First Product Environmental Footprint Representative Product (PEF-RP) study for the Marine Fish PEFCR development

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Acronyms

AF	Allocation Factor
AR	Allocation Ratio
B2B	Business to Business
B2C	Business to Consumer
BFCR	Biological Feed Conversion Ratio
BoC	Bill of Components
BoM	Bill of Materials
CF	Characterization Factor
CFF	Circular Footprint Formula
CFF-M	Circular Footprint Formula – Modular form
COD	Chemical Oxygen Demand
CPA	Classification of Products by Activity
DC	Distribution Centre
DMI	Dry Matter Intake
DNM	Data Needs Matrix
DQA	Data Quality Assessment
DQR	Data Quality Rating
DQS	Data Quality Score
DW	Dry weight
EA	Economic Allocation
EC	European Commission
EF	Environmental Footprint
EF2.0 and EF3.0	Environmental Footprint database version 2 or 3
EFCR	Economic Feed Conversion Ratio
EI	Environmental Impact
ELCD	European reference Life Cycle Database
EoL	End-of-Life
FEFAC	European Feed Manufacturers' Federation
FU	Functional Unit
GE	Gross Energy intake
GHG	Greenhouse Gas
GR	Geographical Representativeness
GWP	Global Warming Potential
GWP100	Global Warming Potentials with a time horizon of 100 years
Ha	Hectare
HH	Human Health (used in ionizing radiation HH)
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
kWh	kilowatt hour
LCA	Life Cycle Assessment
LCDN	Life Cycle Data Network
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LT	Lifetime
LUC	Land Use Change
Lw	Live weight

Lwe	Live weight equivalents
NACE	Statistical classification of economic activities in the European Community
NDA	Non-Disclosure Agreement
NGO	Non-Governmental Organisation
NMVOC	Non-methane volatile compounds
NPK	Nitrogen (N), Phosphorus (P) and Potassium (K)
OEF	Organisation Environmental Footprint
OW	One Way
P	Precision
PCR	Product Category Rules
PDO	Protected Designation of Origin
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PEF-RP	Product Environmental Footprint study of the Representative Products
RAS	Recirculating Aquaculture System
ReCiPe	Impact assessment method
RER	Region Europe
RF	Reference Flow
RP	Representative Product
RUaEP	Resource Use and Emissions Profile
SC	Steering Committee
Scope 1	Referring to the GHG Protocol nomenclature, direct emissions from owned or controlled sources.
Scope 2	Referring to the GHG Protocol nomenclature, indirect emissions from the generation of purchased energy.
Scope 3	Referring to the GHG Protocol nomenclature, all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.
SMRS	Sustainability Measurement & Reporting System
TAB	Technical Advisory Board
TeR	Technological Representativeness
TiR	Time Representativeness
Tonne	1000 kg
TS	Technical Secretariat
UNEP	United Nations Environment Programme
UUID	Universally Unique Identifier
WW	Wet weight

Definitions

The PEF Method [1] provides a complete list of definitions, and the most relevant ones for this PEF-RP Report are also presented here.

Activity data - This term refers to information which is associated with processes while modelling Life Cycle Inventories (LCI). The aggregated LCI results of the process chains that represent the activities of a process are each multiplied by the corresponding activity data[1] and then combined to derive the environmental footprint associated with that process. Examples of activity data include quantity of kilowatt-hours of electricity used, quantity of fuel used, output of a process (e.g. waste), number of hours equipment is operated, distance travelled, floor area of a building, etc. Synonym of “non-elementary flow”.

Additional environmental information – Environmental information outside the EF impact categories that is calculated and communicated alongside PEF results.

Additional technical information – Non-environmental information that is calculated and communicated alongside PEF results.

Allocation – An approach to solving multi-functionality problems. It refers to “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).

Attributional – Refers to process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects

Average Data – Refers to a production-weighted average of specific data.

Benchmark – A standard or point of reference against which any comparison may be made. In the context of PEF, the term ‘benchmark’ refers to the average environmental performance of the representative product sold in the EU market.

Bill of materials – A bill of materials or product structure (sometimes bill of material, BOM or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture the product in scope of the PEF study. In some sectors it is equivalent to the bill of components.

Bycatch - The catch of organisms that are not targeted. This includes organisms that are outside legal-size limits, over-quotas, threatened, endangered and protected species, and discarded for whatever other reasons, as well as nontargeted organisms that are retained and then sold or consumed[2].

[1] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 2011).
[2] http://www.fao.org/documents/card/en/c/CA2905EN/

Company-specific data – It refers to directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It is synonymous to “primary data”. To determine the level of representativeness a sampling procedure may be applied.

Comparative Assertion – An environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function (including the benchmark of the product category) (adapted from ISO 14044:2006).

Comparison – A comparison, not including a comparative assertion, (graphic or otherwise) of two or more products based on the results of a PEF study and supporting PEFCRs.

Co-product – Any of two or more products resulting from the same unit process or product system (ISO 14040:2006).

Cradle to Gate – A partial product supply chain, from the extraction of raw materials (cradle) up to the manufacturer’s “gate”. The distribution, storage, use stage and end of life stages of the supply chain are omitted.

Cradle to Grave – A product’s life cycle that includes raw material extraction, processing, distribution, storage, use, and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Data Quality – Characteristics of data that relate to their ability to satisfy stated requirements (ISO 14040:2006). Data quality covers various aspects, such as technological, geographical and time-related representativeness, as well as completeness and precision of the inventory data.

Data Quality Rating (DQR) - Semi-quantitative assessment of the quality criteria of a dataset based on Technological representativeness, Geographical representativeness, Time-related representativeness, and Precision. The data quality shall be considered as the quality of the dataset as documented.

Direct elementary flows (also named elementary flows) – All output emissions and input resource use that arise directly in the context of a process. Examples are emissions from a chemical process, or fugitive emissions from a boiler directly onsite.

Direct land use change (dLUC) – The transformation from one land use type into another, which takes place in a unique land area and does not lead to a change in another system.

Discards - Discards, or discarded catch is that portion of the total organic material of animal origin in the catch, which is thrown away, or dumped at sea for whatever reason. It does not include plant materials and post-harvest waste such as offal. The discards may be dead, or alive.[3] (In some fisheries it can also be referred to as "slipping".)

Elementary flows – In the life cycle inventory, elementary flows include "material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation" (ISO 14040, 3.12). Elementary flows include, for example, resources taken from nature or emissions into air, water, soil that are directly linked to the characterisation factors of the EF impact categories.

Environmental aspect – Element of an organisation's activities or products or services that interacts or can interact with the environment (ISO 14001:2015).

Environmental Footprint (EF) compliant dataset – Dataset developed in compliance with the EF requirements provided at http://eplca.jrc.ec.europa.eu/LCDN/developer.xhtml.

Environmental Footprint (EF) Impact Assessment – Phase of the PEF analysis 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 (based on ISO 14044:2006). The impact assessment methods provide impact characterisation factors for elementary flows in order to aggregate the impact to obtain a limited number of midpoint indicators.

Environmental Footprint (EF) Impact Assessment method – Protocol for quantitative translation of life cycle inventory data into contributions to an environmental impact of concern.

Environmental Footprint (EF) Impact Category – Class of resource use or environmental impact to which the life cycle inventory data are related.

Foreground elementary flows - Direct elementary flows (emissions and resources) for which access to primary data (or company-specific information) is available.

Foreground Processes – Refer to those processes in the product life cycle for which direct access to information is available. For example, the producer's site and other processes operated by the producer or its contractors (e.g. goods transport, head-office services, etc.) belong to the foreground processes.

Functional unit – The functional unit defines the qualitative and quantitative aspects of the function(s) and/or service(s) provided by the product being

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[3] http://www.fao.org/documents/card/en/c/CA2905EN/

evaluated. The functional unit definition answers the questions “what?”, “how much?”, “how well?”, and “for how long?”.

Gate to Gate – A partial product supply chain that includes only the processes carried out on a product within a specific organisation or site.

Gate to Grave – A partial product supply chain that includes only the distribution, storage, use, and disposal or recycling stages.

Indirect land use change (iLUC) – It occurs when a demand for a certain land use leads to changes, outside the system boundary, i.e. in other land use types. These indirect effects may be mainly assessed by means of economic modelling of the demand for land or by modelling the relocation of activities on a global scale.

Input flows – Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products (ISO 14040:2006).

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).

Life cycle impact assessment (LCIA) – Phase of life cycle assessment that aims at understanding and evaluating the magnitude and significance of the potential environmental impacts for a system throughout the life cycle (ISO 14040:2006). The LCIA methods used provide impact characterisation factors for elementary flows to in order to aggregate the impact to obtain a limited number of midpoint and/or damage indicators.

Live weight (Lw) and live weight equivalents (Lwe) - Used to specify the weight of fish before it is killed. For farmed fish this also indicates the weight before starving and bleeding.

PEFCR supporting study – PEF study based on a draft PEFCR. It is used to confirm the decisions taken in the draft PEFCR before the final PEFCR is released.

