U	Ecoinvent	2021	No
General waste	RoW	Market for municipal solid waste | municipal solid waste | Cutoff, U	Ecoinvent	2021	No

3.4. Conversion of salmon mass to protein

Information to convert salmon mass (1 kg) to protein (100 g) was taken from the New Zealand Food Composition Data (Plant and Food Research & Ministry of Health) for king salmon, skin and bone removed, fresh pan-fried with oil. The nutritional information notes there is 202 g protein per 1 kg of salmon. 0.5 kg of salmon is needed to provide 100 g of protein.

4. Life Cycle Impact Assessment

This chapter contains the results for the impact categories defined in section 2.7. The reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Salmon Assessment Results per kg edible salmon

The indicator results for the upstream, core and downstream processes for salmon can be seen below in Table 4 1. These results are for New Zealand distribution of salmon, so the downstream environmental impacts are relatively low. The upstream and salmon farming combined contributed more than 90% of environmental impacts for all environmental indicators (Table 4-1 and Figure 4-1).The upstream impacts are due to feed production and feed input transport. Most datasets used for feed production come from the Agri-footprint database (Blonk Consultants, 2014) and all feed production datasets use economic allocation, which aligns with the Fish and Fish Products PCR. Eutrophication freshwater and marine is significant due to the phosphate and ammonium released as salmon waste during the salmon farming (Figure 4-1).

There is significant variation in across the different salmon farming companies as shown in Table 4-1. The variation in GWPt is largely due to differences in feed inputs. The variation in EPf is mostly due to differences in phosphorus release to freshwater at the farm stage..

Table 4-1: Environmental Impacts of salmon, New Zealand distribution (per 1 kg of edible meat)

Indicator	Unit	Upstream	Core	Downstream	Total	Variation
GWPt	kg CO_2 eq.	6.411	1.122	0.695	8.228	-19-33%
EPf	kg P eq.	0.001	0.002	0.000	0.003	-94-1026%
EPm	Kg N eq.	0.035	0.135	0.001	0.170	-9-28%
EPt	Mole of N eq.	0.214	0.041	0.007	0.261	-19-16%
AP	kg SO_2 eq	0.052	0.009	0.002	0.063	-18-19%
POCP	kg $NMVOC^-$ eq	0.028	0.011	0.002	0.040	-27-23%

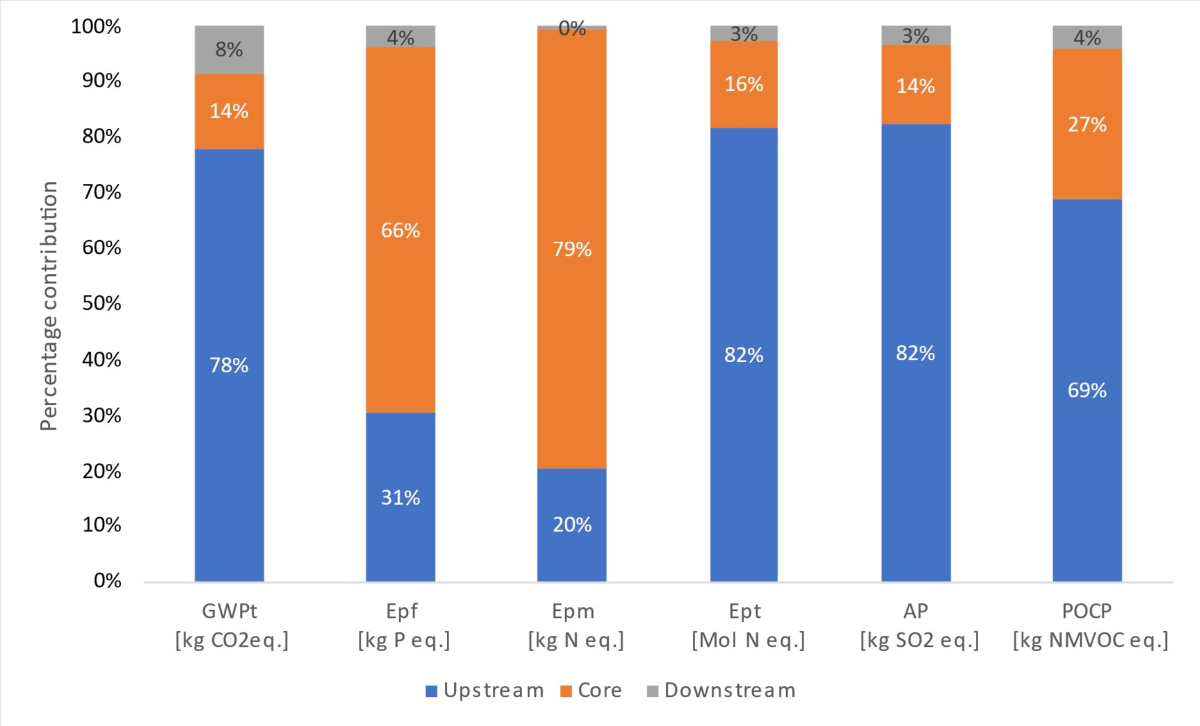

Figure 4-1: Environmental impacts of salmon, New Zealand distribution (per 1 kg of edible meat)

Upstream feed production is the highest contributor to the carbon footprint (GWPt), terrestrial eutrophication (EPt), acidification (AP) and summer smog (POCP) as shown in Figure 4-1. The core processes contribute the most to the freshwater and marine eutrophication (EPf and EPm), due to some feed lost when it goes into the water, as well as the excretions of the fish.

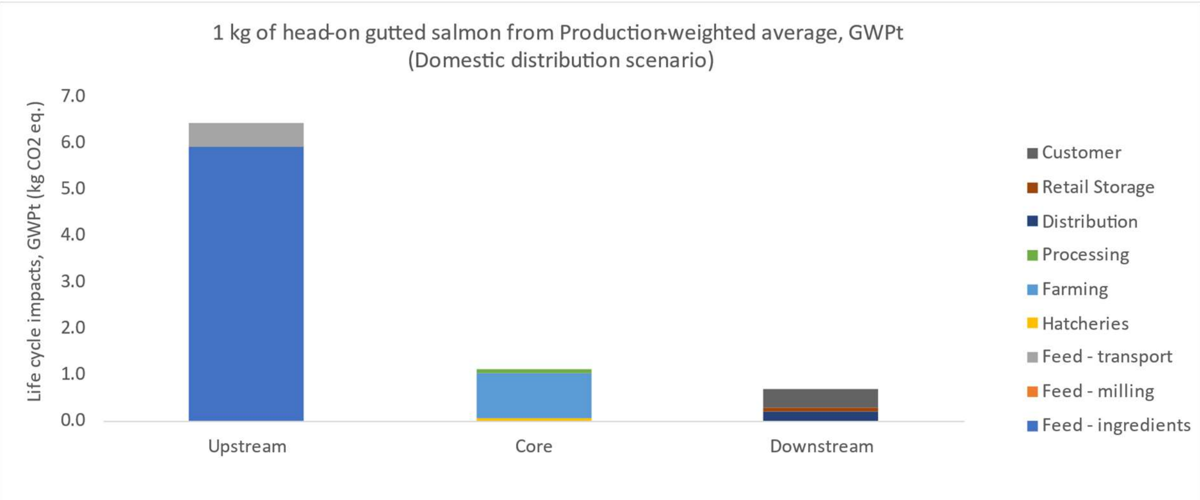

Figure 4-2: GWPt of salmon, New Zealand distribution (per 1 kg of meat)

Feed ingredient production and transport contributes the most to the GWPt environmental impact, for upstream impacts (Figure 4-2). Fuel used by the salmon farm contributes the most to the core environmental impacts. Customer use (refrigeration and cooking) of the salmon contribute most to the downstream GWPt impact.

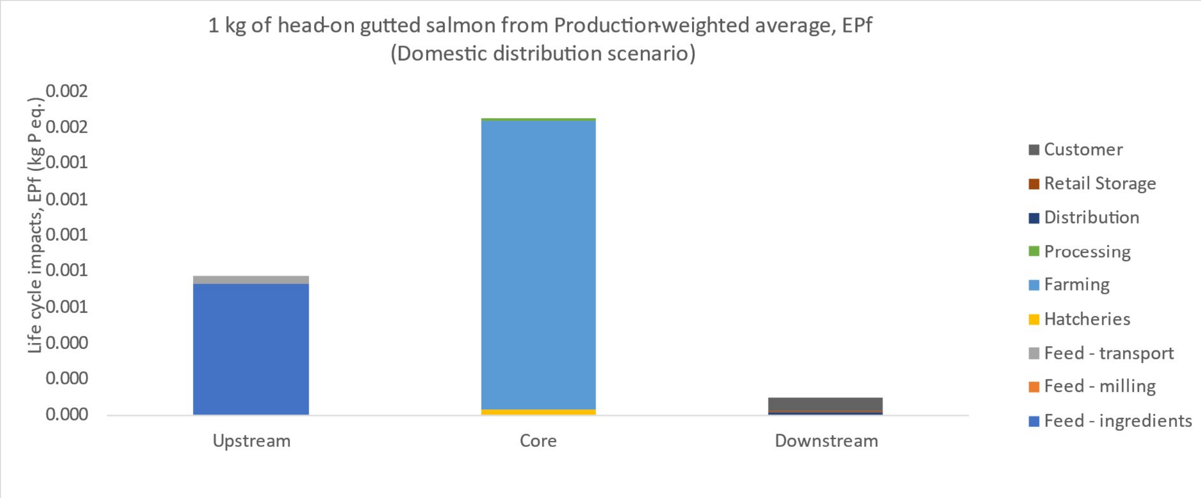

Figure 4-3: EPf of salmon, New Zealand distribution (per 1 kg of meat)

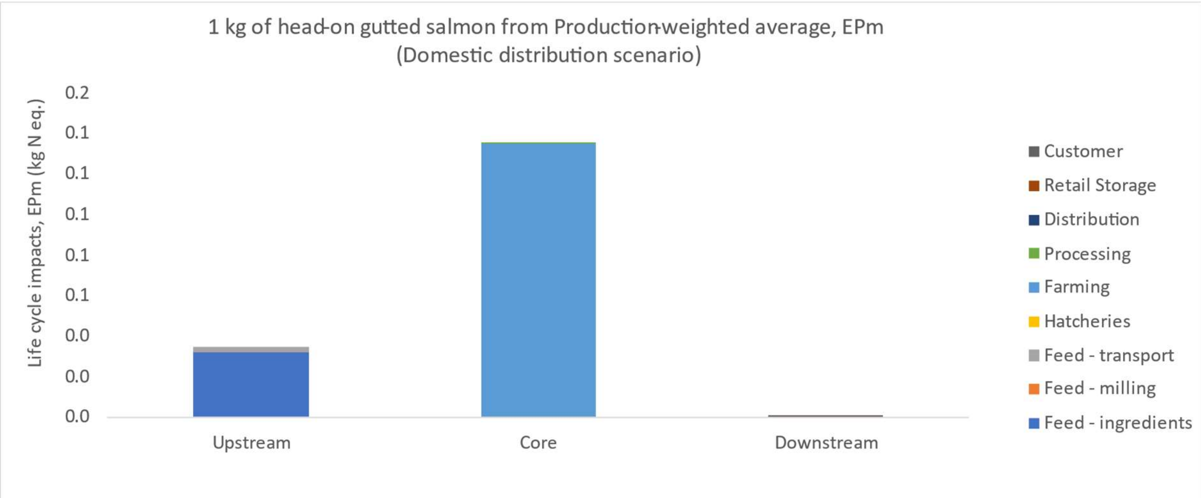

Figure 4-4: EPm of salmon, New Zealand distribution (per 1 kg of meat)

As shown in Figure 4-1, Figure 4-3 and Figure 4-4 echo how the predominant marine and freshwater eutrophication impacts are from the core life cycle stage, nearly exclusively from farming. Meanwhile, feed production accounts for the majority of eutrophication impacts in the upstream life cycle stage. Among downstream eutrophication impacts, the only notable impact source is treatment of food waste from preparation by the customer, producing freshwater eutrophication impacts.

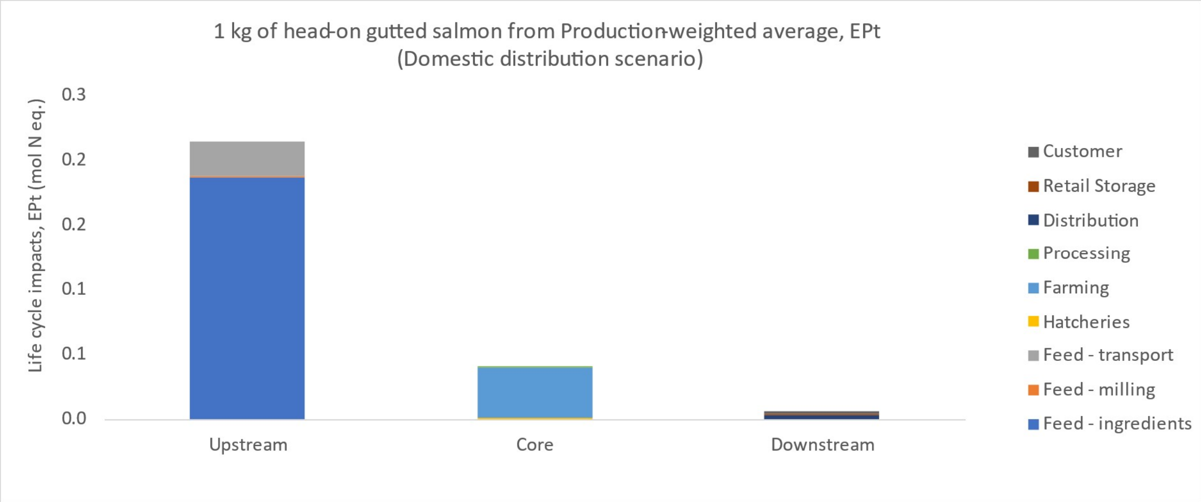

Figure 4-5: EPt of salmon, New Zealand distribution (per 1 kg of meat)

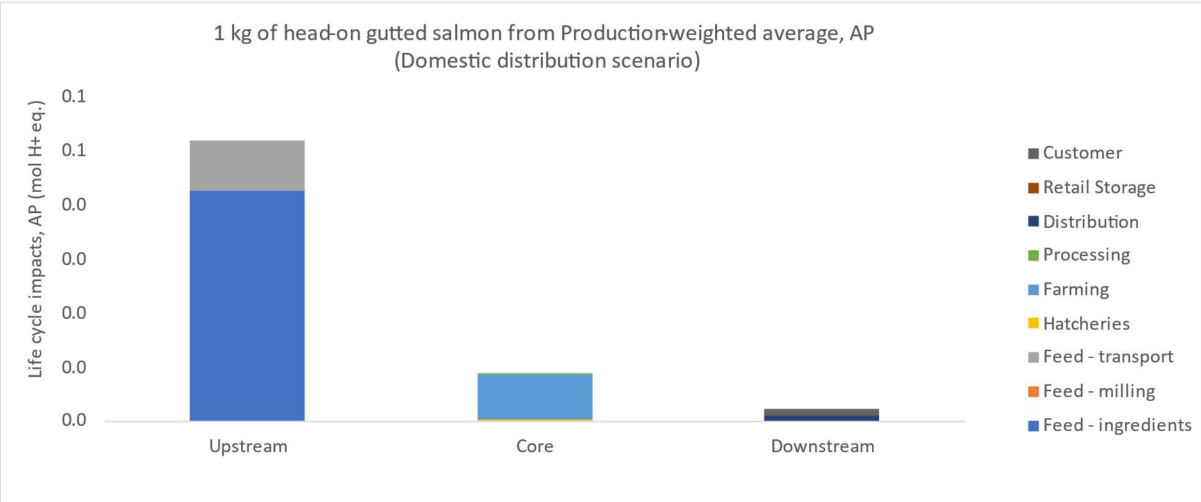

Figure 4-6: AP of salmon, New Zealand distribution (per 1 kg of meat)

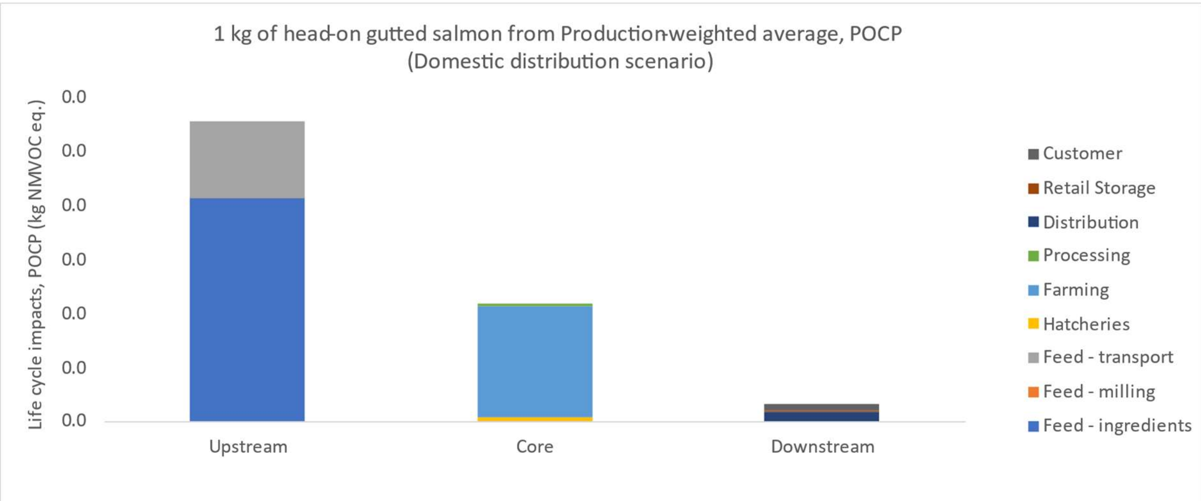

Figure 4-7: POCP of salmon, New Zealand distribution (per 1 kg of meat)

As shown in Figure 4-5, Figure 4-6 and Figure 4-7 the majority of the Terrestrial Eutrophication, Acidification and Photochemical Ozone impacts are from the upstream stage due to the production of the feed ingredients and feed transport. In the core stage most impacts are due to salmon farming. Among downstream impacts the majority are due to customer transport and disposal of waste.