PEF report – Document that summarises the results of the PEF study.

PEF study of the representative product (PEF-RP) – PEF study carried out on the representative product(s) and intended to identify the most relevant life cycle stages, processes, elementary flows, impact categories and any other major requirements needed for the definition of the benchmark for the product category/ sub-categories in scope of the PEFCR.

PEF study – Term used to identify the totality of actions needed to calculate the PEF results. It includes the modelling, the data collection, and the analysis of the results. It excludes the PEF report and the verification of the PEF study and report.

Prepared fishery products - Unprocessed fishery products that have undergone an operation affecting their anatomical wholeness, such as gutting, heading, slicing, filleting, and chopping.

Primary data[4] - This term refers to data from specific processes within the supply chain of the user of the PEF Method or user of the PEFCR. Such data may take the form of activity data, or foreground elementary flows (life cycle inventory). Primary data are site-specific, company-specific (if multiple sites for the same product) or supply chain specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the user of the PEF Method or user of the PEFCR. In this method, primary data is synonym of "company-specific data" or "supply-chain specific data".

Processed fishery products – Products that have undergone a process that substantially alters the initial product, including heating, smoking, curing, maturing, drying, marinating, extraction, extrusion or a combination of those processes.

Product Category Rules (PCRs) – Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories (ISO 14025:2006).

Product Environmental Footprint Category Rules (PEFCRs) – Product category specific, life cycle based rules that complement general methodological guidance for PEF studies by providing further specification at the level of a specific product category. PEFCRs help to shift the focus of the PEF study towards those aspects and parameters that matter the most, and hence contribute to increased relevance, reproducibility and consistency of the results by reducing costs versus a study based on the comprehensive requirements of the PEF method. Only the PEFCRs listed on the European Commission website (http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm) are recognised as in line with this method.

Product flow – Products entering from or leaving to another product system (ISO 14040:2006).

Reference flow – Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit (based on ISO 14040:2006).

Representative product (model) - The RP may be a real or a virtual (non-existing) product. The virtual product should be calculated based on average European market sales- weighted characteristics of all existing technologies/materials covered by the product category or sub-category. Other weighting sets may be

[4] Based on GHG protocol scope 3 definition from the Corporate Accounting and Reporting Standard (World resources institute, 20011).

used, if justified, for example weighted average based on mass (ton of material) or weighted average based on product units (pieces).

Round fish - For wild fish this is identical to “live fish”, but for certain aquaculture systems the term “round weight” refers to the biomass after starving and bleeding.

Secondary data[5] - It refers to data not from a specific process within the supply-chain of the company performing a PEF study. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third party LCI database or other sources. Secondary data includes industry average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and may also be based on financial data, and contain proxy data, and other generic data. Primary data that go through a horizontal aggregation step are considered as secondary data.

Specific Data – Refers to directly measured or collected data representative of activities at a specific facility or set of facilities. Synonymous with “primary data.”

System boundary – Definition of aspects included or excluded from the study. For example, for a “cradle-to-grave” EF analysis, the system boundary includes all activities from the extraction of raw materials through the processing, distribution, storage, use, and disposal or recycling stages.

Unit process – Smallest element considered in the LCI for which input and output data are quantified (based on ISO 14040:2006).

Unprocessed fishery products - Products that have not undergone processing, and includes products that have been divided, parted, severed, sliced, boned, minced, skinned, ground, cut, cleaned, trimmed, husked, milled, chilled, frozen, deep-frozen or thawed.

User of the PEFCR – a stakeholder producing a PEF study based on a PEFCR.

Waste – Substances or objects which the holder intends or is required to dispose of (ISO 14040:2006).

[5] ídem

DOCUMENT OUTLINE

This document presents a Product Environmental Footprint (PEF) study of virtual products that represent the EU consumption of marine fish products. These products are called “representative products” (RP). This study is used as a part of the knowledge background to develop a Product Environmental Footprint Category Rule (PEFCR) for marine fish products in the EU market. In this document you will find:

- Section 1: Introduction. Here we provide more information about the background and purpose of this analysis.
- Section 2: Method. Here we present the method that is used in the study of the representative products. **This is not the PEFCR. The PEFCR is a separate document.**
- Section 3: Inventory analysis. Here we describe what the study includes and the numbers/data that are used to model and calculate the Product Environmental Footprint (PEF) profile of the representative products.
- Section 4: Results. Here we present the results and a hotspot analysis. This identifies the most important impacts and the stages, processes and flows that causes them. These results are presented in a separate Excel sheet.

In this report, green boxes like this provide information about aspects that are relevant for the current version of this PEF-RP report.

1 INTRODUCTION

This report is a preliminary version of the Product Environmental Footprint of two virtual marine fish products that represent the consumption of unprocessed wild caught and farmed marine fish (for direct human consumption) in the EU market.

The study presented in this report is part of the development of marine fish product environmental footprint category rules (i.e. the Marine Fish PEFCR) and it is performed according to the guidelines for PEFCR development [2].

1.1 Comment on the current version

This report presents the current status of the PEF-RP study and the preliminary results from the hotspot analysis. This study is continuously updated according to input from consultations and other stakeholders. The final PEF-RP report will also be made available for public consultation.

2 Method description

2.1 Goal

2.1.1 Intended application and reason for carrying out the study

This study is performed as a mandatory step in the development of a PEFCR for marine fish.

The aim of the PEF-RP study is defined in section A.2.4 of the PEF method [2]:

- Identifying the most relevant impact categories;
- Identifying the most relevant life cycle stages, processes and elementary flows;
- Identifying data needs, data collection activities and data quality requirements

Section A.2.4 of the PEF method [2] also provide instructions on the method that shall be applied, most important:

- If an EF compliant proxy can be found it shall be used
- If an ILCD entry level compliant proxy can be found: it shall be used but shall not be included in the list of default datasets of the first draft PEFCR
- If no EF compliant or ILCD entry level compliant proxy can be found, another dataset may be used.
- In the first PEF-RP no cut-off of processes, emissions to the environment and resources from the environment is allowed. All the life cycle stages and processes shall be included (incl. capital goods).

2.1.2 Target audience

The target audience for this PEF study is the Technical Secretariat that develop the Marine Fish PEFCR and other stakeholders in the development of that PEFCR. That includes everyone who participates in the public consultations and the consultations by the different EC bodies.

2.1.3 Commissioner of the study

This study is performed by Erik Skontorp Hognes (Asplan Viak AS) as a project commissioned by the Marine Fish PEFCR Technical Secretariat (TS). The PEFCR document includes a more comprehensive presentation of this TS and the way in which the PEFCR is being developed. The development of this PEF-RP is possible thanks to the financial contributions of the TS members and a generous grant from the Norwegian Seafood Research Fund (FHF)[6].

2.1.4 Identification of the verifier

Table 2-1 presents the members of the independent panel that provided external reviews throughout the development of the Marine Fish PEFCR, including this PEF-RP analysis. Their reviews were performed according to section A.2.9 in Annex A of the PEF Method.

Table 2-1 Members of the PEFCR review panel

Category	Name	Affiliation
Industry expert	Alex Olsen (Chair)	Self-employed (Formerly Espersen)
LCA expert	Angel Avadí	CIRAD
LCA expert	Ian Vázquez-Rowe	PUCP

Annex 6.2 presents the biographical sketches of the Review Panel members.

2.2 Scope

The product scope of the Marine Fish PEFCR includes unprocessed wild and unprocessed farmed marine fish for direct human consumption in the EU market. This scope excludes crustaceans, molluscs, and freshwater fish, both wild and farmed (see Chapter 3 and the section on product scope in the PEFCR for more detail).

2.2.1 Functional unit and reference flow

The functional unit is 1 kg of consumed marine fish product. Table 2-2 presents a more detailed definition of the functional unit.

The functional unit is defined as "consumed" and not "consumable" because the study covers the complete life cycle of the fish to the point where it is consumed and all types of loss of fish until that stage. The results of this study are presented per 1 kg of consumed fish.

Section 2.2.4 presents the representative products that are studied.

[6] https://www.fhf.no/fhf/about-fhf-english/

The reference flow is the mass of fish required to deliver 1 kg of edible portion plus the required mass of packaging.

Table 2-2 Definition of functional unit

What	Unprocessed marine fish products for human consumption and the packaging needed to deliver them.
How much	1 kg consumed marine fish product.
How well	The product shall be appropriate for human consumption.
How long	For products where durability or shelf-life is established.

2.2.2 Products covered by this analysis

This study covers marine fish products consumed in the EU market over the years 2016-2018. This includes all sources for the unprocessed marine fish consumed in the EU.

Regulation (EC) no 852/2004[7] defines "*processing*" as any action that substantially alters the initial product, including heating, smoking, curing, maturing, drying, marinating, extraction, extrusion or a combination of those processes. This is different from "*unprocessed products*", which refers to foodstuffs that have not undergone processing, and includes products that have been divided, parted, severed, sliced, boned, minced, skinned, ground, cut, cleaned, trimmed, husked, milled, chilled, frozen, deep-frozen or thawed.