4.2. Hotspot analysis

4.2.1. Product hotspots

A hotspot analysis was carried out by splitting the modules up into several stages. The results of this analysis can be seen in Table 4-2 for the distribution scenario in NZ. This table shows that the production of salmon feed ingredients is a hotspot for GWPt, AP, EPt and POCP. This is mainly due to the agricultural (and fishery) impacts associated with producing the feed (analysed further in below).

The farming process is significant for the EPf, EPm indicators due to the phosphate and ammonium released as salmon waste during the salmon farming stage.

Table 4-2: Environmental impacts by stage[4]

Indicator	Unit	Feed - ingredients	Feed - milling	Feed - transport	Hatchery	Farming	Processing	Distribution	Retail Storage	Customer
GWPt	kg CO_2 eq.	72%	0%	6%	1%	12%	1%	3%	1%	5%
EPf	kg P eq.	29%	0%	2%	1%	64%	1%	1%	0%	4%
EPm	Kg N eq.	19%	0%	1%	0%	80%	0%	0%	0%	0%
EPt	Mole of N eq.	72%	0%	10%	0%	15%	0%	1%	0%	1%
AP	kg SO_2 eq	68%	0%	15%	1%	13%	1%	1%	0%	2%
POCP	kg NMVOC- eq	51%	0%	18%	1%	25%	1%	2%	0%	2%

[4] Table Colour coding is as follows:
White: <5%
Yellow: >5% and <25%
Orange: >25% and <50%
Red: >50%

4.2.2. Feed mix impact breakdown

As the feed mix is the most relevant source of impact for GWPt, AP, EPt, and POCP indicators the breakdown of impacts was studied further. As can be seen in Figure 4-8 most of the carbon impacts come from the fish meals, soy protein concentrate, wheat feed, animal meal and rapeseed oil. The % of mass show that the soy protein and rapeseed oil contribute 3% and 4% to the feed mass. On the other hand, they contribute 15% and 11% to GWPt emissions, respectively. The choice of feed mix and the dataset used for each feed type has significant impact on the carbon emissions and sensitivity analysis is presented in 6.3.

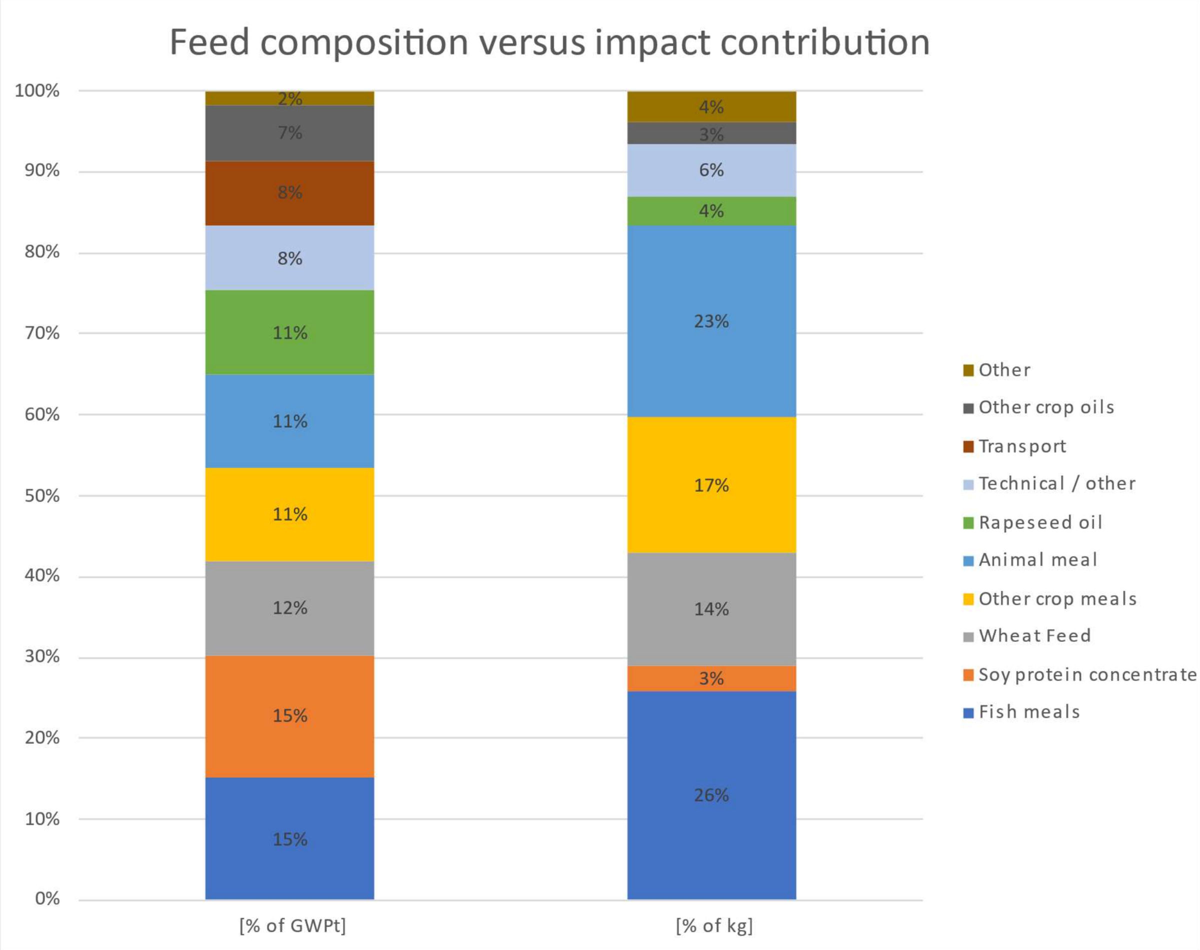

Figure 4-8: Feed emissions contribution (% of feed GWPt) and mass contribution (%of kg)

4.3. Comparison to other Salmon studies (cradle to distribution)

This study was compared to other published salmon LCAs. Due to significant differences in methodology and functional units, it can be difficult to make fair comparisons with other studies and care should be taken whenever doing so. All studies considered use feed datasets that follow economic allocation. Results from this LCA are only directly comparable to the NZ King Salmon EPD (New Zealand King Salmon, 2021) as both studies are of the same species (King Salmon), same functional unit (1 kg of edible meat) and results for the same scope (cradle to distribution) are presented here. Parker (2018) and Boissy et al (2011) are included in the comparison as Atlantic salmon are the most commonly farmed salmon species globally.

Table 4-3 and Figure 4-9 show the cradle-to-gate/distribution carbon footprint of salmon in this study compared to other studies. The Parker (2018), White (2013) and Boissy et al (2011) studies are for Atlantic salmon which have a lower eFCR compared to King salmon. The eFCR calculated in this study[5] of King salmon is substantially higher than Atlantic salmon which have a relatively efficient eFCR in the range of 1.1-1.6 (Parker 2018, White 2013, Boissy et al 2011). Farmed King salmon are reported to have a higher FCR ranging from 1.7-1.9 (New Zealand King Salmon, 2022).

The Parker (2018) results include distribution in Australia (659 km by truck and 356 km by ferry) per kg HOG and have been adjusted to per kg of edible meat assuming edible yield of 70%. The base case had high proportion of animal by-product contributing to the feed inputs, leading to a high carbon footprint. A scenario was also presented using Norway feed composition (which contained no animal by-products). This substantially decreased the carbon footprint.

Boissy et al results are for cradle to farm gate and were presented per kg of fish live weight. These results have been adjusted to per kg of edible meat assuming edible yield of 70%. The base case standard diet included fish and plant-based feed inputs while the low fishery diet replaced fish oil with plant-based oils which increased the carbon footprint slightly. The FCR in Boissy et al is lower than the Parker study, leading to a lower carbon footprint. The Boissy et al study doesn’t include distribution and the feed composition includes no animal by-products.

[5] The economic feed conversion ratio (eFCR, the amount of dry feed purchased to produce a kg of salmon) of New Zealand King salmon is the subject of ongoing work by the salmon industry and wasn’t used in the modelling. The eFCR calculated in this study is presented in the confidential annex only.

Table 4-3: Cradle-to-gate/distribution carbon footprint of Atlantic and King salmon.

Species	System	Country	GWP (edible meat) (kg CO_2e/kg)	Comment	Source
Atlantic Salmon	Marine net pens	AU	4.4	Cradle to gate	White, 2013
Atlantic salmon	Marine net pens	AU	18.9	Base case. Australian distribution	Parker, 2018
Atlantic salmon	Marine net pens	AU	5.9	Norway feed composition, Australia distribution	Parker, 2018
Atlantic salmon	Marine net pens	FR	3.1	Base Case, std diet, cradle to gate	Boissy et. al., 2011
Atlantic salmon	Marine net pens	FR	3.6	Low fishery diet, cradle to gate	Boissy et. al., 2011
King salmon	Marine pens	NZ	6.2	NZ distribution	NZKS EPD, 2021
King salmon	Marine and Freshwater pens	NZ	7.7	NZ distribution	This study

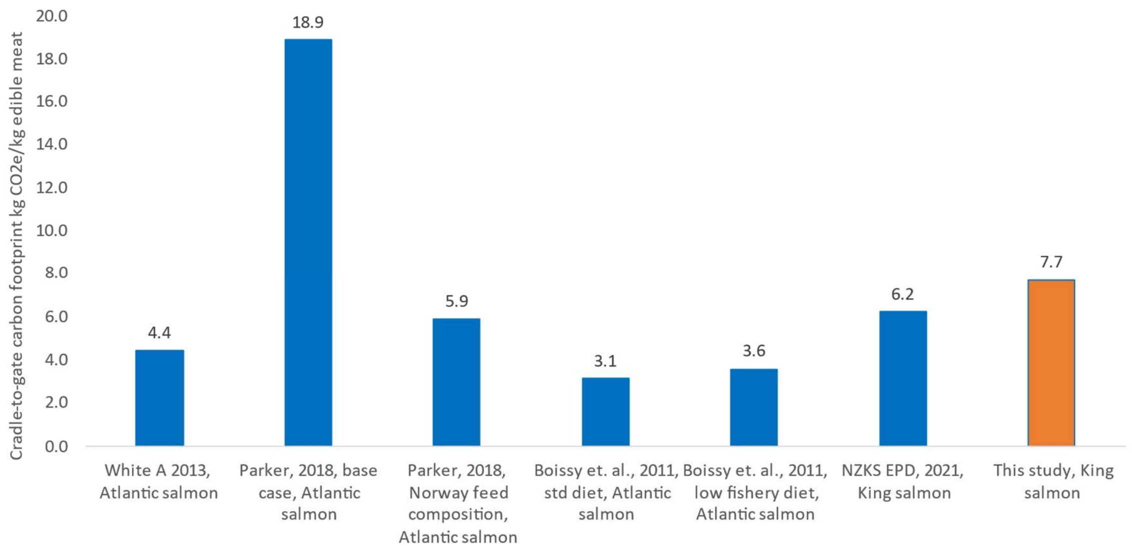

Figure 4-9: Carbon footprint comparison to other salmon studies. The result from this study is shown in orange.

4.4. Carbon Footprint Result per 100 Grams of Protein

Figure 4-10 presents the impacts per 100 g of protein for New Zealand distribution. This information will be used to compare NZ salmon with other sources of protein in Section 4.5.

Food provides a range of nutritional benefits and this LCA provides results for 100g of protein. This study doesn't take into consideration the complexities of the human dietary requirement for specific amino acids or the digestibility of different protein sources.

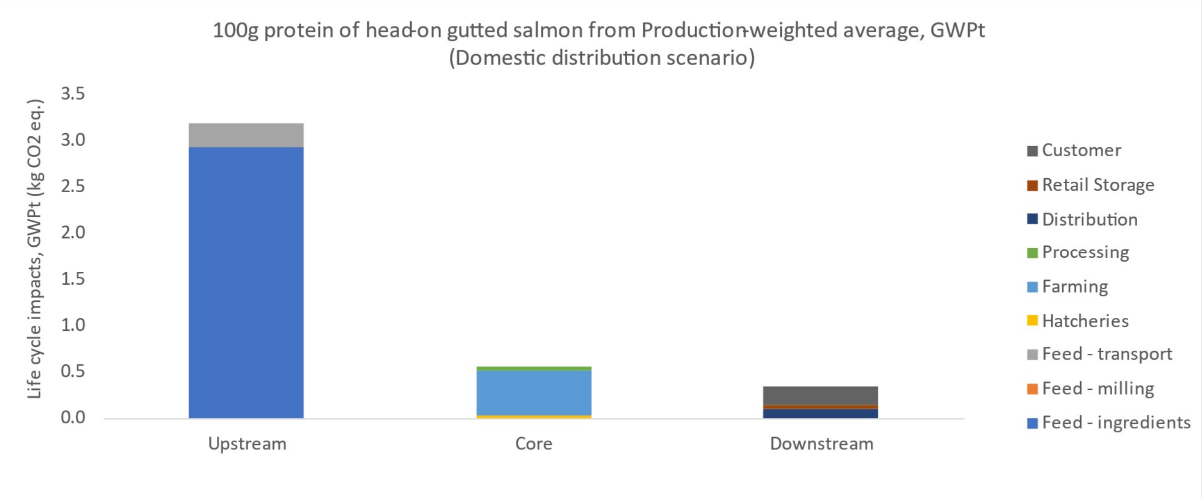

Figure 4-10: GWPt of 100 g protein of salmon, New Zealand distribution

4.5. Comparison to Other Protein Sources (Cradle-to-Retail)

The carbon results from this study have been compared to mussels and oysters from the Aquaculture New Zealand study (2021) and another study by Poore and Nemecek (2018) that consolidated data on the environmental impacts of various types of food production systems, covering 40 agricultural products. In doing this, the study created global production averages per 100 g protein for a variety of food products.

Bars are used to show the 10th and 90th percentiles provided by Poore & Nemecek which give an indication of the range of results within a particular protein source, due to different production methods, technologies, and location. It should be noted that the 90th percentile value of beef from beef herds extends to 105 kg CO_2e, which was cut off from the graph in order to not compress the rest of the data.

It is difficult to compare results from different life cycle studies as there are often differences in scope and methodology. To facilitate the comparison with the Poore and Nemecek values we have considered the same system boundary (from “cradle-to-retail” which includes the inputs through to the point of retail i.e., farming, processing, distribution, and distribution loss if applicable). The system boundary for this comparison doesn’t cover the full life cycle as it doesn’t include retail storage, customer use or end of life for packaging. In this salmon LCA these life cycle stages aren’t significant, but they could be for some of the other proteins in the comparison.

Where applicable, Poore and Nemecek consider studies which only use economic allocation (or studies that can be adjusted to economic allocation) to split production impacts between co-products. Similarly economic allocation is used in this study for the feed inputs and offal co-product.

New Zealand farmed salmon has a lower carbon footprint compared to the global average of other animal proteins and is higher than New Zealand mussels and oysters, per 100 g protein. The New Zealand salmon carbon footprint falls within the range provided by Poore and Nemecek for global egg, poultry and farmed fish protein. (Figure 4-11). The allocation method for feed by-products has a large influence over the salmon results and is likely to have less influence on the New Zealand beef, lamb, mussel and oysters carbon footprints as these systems have low or no input of feed by-products.

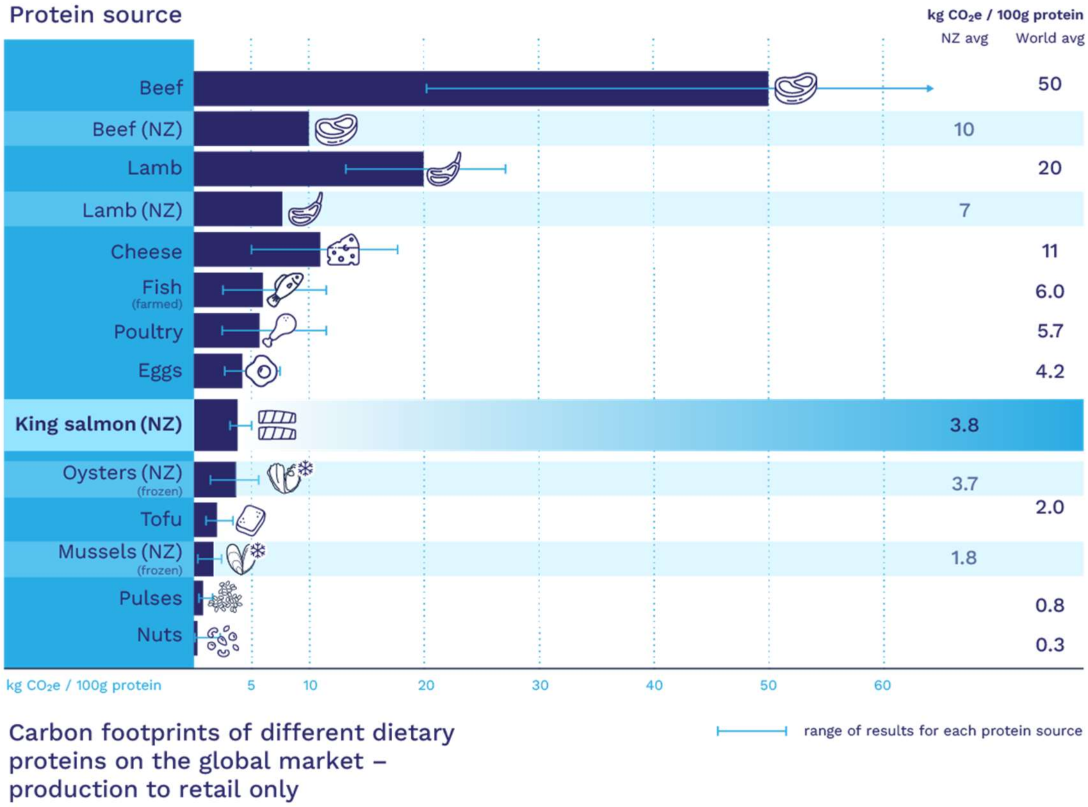

Figure 4-11: Cradle-to-retail carbon footprint comparison to other protein sources (kg CO_2e/100g protein).[6]