2.2.3 System boundary

Figure 2-1, Figure 2-2 and *Table 2-3* present the life cycle stages and processes included in this PEF-RP study. For marine fish products, the life cycle stages from raw material acquisition through preparation (included in the "manufacturing" stage per the PEF Method) and consumption (included in the "use" stage per the PEF Method) are included until the end-of-life.

For marine fish from aquaculture, feed is included in this PEF-RP study, but the Marine Fish PEFCR will not include the requirements for how the PEF profile is calculated as that is done by the existing "PEFCR Feed for Food-producing Animals" [3]. In the PEF-RP study presented in this report, feed is included using the results from salmon, bass and sea bream feed according to the stated biological feed conversion ratio (BFCR) and the corresponding fish mass balance.

[7] Regulation (EC) no 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs (OJ L 139, 30.4.2004, p. 1)

Table 2-3 Description of life cycle stages that shall be included

Life cycle stage	Farmed	Wild
Raw material acquisition	Growing, fishing and other production of feed raw materials. Processing of feed ingredients and compound feed production.	Fishing (including production of bait and onboard preparation).
Production (Manufacturing)	Hatchery, juvenile production and grow out of fish.	N/A
Preparation (Manufacturing)	Harvest (slaughter), gutting, filleting, refrigeration and/or freezing.	Gutting, filleting, refrigeration and/or freezing.
Distribution	Packaging materials and transport, including cooling, from preparation to retailer.	
Consumption (Use)	Retail of the product and consumption.	
End of life	Handling of fish mass that is not sold as a commercial product, or not consumed.	

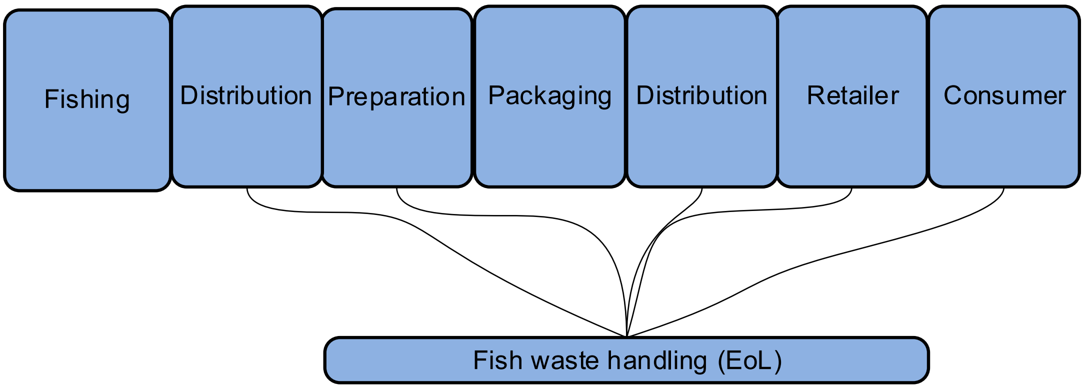


Figure 2-1 System scope wild marine fish product

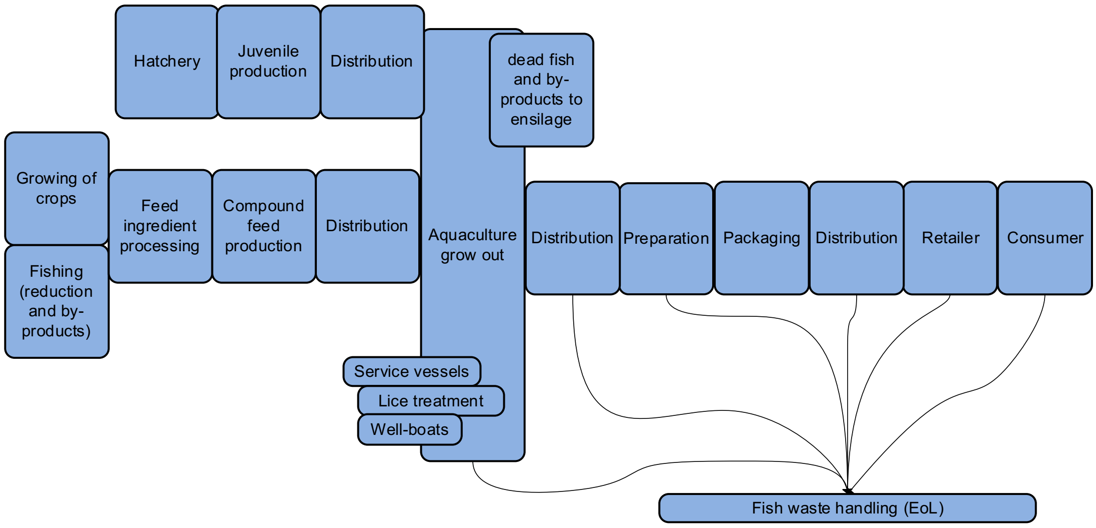


Figure 2-2 System scope farmed marine fish product

2.2.4 The representative products

This study presents the results of a PEF performed for "virtual (non-existing) products" that reflect marine fish consumed in the EU market. Two representative products are modelled:

1) a virtual product representing the EU consumption of wild marine fish and
2) a virtual product representing the EU consumption of farmed marine fish.

The following sections provide more detail about how they were quantified from consumption back to production (i.e. how the representative product models were constructed).

This PEF-RP study <u>does not include</u> freshwater fish or crustaceans, nor does it include processed products as these products are not within the product scope of the Marine Fish PEFCR.

The Representative Product (RP) model is in principle built through these steps:

1. The consumption of marine fish on a commodity group and species level is retrieved from data published by The European Market Observatory for Fisheries and Aquaculture Products (EUMOFA) [4]. Table 2-4 presents data on the EU consumption of marine fish per commodity group[8] for wild and farmed marine fish.
    - In these data the marine fish consumption is split into the commodity groups flatfish, groundfish, salmonids, small pelagic and tuna and tuna-like species. This grouping is also used in this study in the annex **Error! Reference source not found.** the most important species of each group is presented.
    - The years 2016-2018 are used as these are the latest data available.
2. The state in which the products are distributed (e.g. filet, head on gutted, etc.) is retrieved from trade data collected by EUMOFA [5] (data was sent the TS as an excel file).
3. The different species are traced back to origin (country or region) and fishing/aquaculture method through data on production and trade from EUMOFA, Eurostat, FAO and other sources.
    - Important note: Communication with experts at EUMOFA reveals that data do not exist on the original source of the marine fish that is consumed in the EU. The only data that is available on an EU level is trade data. These data only indicate from where the fish was bought. For example: Trade data will list the source of a considerable part of the cod consumed in the EU as Italy, even though it is clearly originally from Norway. Given the existing regulations on traceability, we know that the data on the true origin of products do exist, but as of today these data are not collected for EU consumption.

[8] A commodity group is a group of products with similar properties.

In this current version, the full procedure to quantify the RP models is not finished and the source (country and/or method) is set based on expert judgment. Sensitivity analysis shows that this proximation does not change the main conclusions of the results and hotspot analysis.

Table 2-4 EU marine fish apparent consumption per commodity group for 2016-2018. This present consumption of both wild AND farmed products)

Commodity Group	Apparent consumption (tonne)	% of marine fish apparent consumption	% of group wild caught	% of group farmed
Flatfish	839 546	3 %	96 %	4 %
Groundfish	9 595 090	36 %	100 %	0 %
Other marine fish	2 586 101	10 %	69 %	31 %
Salmonids	4 141 699	15 %	1 %	99 %
Small pelagics	5 000 105	19 %	100 %	0 %
Tuna and tuna-like species	4 690 631	17 %	99 %	1 %
Grand Total	26 853 173			
Source: EUMOFA https://www.eumofa.eu/supply-balance [4]				

2.2.4.1 Wild marine fish representative product

Table 2-5 presents the apparent consumption of wild marine fish per commodity group and species in 2016-2018 in the EU, and a preliminary expert judgement on how each species was sourced. Each fishery type has distinctive differences in their footprint per unit landed. The distribution of each commodity group (e.g. how much of the groundfish was landed by demersal trawlers) is based on expert judgement and data on how these species were landed by Norwegian fisheries [6].