[6] The carbon footprints of the oysters and mussels in Figure 4.8 come from thinkstep-anz (2021). The carbon footprints of New Zealand beef and lamb are from Beef and Lamb NZ (2022), converted to per 100g protein. The other nutritional proteins come from global production data from Poore and Nemecek (2018). All products are shown using a system boundary that spans from farming to retail. The results for salmon are for domestic distribution. The bars in Figure 0.2 are used to show the tenth and ninetieth percentiles (the range within which 80% of producers will fall). These bars indicate the range of results for a particular protein source, due to different production methods, technologies, and locations.

5. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from ecoinvent and Agri-footprint were used. These databases are widely distributed and used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.1. Precision and Completeness

- Precision: As the majority of the salmon smolt production and salmon farm foreground data are measured data or calculated based on primary information sources, precision is considered to be high. Seasonal variations were balanced out by using yearly averages. The salmon farm data is from a 12 month period and input data is for all salmon production on site not just for the salmon harvested in that year, so is considered to be representative of the salmon lifecycle. Primary data for the salmon feed inputs was sourced from feed suppliers for the 2021 year. Feed background data was sourced from Agri-footprint and is country specific for Fishmeal, Fish oil and Soy Protein which covers 32% of the feed inputs and are considered high precision. Other feed inputs were modelled based on production in the Netherlands (with a lower precision) and a sensitivity analysis undertaken. All other background data were sourced from ecoinvent with the precision as documented by ecoinvent.
- Completeness: Each foreground process was checked for mass balance and completeness of the emission inventory. Small inputs to the hatchery and salmon farm inventory were omitted from calculations due to their very small contribution and lack of data on ingredients as outlined in section 2.6. These all contributed less than 0.001% of the total input mass, leaving them completely insignificant in terms of impact on the total results. Completeness of foreground unit process data is considered to be high.

5.2. Consistency and Reproducibility

- Consistency: To ensure data consistency, all primary data were collected with the same level of detail. Background data on feed inputs was sourced from Agri-footprint while all other background data were sourced from the ecoinvent databases.
- Reproducibility: Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this

report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.3. Representativeness

- Temporal: All primary data were collected for the calendar year 2021. As the study is intended to compare the product systems for the period 2021, temporal representativeness is considered to be high. The feed secondary data is older than the database version (as noted in Table 3-10). In some cases it is more than 10 years old and temporal representativeness is considered to be low and a sensitivity analysis undertaken.
- Geographical: All primary and secondary data were collected specific to New Zealand. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high for foreground information. All secondary data come from the ecoinvent v3.8 (2021) or Agri-footprint 5.0 (2019) databases. Feed background data was sourced from Agri-footprint and is country specific for Fishmeal, Fish oil and Soy Protein which covers 32% of the feed inputs and are considered high precision. Other feed inputs were modelled based on production in the Netherlands (with a lower precision) and a sensitivity analysis undertaken. Technological: All primary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness for primary data is considered to be high.

5.4. Model Completeness and Consistency

- Completeness: All relevant process steps for each product system were considered and modelled to represent each specific situation. The materials covered in this study account for 99.99% of inputs by mass. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.
- Consistency: All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimised by using LCI data either from the ecoinvent v3.8 or Agri-footprint 5.0 databases. System boundaries, allocation rules and impact assessment methods have been applied consistently throughout the study.

6. Interpretation

6.1. Identification of Relevant Findings

- When considering salmon distributed in New Zealand the upstream feed impacts contribute the most to the GWPt, EP terrestrial, AP and POCP environmental indicators. Most of the feed impacts are due to feed production, not transport of feed inputs or feed manufacture.
- The release of nutrients into freshwater and the ocean from fish excretions at the core process was the largest contributor to EP freshwater and EP marine
- The areas of largest impact from the feed mix were the fish meal and soybean protein concentrate, which contributed 15% each to the carbon footprint of the feed production. The feed mix also contributes to the EPt ;largely due to animal meal (18%) and fish meal (14%).
- The choice of feed allocation method has a significant impact on results.
- New Zealand farmed salmon has a lower carbon footprint compared to the global average carbon footprints published in other animal protein studies (according to Poore and Nemecek (2018) and falls within the range for global egg, poultry and farmed fish protein. NZ salmon carbon footprint is higher than New Zealand mussels and oysters, per 100 g protein.
- Exporting salmon via plane significantly increases the total life cycle carbon footprint.

6.2. Assumptions and Limitations

- The environmental footprint of salmon is heavily dependent on the feed type, and the life cycle inventory data selected for each feed. The life cycle impact assessment results are therefore highly dependent on the choice of database and the choice of co-product allocation method. Notably:
- The databases used are ecoinvent v3.8 (2021) or Agri-footprint 5.0 (2019) databases. Country specific feed datasets have been used for 32% of the feed inputs, the remainder use Agri-footprint Netherlands data as a proxy. The data used in Agri--footprint is older than 2019 and in some cases may be more than 10 years old.
- There are large variances in agricultural production techniques, even within countries and as such results can vary depending on the feed datasets used.
- Economic allocation has been applied for co-product allocation of feed types. This allocation method has been used as it aligns with the Product Environmental Footprint Category Rules, from the EU Commission, International EPD Programme Fish and Fish Product PCR recommendation of economic allocation for co-products. It also facilitates the discussion of the carbon footprint of different protein sources.

- The direct environmental interactions of salmon on freshwater and coastal water systems have been modelled based on stoichiometry. Specific interaction between these emissions and the environment is complex and detailed analysis was not part of this study.
- The study data was for the 2021 calendar year and since then the largest salmon producer has had significant fish mortality due to rising sea temperatures (New Zealand King Salmon, Annual Report, 2022). This is likely to increase the environmental impact of salmon farming.

6.3. Sensitivity Analysis.

6.3.1. Allocation

The feed allocation method used has a significant impact on results as shown in Figure 6-1. Economic allocation has been used as the base case and effectively places most of the environmental impacts on the products that are the main economic reason for the production system. Economic allocation is considered most appropriate as salmon feed inputs are usually low value co-products of another system, and this aligns with the Product Environmental Footprint Category Rules, from the EU Commission and International EPD Programmes PCR for fish and fish products. The same analysis was performed for EPf and EPm in Figure 6-2 and Figure 6-3.

However, it corresponds to the least preferred tier of the ISO 14044 allocation hierarchy as using energy or mass allocation better reflects the physical properties of the feeds. The low value by-products can have high energy values (particularly the animal products and crop oils) and contribute a relatively high mass to their production system, significantly increasing the environmental impacts when energy and mass allocation is used. When energy and mass allocation are used, animal meal contributes 74-79% GWPt of the upstream feed inputs. The energy and mass GWPt emission factors for animal meal are 95 and 96 times higher than the economic GWPt allocation factor.

The allocation to HOG salmon co-products (offal) was also included in this analysis.

As can be seen in Figure 6-1, Figure 6-2, and Figure 6-3 the choice of allocation factor has a significant impact on results for global warming, freshwater and marine eutrophication, with the use of energy and mass allocation factors increasing the resulting impacts.

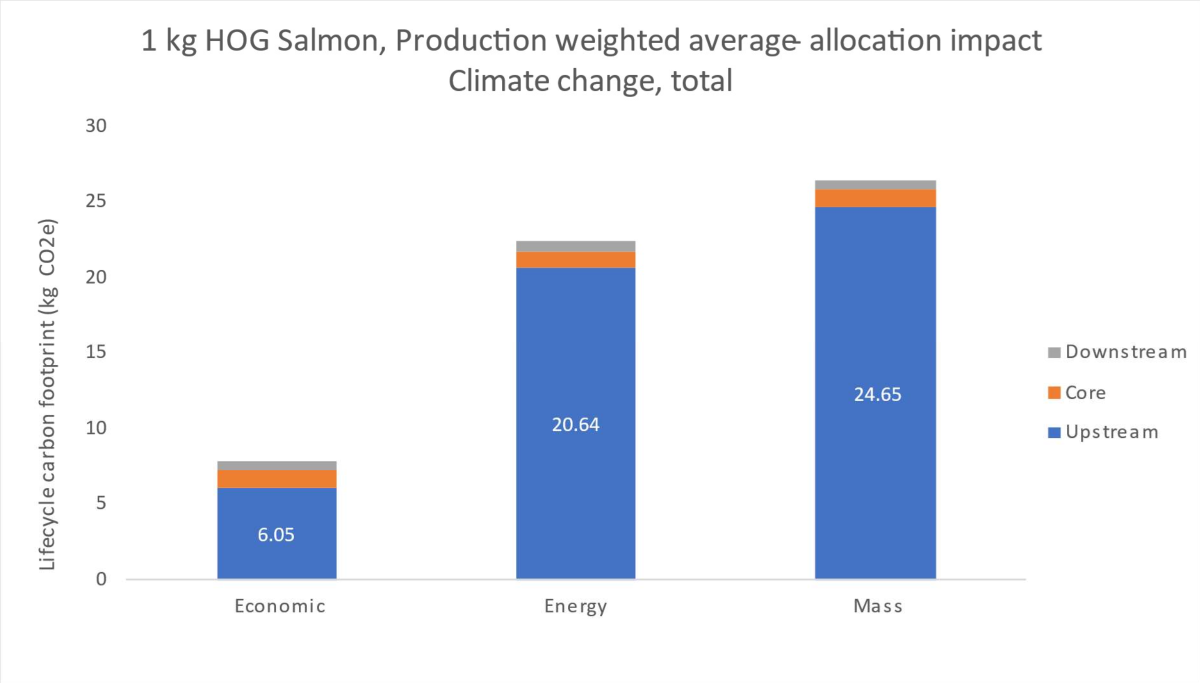

Figure 6-1: Impact of feed allocation method on GWPt of salmon, New Zealand distribution (per 1 kg of meat).

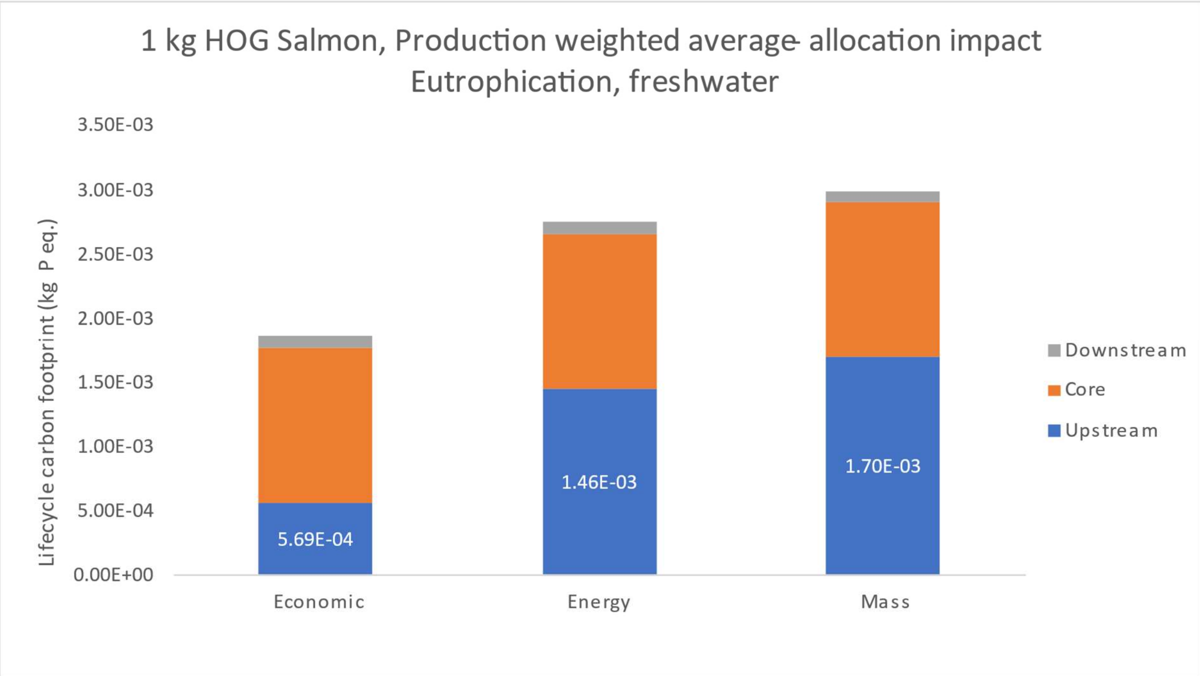

Figure 6-2: Impact of feed allocation method on EPf of salmon, New Zealand distribution (per 1 kg of meat).

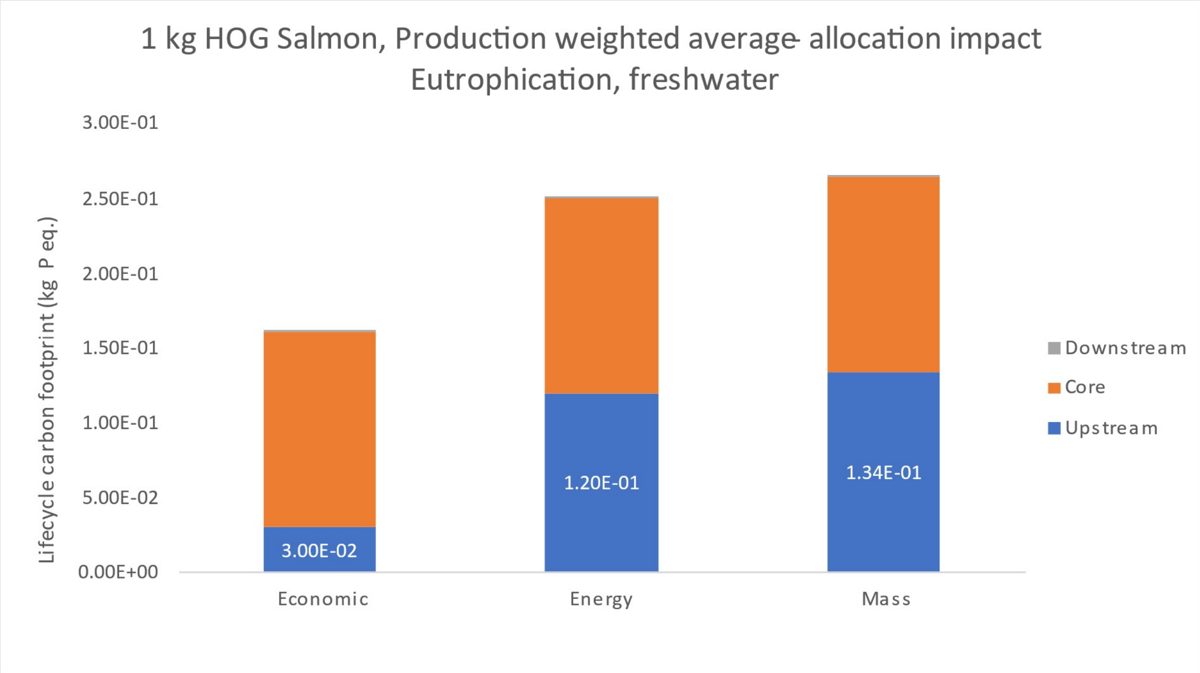

Figure 6-3: Impact of feed allocation method on EPm of salmon, New Zealand distribution (per 1 kg of meat).

6.3.2. Feed geography

A check of alternative datasets showed the NL GWP varies from -16% lower to 59% higher than the other datasets. This sensitivity analysis aims to assess the worst-case scenario in which all datasets with the incorrect geography have a larger impact. This was done by applying a coefficient of1.2 to all impacts for datasets where the actual source geography was unknown, or where the correct geographical source had no available datasets.

The impact on the total results, and on the feed alone were then assessed as a percentage change.

As can be seen in Table 6-1 this scenario increases the carbon footprint of feed inputs by 22% and salmon by 16%. Environmental impacts are increased by 2-21% for the range of indicators.

Table 6-1: Feed geography variance

Indicator	Variance on total (%)	Variance on feed (%)
GWPt	7	9%
EPf	2%	5%
EPm	1%	4%
EPt	5%	7%
AP	6%	8%
POCP	8%	12%

6.3.3. Distribution

The distribution scenarios show that exporting salmon by air has a much higher GWPt impact than New Zealand domestic distribution or international sea freight (Table 6-2 and Figure 6-4).