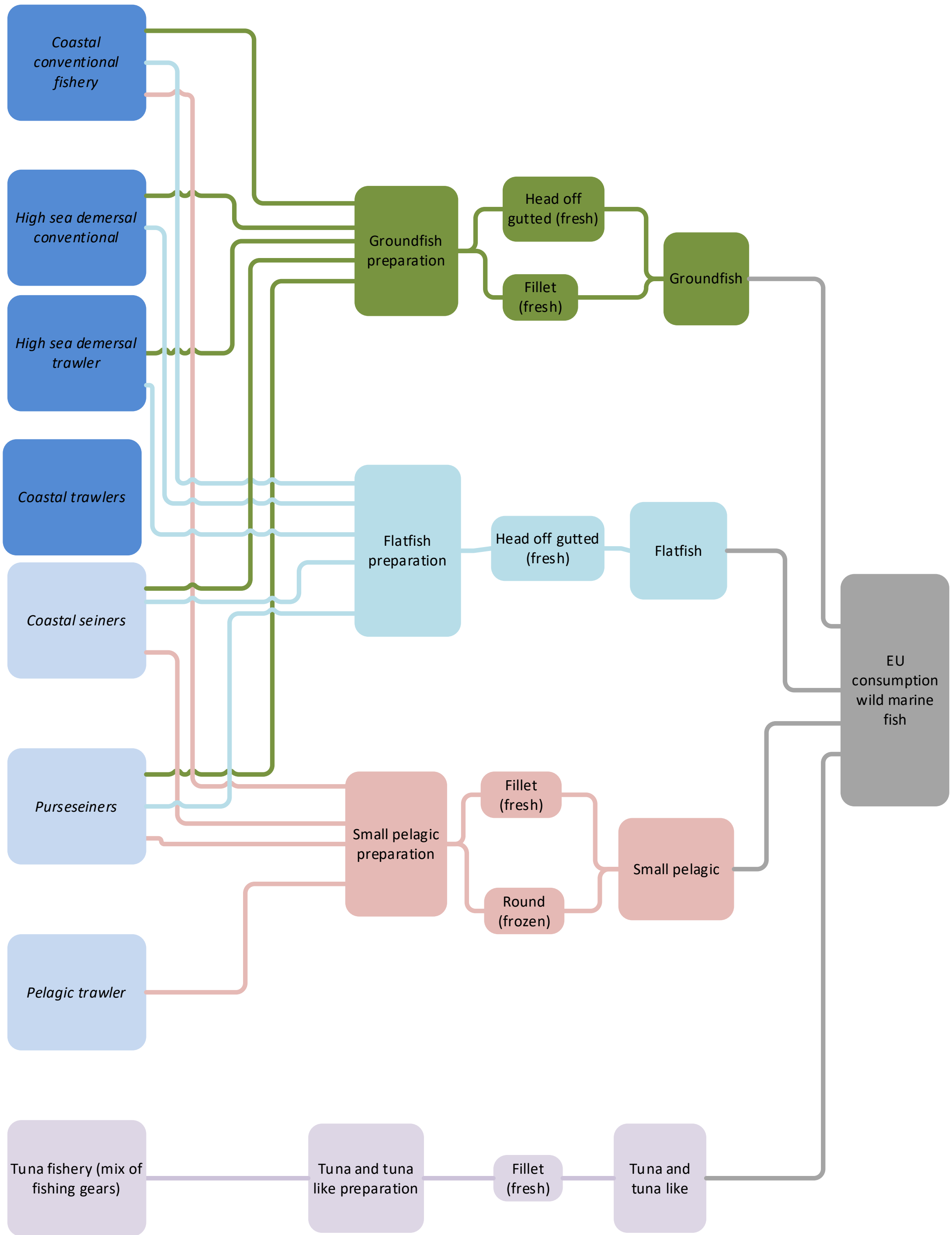
The group “groundfish” dominates consumption at more than 40%, followed by “small pelagics” and “tuna and tuna like” that each represent just over 20% of consumption.

The group “other marine fish” is included with the assumption that it is equal to that of a considerable part of the consumption. In the assessment this group is included under the assumption that it is equal to that of the group “groundfish”. Figure 2-3 illustrates how the wild marine fish RP is modelled.

The selection of fisheries will be expanded, and data to decide how much of each species that are sourced by each fishery are being collected.

Table 2-5 The Wild RP model presenting the apparent consumption of ***wild*** *marine fish in the EU for 2016-2018 and how these species was caught. (Source: https://www.eumofa.eu/supply-balance) [4]*

Data for 2016-2018					**Fisheries**						
Comodity Group	**Species (MCS)**	**Apparent consumptiron WILD (tonne)**	**% of wild marine fish**	***% of comodity group***	**Coastal conventional**	**High sea demersal conventional**	**High sea demersal trawlers**	**Coastal seiners**	**Purse seiners**	**Pelagic trawlers**	**Pelagic fishing (>30cm)**
Flatfish	Plaice, European	250 871	1 %	*31 %*	38 %	9 %	45 %	7 %	1 %		
	Other flatfish	236 071	1 %	*29 %*	38 %	9 %	45 %	7 %	1 %		
Flatfish Total		**804 243**	**4 %**								
Groundfish	Cod	3 499 338	16 %	*36 %*	38 %	9 %	45 %	7 %	1 %		
	Alaska pollock	2 481 709	11 %	*26 %*	38 %	9 %	45 %	7 %	1 %		
	Hake	1 498 095	7 %	*16 %*	38 %	9 %	45 %	7 %	1 %		
	Haddock	477 657	2 %	*5 %*	38 %	9 %	45 %	7 %	1 %		
	Saithe (=Coalfish)	470 034	2 %	*5 %*	38 %	9 %	45 %	7 %	1 %		
	Other groundfish	367 433	2 %	*4 %*	38 %	9 %	45 %	7 %	1 %		
	Blue whiting	243 475	1 %	*3 %*	38 %	9 %	45 %	7 %	1 %		
	Redfish	227 333	1 %	*2 %*	38 %	9 %	45 %	7 %	1 %		
	Grenadier	201 755	1 %	*2 %*	38 %	9 %	45 %	7 %	1 %		
Groundfish Total		**9 594 034**	**44 %**								
Other marine fish	Other marine fish	798 485	4 %	*45 %*	38 %	9 %	45 %	7 %	1 %		
	Monk	292 893	1 %	*16 %*	38 %	9 %	45 %	7 %	1 %		
	Other sharks	234 380	1 %	*13 %*	38 %	9 %	45 %	7 %	1 %		
	Seabream, other	128 789	1 %	*7 %*	38 %	9 %	45 %	7 %	1 %		
Other marine fish Total		**1 791 056**	**8 %**								
Small pelagics	Herring	1 855 323	8 %	*37 %*	10 %			22 %	58 %	10 %	
	Sardine	942 676	4 %	*19 %*	10 %			22 %	58 %	10 %	
	Mackerel	927 387	4 %	*19 %*	10 %			22 %	58 %	10 %	
	Sprat (=Brisling)	569 059	3 %	*11 %*	10 %			22 %	58 %	10 %	
	Anchovy	446 929	2 %	*9 %*	10 %			22 %	58 %	10 %	
	Horse mackerel, other	234 973	1 %	*5 %*	10 %			22 %	58 %	10 %	
Small pelagics Total		**5 000 105**	**23 %**								
Tuna and tuna-like species	Tuna, skipjack	2 415 468	11 %	*52 %*							100 %
	Tuna, yellowfin	1 349 468	6 %	*29 %*							100 %
	Tuna, miscellaneous	489 292	2 %	*11 %*							100 %
	Swordfish	147 005	1 %	*3 %*							100 %
	Tuna, albacore	120 131	1 %	*3 %*							100 %
Tuna and tuna-like species Total		**4 650 378**	**21 %**								



624

625 *Figure 2-3 The Wild fish RP model: key building blocks.*

626

Figure 2-4 illustrates a conceptual model of how the Wild RP can be built using a model of 16 different groups of fisheries. These groups represent different types of fisheries that on average have significantly different environmental footprints (per unit of landed catch) compared to each other. Figure 2-3 illustrates how the Wild Caught RP is composed for the time being.