Table 6-2: Total environmental impacts of salmon considering different distribution scenarios (per 1 kg of meat)

Indicator	Unit	New Zealand	International Sea Freight	International Air Freight
GWPt	kg CO_2 eq.	8.228	8.624	20.228
EPf	kg P eq.	0.002	0.002	0.002
EPm	kg N eq.	0.163	0.165	0.186
EPt	mol N eq.	0.261	0.283	0.508
AP	kg SO_2 eq.	0.063	0.069	0.124
POCP	kg PO_4^{3-} eq.	0.040	0.046	0.104

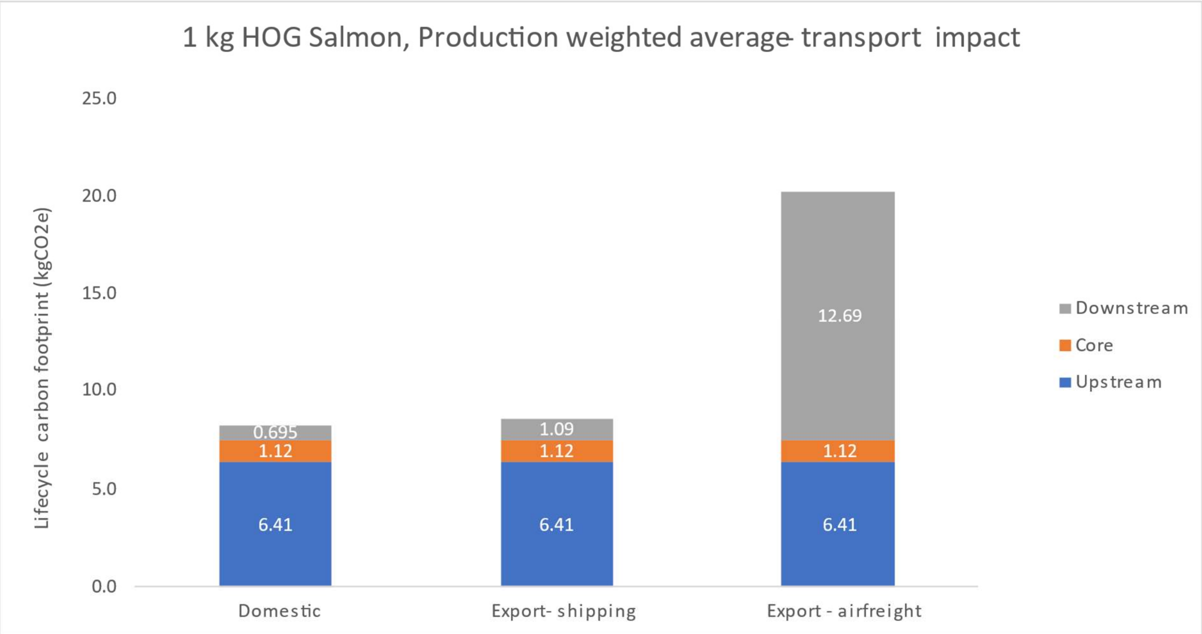

Figure 6-4: Impact of distribution on GWPt of salmon, (per 1 kg of meat).

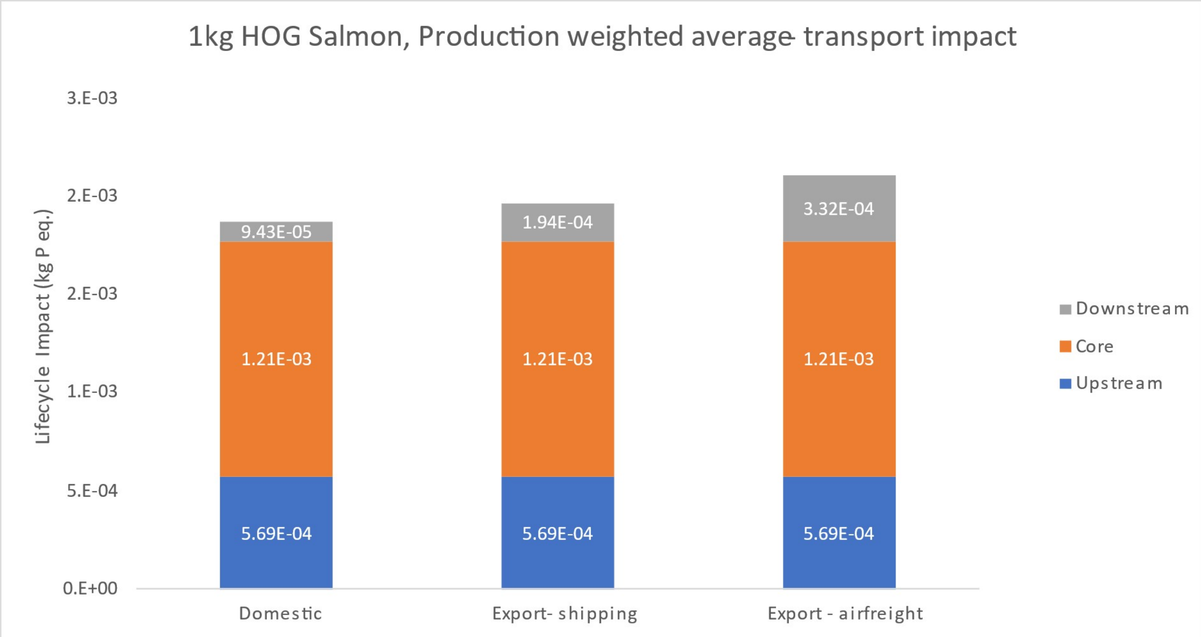

Figure 6-5: Impact of distribution on EPf of salmon, (per 1 kg of meat).

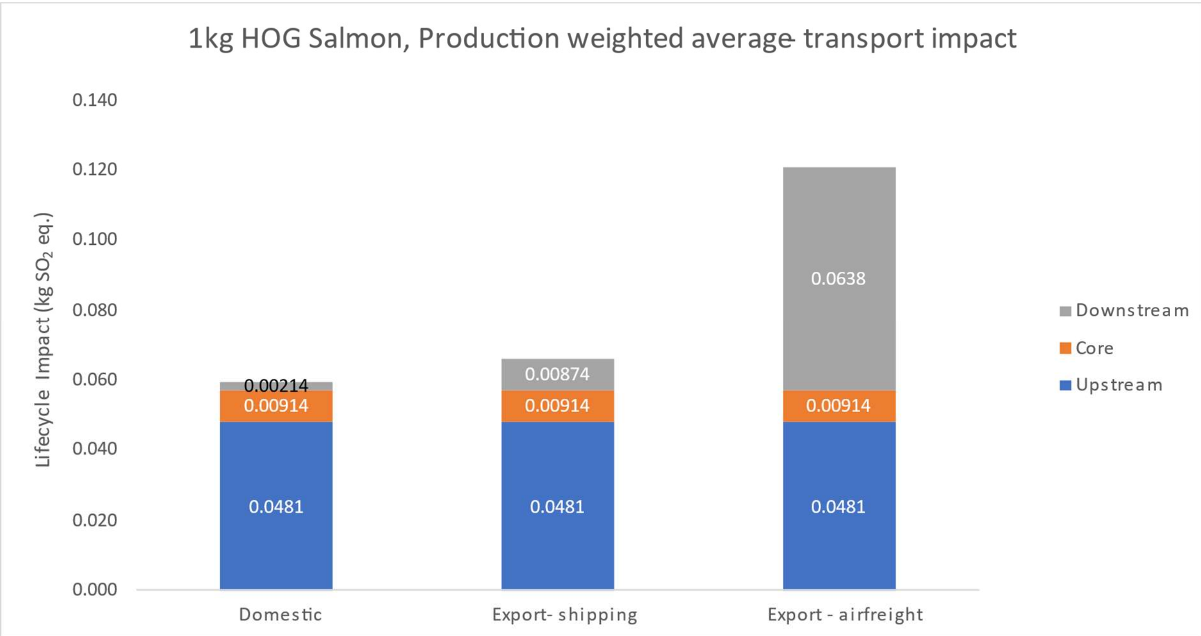

Figure 6-6: Impact of distribution on AP of salmon, (per 1 kg of meat).

Figure 6-5 illustrates how transport scenarios have very little impact on freshwater eutrophication impacts. Meanwhile, acidification impacts increase by a similar magnitude to GWPt impacts s which can be seen in Figure 6-6. This is due to the the additional fuel use for the international transport scenarios. Combustion of fossil fuels have a large impact both in terms of climate change potential and acidification potential.

6.3.4. Sensitivity analysis on technical/other feed

As datasets were not available to accurately model the technical/other feed inputs, the pea protein dataset was used as this too is a heavily processed product which would be true to the technical feeds (e.g., isolated vitamins and antioxidants). To test the sensitivity of this feed input's dataset choice, a worst-case alternative dataset was used, and it's change to the total impacts was recorded as a percentage change.

The results for this can be seen in Table 6-3 and show that the worst case doesn't substantially increase the environment impact.

Table 6-3: Technical/other feed worst case scenario

Indicator	Variance on total (%)
GWPt	8%
EPf	-4%
EPm	2%
EPt	6%
AP	6%
POCP	3%

6.4. Conclusions, Limitations, and Recommendations

6.4.1. Conclusions

Salmon feed contributes most to the carbon footprint, terrestrial eutrophication and acidification for domestic salmon distribution and the choice of feed allocation method has a significant impact on results.

Salmon farming contributes the most to the freshwater and marine eutrophication

New Zealand farmed salmon has a lower carbon footprint compared to the global average of other animal proteins and is higher than New Zealand mussels and oysters, per 100 g protein. The New Zealand salmon carbon footprint falls within the range provided by Poore and Nemecek for global egg, poultry and farmed fish protein.

Exporting salmon via plane significantly increases the total life cycle carbon footprint.