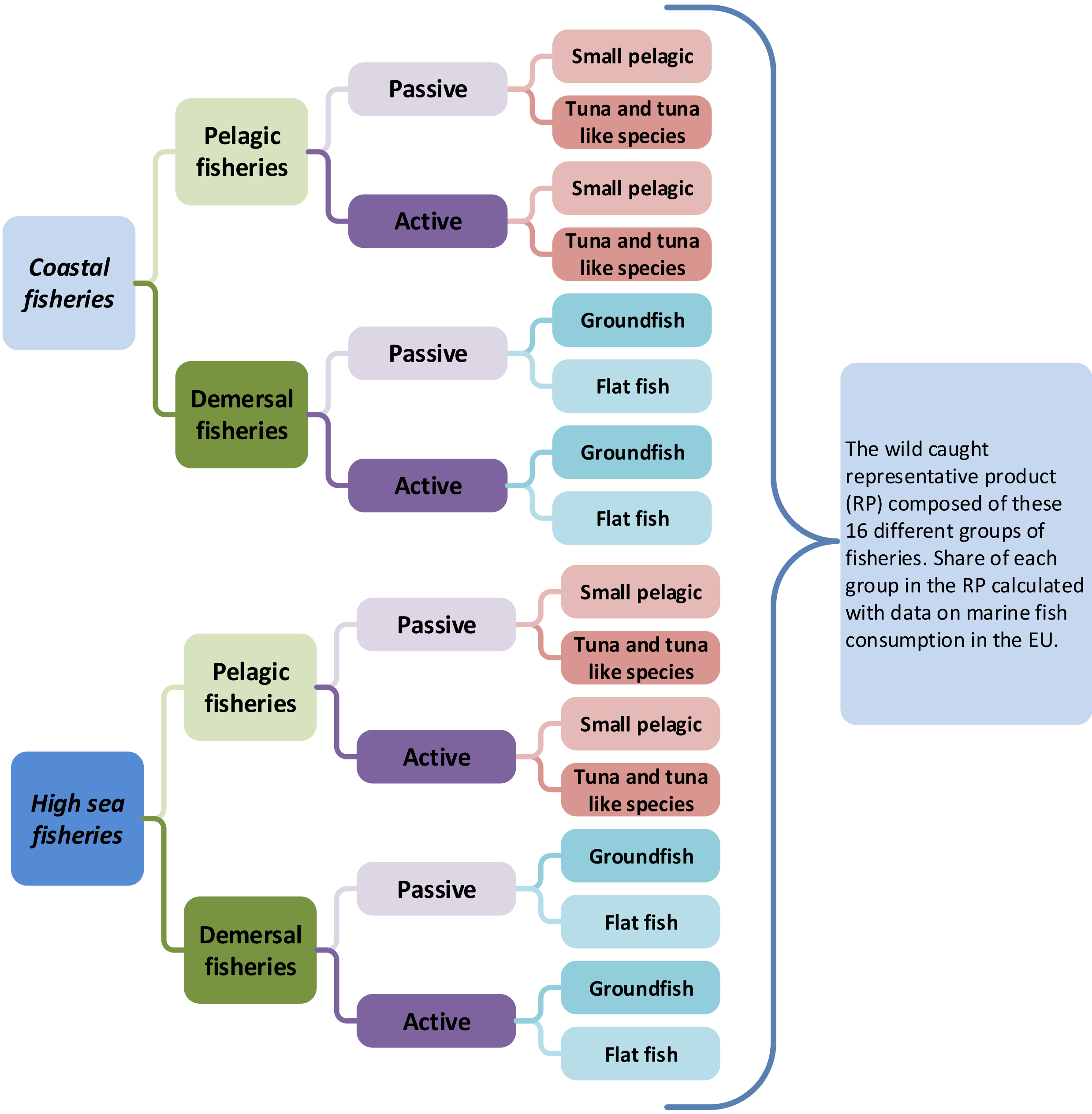


Figure 2-4 Model for the wild marine fish representative product. The terms active/passive refer to the fishing gear. A trawl is a typical example of active fishing gear and a longline is an example of a passive fishing gear.

2.2.4.2 The farmed marine fish representative product

The farmed marine fish RP is in principle composed of four different aquaculture production systems as illustrated in Figure 2-5: Open net pen in sea for salmonids or bass/sea bream and Recirculating Aquaculture System (RAS) for salmonid or bass/sea bream. However, the share of land-based production (full grow out) is so low that the expert judgement by the TS is that this share can be neglected. Table 2-6 presents the apparent consumption of farmed marine fish in the EU and an expert judgement on the systems that sourced each species. It is assumed that species other than salmonids or bass/sea bream are represented by bass/sea bream aquaculture. This assumption is based on expert judgement by the TS.

Full grow out in freshwater is not included according to the product scope of this study.

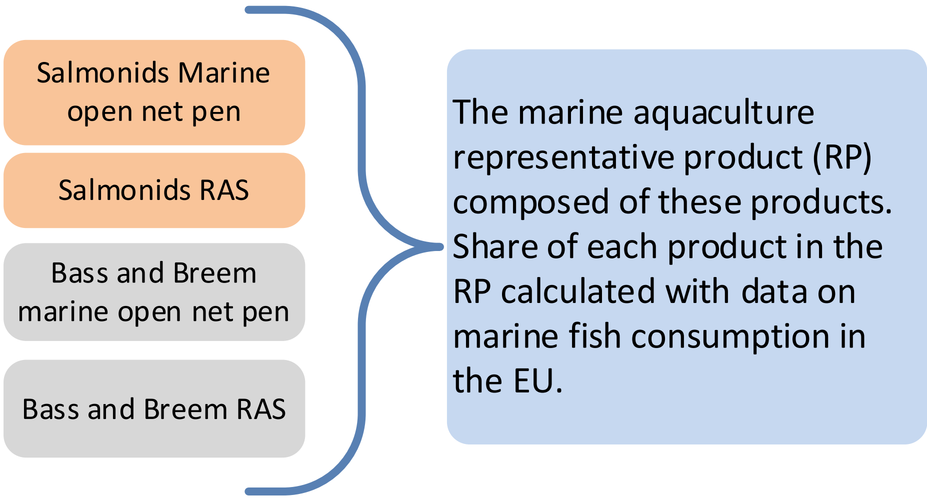


Figure 2-5 Model for the farmed marine fish representative product.

Table 2-6 Apparent consumption of farmed marine fish for the years 2016-2018. (Source: [https://www.eumofa.eu/supply-balance)](https://www.eumofa.eu/supply-balance) [4]

Farmed species	**Apparent consumption (tonne)**	**% of total farmed apparent consumption**	**Marine net pen for salmonids**	**Marine net pen for bass and sea bream**	**RAS system full grow out salmonids**	**RAS system full grow out bass and sea bream**
Salmon	3 436 870	69,2 %	100 %			
Trout	643 407	13,0 %	100 %			
Seabream, gilthead	349 001	7,0 %		100 %		
Seabass, European	298 843	6,0 %		100 %		
Other marine fish	139 063	2,8 %		100 %		
Tuna, bluefin	40 253	0,8 %		100 %		
Turbot	31 601	0,6 %		100 %		
Other salmonids	15 281	0,3 %	100 %			
Seabream, other	7 413	0,1 %		100 %		

Sole, other	3 461	0,1 %		100 %		
Halibut, Atlantic	2 555	0,1 %		100 %		
		Farmed RP	**82 %**	**18 %**	**0 %**	**0 %**

2.2.5 Impacts assessment

The impact assessment is done using the EF3.0 method[9]. Table 2-7 present the impact categories this method includes. For the full detail on the different models for each category refer to the Environmental Footprint reference packages[9].

Table 2-7 Impact categories and reference substances in the current EF3.0 impact assessment method

Impact category	**Reference substance**
Acidification	mol H+ eq
Climate change	kg CO2 eq
Climate change - Biogenic	kg CO2 eq
Climate change - Fossil	kg CO2 eq
Climate change - Land Use and LU Change	kg CO2 eq
Ecotoxicity, freshwater - part 1	CTUe
Ecotoxicity, freshwater - part 2	CTUe
Ecotoxicity, freshwater - inorganics	CTUe
Ecotoxicity, freshwater - metals	CTUe
Ecotoxicity, freshwater - organics	CTUe
Particulate Matter	disease inc.
Eutrophication, marine	kg N eq
Eutrophication, freshwater	kg P eq
Eutrophication, terrestrial	mol N eq
Human toxicity, cancer	CTUh
Human toxicity, cancer - inorganics	CTUh
Human toxicity, cancer - metals	CTUh
Human toxicity, cancer - organics	CTUh
Human toxicity, non-cancer	CTUh
Human toxicity, non-cancer - inorganics	CTUh
Human toxicity, non-cancer - metals	CTUh
Human toxicity, non-cancer - organics	CTUh
Ionising radiation	kBq U-235 eq
Land use	Pt
Ozone depletion	kg CFC11 eq
Photochemical ozone formation	kg NMVOC eq
Resource use, fossils	MJ
Resource use, minerals and metals	kg Sb eq
Water use	m3 depriv.

[9] The current EF impact assessment method can be found on this web page: https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

2.2.6 Biogenic carbon modelling

Fish does not include the storage of biogenic carbon and thus a simplified modelling approach is used where only the flows influencing climate change impact results (namely biogenic methane emissions) are modelled. The modelling followed these rules:

1) Only the emission 'methane (biogenic)' is modelled.
2) No further biogenic emissions and uptakes from atmosphere are modelled; and
3) If methane emissions are both fossil and biogenic, the release of biogenic methane shall be modelled first and then the remaining fossil methane.

The impact assessment of the biogenic emissions is done using the impact assessment method presented in section 0.

In this study only two potential sources for biogenic carbon are considered:

1) From anaerobic degradation of fish biomass going to waste handling and
2) From anaerobic degradation of sludge from juvenile production in RAS plants.

Sludge from open net pen farming can potentially build up and lead to methane emissions. This option is not included yet as the extent of this is not known.

The inventory for the biogenic methane modelling is presented in section 3.6.

2.2.7 Environmental aspects limitations and candidates for additional environmental information

Marine fishing and marine aquaculture are highly relevant for a number of environmental impacts not captured by the current PEF impact assessment method (EF3.0). Among these other impacts, biodiversity impacts (biotic impacts) are the most important. Marine fish production has direct impact on marine ecosystems and indirect impacts through the different inputs. Feed used for farmed products is the most important input in this regard, as it links marine fish to the biodiversity impacts of global agricultural systems.