Recommendations

The majority of the salmon feed datasets are modelled using geographical proxies and the accuracy of results would be improved if feed input origin and country specific datasets were available.

Sourcing feed with lower environmental impacts per kilogram would lead to a significant reduction in environmental impacts. Soy protein concentrate and rapeseed oil have high environmental impact, replacing these with most of the other feed inputs would reduce the overall environmental impact. We recommend industry work with feed suppliers to review feed formulations that balance environmental impact, availability, price and nutritional content.

Improving the economic feed conversion ratio (eFCR, the amount of feed purchased to produce a kg of salmon) would decrease the amount of feed used, so reduce environmental impacts. Reducing feed loss to water, improving the nutritional content and digestibility of feed and using selective breeding could all improve the eFCR.

Lowering the mortality rate would improve salmon farming efficiency and lower the environmental impacts.

Reducing the distance transported by air freight would greatly reduce the salmon carbon footprint.

As North America is a large market for the industry, encouraging air freight companies to use lower carbon fuels can have a significant impact on the carbon footprint of salmon.

Improving freezing and chilling technology which could lead to increased sea freight and lowering the transport footprint.

7. References

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List of Acronyms

ADP	Abiotic Depletion Potential
AP	Acidification Potential
CML	Centre of Environmental Science at Leiden
ELCD	European Life Cycle Database
EoL	End-of-Life
EPf	Eutrophication Potential freshwater
EPm	Eutrophication Potential marine
EPt	Eutrophication Potential terrestrial
FCR	Feed Conversion Ratio
GHG	Greenhouse Gas
GWPt	Global Warming Potential, total
HOG`	Head-On Gutted
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LC	Land Competition
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
POFP	Photochemical Ozone Formation Potential
PCR	Product Category Rule
RoW	Rest of World
SFP	Smog Formation Potential
VOC	Volatile Organic Compound

Glossary

Life cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life cycle interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Environmental Product Declaration (EPD)

"Independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products."

Product Category Rule (PCR)

"Defines the rules and requirements for EPDs of a certain product category."

Functional / Declared unit

"Quantified performance of a product system for use as a reference unit." (ISO 14040:2006, section 3.20)

Functional unit = LCA/EPD covers entire life cycle "cradle to grave".

Declared unit = LCA/EPD is not based on a full "cradle to grave" LCA, common in construction product EPDs.

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study." (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, section 4.3.4.3.3)

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, section 3.45).

Economic Feed Conversion Ratio (eFCR)

A measure of how efficiently a farmed animal puts on weight relative to the amount of feed given to it. Calculated as Feed given / Weight gain.

Applicability and Limitations

Restrictions and Intended Purpose

This report has been prepared by thinkstep-anz with all reasonable skill and diligence within the agreed scope, time and budget available for the work. thinkstep-anz does not accept responsibility of any kind to any third parties who make use of its contents. Any such party relies on the report at its own risk. Interpretations, analyses, or statements of any kind made by a third party and based on this report are beyond thinkstep-anz's responsibility.

If you have any suggestions, complaints, or any other feedback, please contact us at: feedback@thinkstep-anz.com.

Legal interpretation

Opinions and judgements expressed herein are based on our understanding and interpretation of current regulatory standards and should not be construed as legal opinions. Where opinions or judgements are to be relied on, they should be independently verified with appropriate legal advice.

Annex A Critical Review Statement

A.1. Critical Review Statement

Study reviewed "LCA of King Salmon From New Zealand", version 1.4, prepared by Kimberly Robertson and Tor-Anders Waag Strømsvik of thinkstep-anz on behalf of Fisheries New Zealand.

This critical review was undertaken by a Review Panel of three experts (Sarah McLaren, Nathan Pelletier and Gaspard Philis) following ISO 14044:2006, section 6.3 ("Critical review by panel of interested parties"). Its remit was to ensure that the methods in the Life Cycle Assessment (LCA) were consistent with the ISO 14040:2006, 14044:2006 and 14067:2018 standards. In particular, the review was concerned with establishing that:

- The methods used to carry out the LCA are scientifically and technically valid
- The data used are appropriate and reasonable in relation to the goal of the study
- The interpretations reflect the limitations identified and the goal of the study
- The report is transparent and consistent with the aims of the study (whilst respecting any company confidentiality restrictions).

Process

This review consisted of a series of reviews of an LCA report produced by thinkstep for client Fisheries New Zealand. The first review was undertaken in December 2022 (providing initial feedback on the project scope, system boundaries, etc.). Two further detailed reviews of the draft report took place between January and March 2023. Significant issues addressed throughout the reviews included:

1. Comparison of carbon footprint result with existing studies on the carbon footprint of alternative food items on the basis of their protein content: ensuring the text describes the limitations of these comparisons.
2. Choice of impact categories, and presentation of the results for these other impact categories as well as carbon footprint result: justification of choice of impact categories, and presentation of results for all impact categories (not just carbon footprint).
3. Allocation approach for feed ingredients: choice of allocation basis (e.g. energy, mass, economic) has a significant influence on the overall results, and this fact should be highlighted when discussing the results (including through a sensitivity analysis), including the fact that economic allocation has been used in the baseline study (which is the least preferred approach in the ISO hierarchy of approaches to allocation).
4. Nutritional functional unit: protein was selected as the only nutrient for the nutritional functional unit, and the limitations of focusing on this nutrient needs to be made clear.
5. Use of proxy data for feed inputs: a conservative approach should be followed when data for actual feed inputs are not available.

6. Data quality: information should be provided on the quality of different datasets used in the analysis.
7. Sample size: provide information about the proportion of the NZ King Salmon industry represented by the data collected in the study.
8. Provision of more data on production systems and calculation methods, including the FCR: more modelling data are required in order to check calculations during the review.
9. Variability in results across the different salmon farms: show this variability in results.

The reviews and subsequent discussions with the authors led to a final report that is more informative and transparent about the limitations of the results relative to the goal of the study. Although it would have been preferable to include more primary data in the main report, the reviewers understand the company confidentiality restrictions associated with such disclosures.

<u>General Evaluation</u>

The authors constructively engaged with the reviewers' comments throughout the review process. As the limitations of the analysis have now been clearly communicated in the report, we consider it to be a useful study that can assist the company in understanding the environmental impact of New Zealand-farmed King salmon over its lifecycle.

Signed:

Professor Sarah McLaren, Massey University (Panel Chair)

Associate Professor Nathan Pelletier, University of British Columbia

LCA and EPD consultant, LCA.no, Norway

Annex B Salmon Feed Production and eFCR

Feed life cycle inventory and eFCR information is confidential and is only being shared with the critical review panel. Annex B is included in a separate document.

About thinkstep-anz

Our mission is to enable organisations to succeed sustainably. We develop strategies, deliver roadmaps, and implement leading software solutions. Whether you're starting out or want to advance your leadership position, we can help no matter your sector or size.

thinkstep anz

Why us? Because we are fluent in both languages of sustainability and business. We are translators.

We've been building business value from sustainability for 15 years, for small or large businesses, family-owned and listed companies, or government agencies.

Our approach is science-based, pragmatic, and flexible.

Our work helps all industries in Australia and New Zealand, including manufacturing, building and construction, FMCG, packaging, energy, apparel, tourism, and agriculture.

Our services range from ready-to-go packages to solutions tailored to your needs.

As a certified B Corp with an approved science-based target, we make sure we are walking the talk.

Our services cover:

Product

- Life Cycle Assessment (LCA)
- Environmental Product Declarations (EPD)
- Carbon footprint
- Circular Economy (CE)
- Cradle to Cradle (C2C)
- Water footprint
- Packaging
- Independent reviews

Carbon

- Carbon Footprint
- Scope 3 emissions
- Reduction strategy
- Carbon targets
- Science-based targets (SBT)
- Offsetting strategies
- Inventory verification

Strategy

- Materiality assessment
- Green Star
- Sustainable Development Goals (SDGs)
- Foresighting & regenerative futures
- Roadmaps & action plans
- Responsible procurement & supply chain engagement

Software & tools

- GaBi LCA software
- GaBi Envision
- Material Circularity Indicator (MCI)
- OpenLCA
- eTool
- Packaging calculator
- SoFi sustainability reporting

Reporting & disclosures

- Task Force on Climate-related Financial Disclosures (TCFD)
- Global Reporting Initiative (GRI) & Integrated reporting (<IR>)
- B Corp
- Voluntary & compliance reporting
- CDP

Communications

- Short form reports
- Case studies
- Infographics
- Workshops
- Storytelling
- Stakeholder engagement
- Sustainability reports

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Succeed sustainably

thinkstep ltd
11 Rawhiti Road
Pukerua Bay 502
New Zealand

+64 4 889 2520

thinkstep pty ltd
25 Jubilee Street
South Perth WA 6151
Australia

+61 2 8007 3330

meet@thinkstep-anz.com
www.thinkstep-anz.com

@thinkstepANZ
thinkstep-anz
thinkstep-anz

New Zealand: Wellington | Auckland | Hamilton | Christchurch
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