This study includes the types of environmental impacts that are currently covered by the EF3.0 impact assessment method, in accordance with the framework for the PEFCR development and the stated goal and purpose of this analysis. **It does not, however, purport to cover all known environmental aspects of marine fish products.**

The current draft of the Marine Fish PEFCR includes suggestions for other environmental and technical information that can be included in a marine fish PEFCR.

2.2.8 Consideration of relevance for biodiversity

According to section A.3.2.7.1 of the PEF method [2] the TS shall make an assessment about the relevance of biodiversity for the products in scope of the PEFCR. This assessment is based on expert judgement: **Marine fishing and marine aquaculture are highly relevant for biodiversity as these activities have direct impact on marine ecosystems. Farmed marine fish is also highly relevant for terrestrial biodiversity through its input of feed raw materials from agricultural systems.** This judgement is supported by the report of the Scientific, Technical and Economic Committee for fisheries (STECF), which has suggested *Criteria and indicators to incorporate sustainability aspects for seafood products in the marketing standards under the Common Market Organisation*. (STECF-20-05) [10]. The report points out that a major challenge regarding quantification of impacts is the general lack of available data, thus no assessment of the impact on biodiversity has been done for the RP.

2.2.9 System limitations

The study strives to include all known activities in the life cycle of the products from feed production/fishing through consumption. Since the products that are analysed represent a product category with tremendous variation these activities have to be covered with proxies and all possible iterations of the marine fish life cycle are not covered.

According to the guidelines for the PEFCR development (section A.2.4 in the PEF method [2]) this PEF-RP study shall include everything (all inventory items) and no cut-offs are allowed. "In the first PEF-RP no cut-off of processes, emissions to the environment and resources from the environment is allowed. All the life cycle stages and processes shall be included (incl. capital goods)."

2.2.10 Data gaps and impact assessment gaps

During this analysis, inputs (materials and energy), processes and outputs (emissions) are identified for which there is no available PEF/LCA data. These data gaps will be listed here. Gaps here include data that are not included in any of the established LCA databases nor in the EF2.0/3.0 data.

Preliminary list:

- Plastic waste lost to sea. (No elementary flows suitable or impact categories that will react to such flows.)
- Fish vaccines and antibiotics
- Impacts to seabed (specify the temporal aspect of the impact)
- Biodiversity/biotic impacts.
    - The report "Criteria and indicators to incorporate sustainability aspects for seafood products in the marketing standards under the Common Market

[10] https://stecf.jrc.ec.europa.eu/nb_NO/reports/strategic-issues/-/asset_publisher/5fZb/document/id/2872432?inheritRedirect=false&redirect=https%3A%2F%2Fstecf.jrc.ec.europa.eu%2Fnb_NO%2Freports%2Fstrategic-issues%3Fp_p_id%3D101_INSTANCE_5fZb%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_p_col_id%3Dcolumn-2%26p_p_col_pos%3D1%26p_p_col_count%3D2

Organisation (STECF-20-05)" presents a more complete presentation of the different environmental aspects of marine fish production.

2.3 Screening

A screening was done using existing LCA models for carbon footprint of seafood products. That screening covered the system from fishing and feed production to retailer gate (i.e. the consumption (use) stage was not included) for wild caught products and a marine aquaculture product. The screening was based on data from more than a decade of LCA studies of Norwegian seafood products. This screening is used as a guide and reminder regarding the determining processes and flows in the footprint of marine fish products.

2.4 Modelling choices

The different modelling choices are presented in more detail in their respective sections in the inventory study (section 3).

These are the most important modelling choices:

- Capital goods are included. This includes construction of fishing vessels and gear, and the fish farm and equipment.
- Maintenance of fishing vessels and fish farm is included.
- All transports of the fish are included. So are transports of the different operational and capital expenses in the system.
- The retail and use stages are included based on scenarios established by the PEF method.
- Waste handling of materials (including the fish) is included.
- Electricity use is included as average European electricity, but electricity use will be regionalized as much as possible based on the fish source data.
- No specific sampling procedure was used. The data that is identified is not of a volume or nature where a specific sampling procedure is considered relevant or applicable.
- No greenhouse gas removals are included in the foreground system.
- No type of offsets, system expansion, substitution speculations, credits or any other form of off-writing impacts is included in this assessment.
- Biogenic carbon emissions are included with the simplified approach option (section 2.2.6).

2.5 Allocation

For processes with multiple outputs (co-products) and where it is not possible to separate out product-specific units, economic allocation is used (i.e. the footprint up to that point is shared among the co-products based on the ratio of their economic value at that point).

Mass flows that have a zero economic value are considered waste products and are not attributed any of the footprint up to the point of allocation.

The allocation factor for each co-product is calculated based on the value ratio between the different co-products at the stage where the allocation is done. The basic principle is that the allocation factor shall reflect the value of the co-product flow for the producer and thus these values are mandatory company-specific data.

Equation (1) presents how the economic allocation factor (AF) to "product a" is calculated using the market price (V_a and V_b) and mass yield of "co-products a and b" (M_a and M_b).

$$Allocation\ factor\ (AF)\ for\ product\ a: A_a = \frac{M_a * V_a}{(M_a * V_a + M_b * V_b)} \qquad (1)$$

The following figure and equation present a generic example of how economic allocation is done at stage/process X among "co-products a and b". The example uses the carbon footprint as an example, but the principle is the same for a complete PEF study:

$$CF_a\left(\frac{kgCO2e}{kg\ product\ a}\right) = \frac{CF_{TOT} * \frac{M_a * V_a}{V_{TOT}}}{M_a} = \frac{CF_{TOT} * \frac{M_a * V_a}{(M_a * V_a + M_b * V_b)}}{M_a}$$

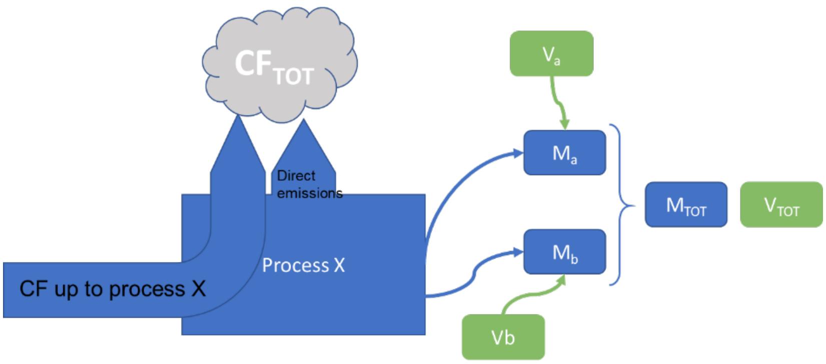


Figure 2-6 Example of economic allocation

2.6 Data sources and primary and secondary data

This study uses data from LCA studies of marine fish products from all over the globe. For the wild caught products, the fuel use intensity is calculated based on data from the different fisheries that source the products.

The PEF-RP study starts with a screening based on the studies of the carbon footprint of seafood products (Norwegian seafood products). This screening is used as a guide to what data is necessary to include and also indicates when high data quality is especially important.

This study includes both primary and secondary data. Since the product that is analysed is a non-existing virtual product it is not straightforward to define what separates primary and secondary data. As a general rule the following background data is included using generic data:

- The footprint of materials, energy carriers and transports are included with generic data. The activity data (e.g. amount of fuel spent, transport distances, etc.) is generally primary data (i.e. data from actual marine fish production systems).
- The retail and consumption stage includes generic data, as suggested by the PEF method.

Section A.2.4 in the PEF method [2] states that the TS shall use EF compliant datasets for the PEF-RP, if available. If an EF compliant dataset does not exist, the procedure outlined in that section shall be followed. The data used to calculate this PEF-RP are mainly EF2.0 and EF3.0 data. EF2.0 is only used when EF3.0 is not available. Agri-footprint data (v5.0, economic allocation) [7] are used for the aquaculture feed except for the marine ingredients that are modelled with data from literature. Data that could not be found in the EF2.0 or 3.0 data is sourced from ecoinvent (v3.6 and “cut off by classification” data). The production of bass and sea bream is included with data from the Agribalyse 3.0.1 database [8].

2.7 Data quality rating

Data quality rating is not done at the current stage. This will be done according to the guidance in the PEF method. The organization and procedure for calculating the data quality rating is prepared in the Excel sheet “Marine Fish PEFCR Inventory Data”.

3 Life Cycle Inventory Analysis

This section presents the data that is used to calculate the PEF profile of the RPs and how the RPs are modelled.

3.1 Fishing

The fisheries are included with:
- Fuel use, including production of the fuel
- Emission of refrigerants and production of refrigerants
- Production and end of life handling of fishing gear
- Production, maintenance, and end of life handling of fishing vessel
- Production of bait
- Antifouling, production of the chemical and emission to sea
- Packaging use at fishing vessel

See section 2.2.7 on limitations for more information on recognized environmental aspects of fisheries that are not quantified in this PEF-RP study.

3.1.1 Fishing fuel use

Table 3-1 presents the fuel intensity for the different fisheries that are used in the wild caught RP model (Table 2-5 in section 2.2.4). The intensities in Table 3-1 are set based on expert judgement of data from global fisheries [9], [10]. The precision of these intensities will be improved as the tracing from consumption to source is improved. This fuel use is modelled as presented in section 3.1.2.

Table 3-1 Fuel intensity for fisheries that are used in the wild caught RP model.

Fishery	**L fuel (diesel)/tonne fish live weight landed**
Coastal conventional	130
High sea conventional	240
Demersal trawl	348
Coastal seiners	70
Purse seiners	100
Pelagic trawlers	75
Tuna and tuna like (pelagic>30cm) fishery	430 [10]

3.1.2 Fuel production data and use emission factors

The fuel used by the fishing vessels and at the fish farms and by the vessels included in the fish grow out is modelled as diesel. The production and the use (combustion) of the fuel is modelled with the EF3.0 data set "*Diesel combustion in construction machine {GLO} | diesel driven | production mix, at plant | LCI result*" (UUID: 6f06614d-fd12-4072-89ff-909caf1d744f).

3.1.3 Fishing refrigerant emissions

Emissions of refrigerants from the refrigeration systems onboard the fishing vessels are included. These emissions have shown that they can be of significant importance for the carbon footprint of seafood products.

Table 3-2 presents the data that is used to include emission of refrigerants, input and waste handling. The refrigerants that are used include a range of different chemicals. Many of these are under strict and continuously developing regulations (e.g. both to reduce ozone layer depletion and climate impact). For the time being, all refrigerants are presented by a mix of R22, ammonia and CO2. This mix can be expanded and adjusted as more data on the actual use of refrigerants are collected. The emission rate is estimated based on an assumption about annual emission rate, the typical load of refrigerant per vessel for each fishery and their annual catch per vessel. Annual catch is based on expert judgement and data from the Norwegian fishing fleet. All of these parameters will show a considerable variation, thus these are very rough estimates, but estimates that will be improved through more data collection. The mass that goes to waste handling is estimated by an assumption of how often the refrigerants are replaced due to maintenance and other changes in the system.

Table 3-2 Refrigerant emission and refrigerant waste handling data

	Load in system	Annual emission rate	Annual catch rate estimate	Emission rate	Ecpected lifetime of refrigerant not lost	Waste rate	Refrigerant mix		
Fishery	kg/vessel	kg emitted/kg in system/yr	Tonne biomass fished/yr/vessel	kg refrigerant emitted/tonne biomass fished	yrs	kg to waste handling/tonne biomass fished	Ammonia	CO2	R22
Coastal conventional	400	0,1	238	0,17	5	0,34	33 %	33 %	33 %
High sea conventional	2000	0,1	3382	0,06	5	0,12	33 %	33 %	33 %
Demersal trawl	2000	0,1	8385	0,02	5	0,05	33 %	33 %	33 %
Coastal seiners	2000	0,1	1735	0,12	5	0,23	33 %	33 %	33 %
Purse seiners	400	0,1	11183	0,00	5	0,01	33 %	33 %	33 %
Pelagic trawlers	400	0,1	15617	0,00	5	0,01	33 %	33 %	33 %
Tuna and tuna like (pelagic>30cm) fishery	2000	0,1	10 000	0,02	5	0,04	33 %	33 %	33 %

Table 3-3 Data used to model production of refrigerants and waste handling of refrigerants.

	Data set
Production	
R22	EF2.0 (UUID: 2dc3b199-de3b-4b52-b624-b820832abf0c): Tetrafluoroethane (R134a) {DE} | estimation | production mix, at plant | 102.03 g/mol ; Melting point -103.3 °C; Boiling point -26.3 °C; | LCI result
Ammonia	EF2.0 (UUID: 17be19f9-3e68-4792-9924-911fe279550b): Ammonium chloride {EU-28+3} | Solvay process | at plant | per kg | LCI result
CO2	EF2.0 (UUID: f418d090-af36-4aac-a593-206e9cc3141c Version: 03.00.009): Carbon dioxide, liquid production {RER} | technology mix | production mix, at plant | 100% active substance | LCI result
Waste handling	
All refrigerants	EF3.0 (Process UUID: fa158634-c471-4b0e-afef-407d1073b086): Waste incineration of hazardous waste {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | hazardous waste | LCI result

3.1.4 Wild product composition and value at landing

The study of the wild RP includes the following aspects of how the landed fish is utilized and valued:

- In the model all fish is landed as round. The split into main and co-products occurs in the preparation stage (section 3.2.8).
    - ➢ This part of the modelling will be changed to reflect that most of the wild fish is landed as gutted.
- Round fish at landing is divided into targeted catch and by-catch. The fishing footprint is allocated between them based on their value ratio. The model takes into consideration how much of the by-catch is utilized. Table 3-4 presents the ratios that are used in this allocation for each commodity group in terms of how much of the landed fish is considered by-catch, the ratio in value between the targeted and by-catch, and the by-catch utilization ratio.
- Fish discarded from the fishing vessel is only included as an inefficiency of the fishery (i.e. the fishing effort is included per unit landed and not per unit caught). See section 2.2.7 for more detail about the environmental aspects that are included.

Table 3-4 Data for allocation of fishing for each commodity group

Property	Ground fish	Small pelagics	Flatfish	Tuna and tuna like
Ratio targeted catch vs by-catch of the landed fish	90:10	93:7[11]	90:10	90:10
Ratio value of targeted catch vs by-catch	91:10	91:10	91:10	91:10
By-catch utilization (%).	100	100	100	100

As more data become available on the different species that compose each commodity group, these data will be expanded, and precision will improve as more species/origin specific data can be used. It is well known that the ratio between targeted and by-catch show high variation between species and sources.

3.1.5 Bait

Bait is included as a product fished by a pelagic fishery. The input factor is determined based on data from the fishing gear producer Mustad Longline. One hook uses 25 g of bait and hooks on coastal liners have a catch rate of 0,7 kg bait lwe/hook and auto-liners 0,4 kg fish/hook. The fisheries “coastal conventional” and “high sea conventional” are attributed with bait. Bait can be produced in many different ways, including using fish and squid, or synthetic material.

The bait input is included assuming that it is fish that is sourced from a pelagic trawl fishery with a fuel intensity of 0,1 l fuel/kg lwe landed. Preparation (freezing), storing, packaging and distribution (500 km by road) of the bait is included.

3.1.6 Fishing vessel and gear

Construction of the fishing vessel is included based on: 1) data on the ship lightweight[12] of fishing vessels; 2) yearly catch rate for these vessels and assumption of their lifetime; and 3) data on the construction, maintenance and end of life handling of a steel longliner from the ecoinvent database[13]. Table 3-5 presents the data that is used.

The same “fishing vessel per unit of fish landed” and the same model of the construction and end of life of the vessel is used for all fisheries. Recognizing the great variety in how fishing vessels are constructed, and their lifetime catch, this is a rough assumption (to use the same data for all fisheries), but the screening and all

[11] Data from Pelagia for herring and mackerel (Andri Thorleifsson, 2021).

[12] Lightship or lightweight measures the actual weight of the ship with no fuel, passengers, cargo, water, and the like on board

[13] Ecoinvent data set: “Long liner, steel {RoW}| long liner construction, steel | Cut-off, U”, “Long liner maintenance, steel {GLO}| market for long liner maintenance, steel | Cut-off, S” and “Used long liner, steel {GLO}| treatment of used long liner, steel | Cut-off, S”

known literature on LCAs of fish products show that his process is not of major importance.

Input of fishing gear was estimated based on data from Deshpande et al., 2019 [11]. They estimate that commercial fishing in Norway contributes to around 380 tonne/year of marine plastic pollution from lost fishing gear and parts, and that 4 000 tonne/year of plastic waste is collected from fishing gear. Combining this with an annual catch of around 2.4 million tonnes (all Norwegian fisheries), this equals a plastic input rate of 1.83 kg plastic per tonne round weight fish landed.

Table 3-5 Data used in the modelling of fishing gear and vessel input

Parameter	Data
Lifetime fishing vessel (years)	30 (assumption)
Light ship weight of demersal trawler (tonne)	3 500 [12]
Annual catch of demersal trawler (tonne)	8 385 (Table 3-2)
Plastic (fishing gear lost at sea) (tonne/year)	380 [11]
Plastic (fishing gear) collected as waste (tonne/year)	4 000 [11]
Annual catch of Norwegian fisheries (million tonne)	2.4
Plastic/metal use (tonne of material/tonne fish landed round weight)	(380+4 000)/2 400 000 = 1.83e-3

3.1.7 Antifouling paint production, emission and waste handling from use on fishing vessel

The use of antifouling paints on the fishing vessel is modelled by the ecoinvent dataset "market for antifouling paint emissions GLO" (UUID: ab1fbf1d-c727-41cd-ae88-70ecb3145f1f) and an intensity of **0,035 g antifouling paint/kg lwe landed catch**. The same intensity is used for all fisheries.

> The elementary flows that are used to model the antifouling chemical emissions are being investigated, as are the data used to quantify input, emissions and waste handling (activity data). The preliminary results of the RPs' PEF profiles indicate that antifouling chemicals are not very important, but it is being investigated to determine if this is because it is not correctly modelled within the EF3.0 method, or if it simply is not of high importance for the final result.

3.2 Marine net pen farming (aquaculture)

The farmed marine fish representative product is currently modelled as a mix of salmonids and bass/sea bream (Table 2-6). The bass and sea bream are included with a complete cradle-to-gate dataset from Agribalyse. The salmonid is included based on the data presented in the following sections.

3.2.1 Bass and sea bream production

The bass and sea bream production up to the preparation stage is included from the Agribalyse database data "*Mediterranean bass, consumption mix/FR U*". This includes the complete cradle-to-gate system (feed, juvenile and grow out).

3.2.2 Farmed marine fish yields, utilization, value and loss

Table 3-6 (salmonids) and Table 3-7 (bass and sea bream) present the most important data that defines the mass flow of fish and the allocation on the farmed RP model from fish grow out to consumed fish. The production of feed dominates the environmental footprint of most farmed fish and thus the Feed Conversion Ratio (FCR) is an especially important parameter. In this assessment, the Biological Feed Conversion Ratio (BFCR) is used as it includes all of the fish that is produced, not only the mass that is sold for harvesting.

Table 3-6 Yield and values fish farming of salmonids (per calendar year)

Property	Unit	Value Salmon and salmonids	Comment/reference
Mortality rate	kg dead fish/kg biomass production	0,09	Based on data from Norwegian aquaculture
Utilization rate dead fish	kg utilized dead fish/kg dead fish total	0,5	Expert judgement by TS. Utilized means that it is sold. That it has a value for the producer.
Disappeared rate	kg fish disappeared/kg biomass produced	0,01	Expert judgement by TS
BFCR (biological feed conversion ratio)	kg feed/kg biomass produced	1,12	The Economic FCR of Norwegian Atlantic salmon aquaculture was ~1,3 in 2017
Energy use fish farm, electricity	kWh/kg biomass produced	0	In the current data set fish farms with grid connection or on-site production was so few that on an average they are negligible. The share of farms with electricity (from grid or on-site production is rapidly increasing so this number will be evaluated).
Energy use fish farm, diesel	l/kg biomass produced	0,05	
Value dead fish vs fish sold to human consumption		4:100	

Table 3-7 Yield and values fish farming of bass and sea bream (per calendar year) TABLE TO BE COMPLETED!

Property	Unit	Value Bass and sea bream	Comment/reference
Mortality rate	kg dead fish/kg biomass production		
Utilization rate dead fish	kg utilized dead fish/kg dead fish total		
Disappeared rate	kg fish disappeared/kg biomass produced		
BFCR (biological feed conversion ratio)	kg feed/kg biomass produced		
Energy use fish farm, electricity	kWh/kg biomass produced		
Energy use fish farm, diesel	l/kg biomass produced		
Value dead fish vs fish sold to human consumption			

3.2.3 Antifouling emission from salmonid fish farm

The net pens include use of antifouling paint. This paint leaves the system from controlled washing and maintenance of the net (mainly on shore) and as emissions to the sea from wear and handling of the net. There is a wide range of chemicals used for antifouling, but here copper based is used as a proxy. Based on information from the industry Cu based is still the most common to be used for fish farms. There is also very high variation regarding how much antifouling chemicals are used. This depends on where the fish farming is situated (how much on-growing) and the strategy the fish farmer uses to handle on-growing. Many fish farms will not use any kind of antifouling chemicals as they have other strategies to handle fouling.

Quantification of Cu emission from marine open net pen aquaculture is done based on data from Norwegian marine aquaculture and literature [13]: in 2013, 1 016 tonne of copper were used to produce antifouling coatings for net pens in Norwegian salmon farms alone. Fish production in that sector in 2013 was 1 239 876 tonne. Assuming that 20-30% of this copper is collected by on-shore washing of nets (expert judgement) we get the following calculation:

1 016 tonne Cu/1 239 879 tonne fish*0,8 lost/total =**0,65 kg Cu/tonne lwe fish produced**.

To model the emission to sea, the ecoinvent dataset “*Antifouling paint emissions {RoW}| treatment of Cu-based antifouling paint emissions | Cut-off, U*”, was used. It was manipulated by normalizing it against the Cu emitted it represented. This dataset includes the Cu emission as Copper emitted and **it will be investigated whether or not this actually represents the elementary flow in which copper enters the marine water.**

The elementary flows that are used to model the antifouling chemical emissions are being investigated, as are the data used to quantify input, emissions and waste handling (activity data). The preliminary results of the RPs’ PEF profiles indicate that antifouling chemicals are not very important, but it is being investigated whether this is because it is not correctly modelled within the EF3.0 method, or if it simply is not of high importance for the final result.

3.2.4 Emission of feed nutrients from fish farm net pen

Emissions from feeding is included by a mass balance. This model and the emission factors that are used per unit of fish produced is presented in the excel file “Marine Fish PEFCR - Feed emission mass balance mode”. Figure 3-1 illustrates the basic building blocks of the mass balance.

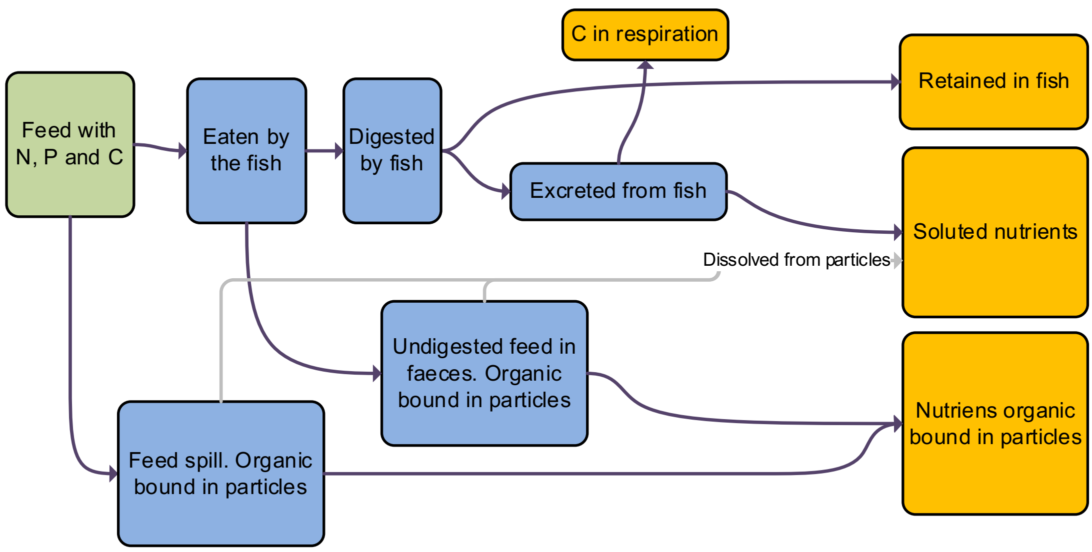


Figure 3-1 Feed nutrient mass balance model

3.2.5 Hatchery

The hatchery is included based on data from a leading producer of fertilized eggs sold to the salmon aquaculture industry.

Table 3-8 data hatchery

Property	Unit	Value
Energy use, electricity	kWh/egg	0,005
Fresh water	l/egg	17

3.2.6 Juvenile production in Recirculating Aquaculture System (RAS)

The juvenile production is included with a RAS production for all farmed species. This process is included based on data from Norwegian aquaculture and includes energy use, water input, infrastructure, and sludge handling.

Table 3-9 Data salmonid juvenile production

Property	Unit	Value	Comment
EFCR (economic feed conversion ratio)	kg feed/kg fish sold	1,0	
Energy use fish farm, electricity	kWh/kg fish sold	10	
Diesel	l/kg fish sold	0,033	
Sludge output	kg sludge/kg feed	1,5	
Fresh water	kg/kg fish sold	15	Recirculating systems include some replacing of water.
Eggs from hatchery	Eggs/kg fish sold	7	Assumed average weight of juvenile is 150 g when it is sold. 1/0,15=7 eggs/kg fish sold.

3.2.7 Sludge from RAS aquaculture

This is included as a process of drying the sludge and then transporting it to final use. This process is included using data from the Agribalyse database [8] and the data set "F. Sludge, thickened, dewatered and thermally dried".

This data represents drying of sludge with 1-3w% dry content to a dry content of 90w%.

3.2.8 Feed production

As stated in section 2.2.3 on the system boundaries, the Marine Fish PEFCR that this PEF-RP study supports will not contain the instructions/rules on how the PEF profile of the feed shall be calculated, as that is done by the existing "PEFCR Feed for Food-producing Animals" [3]. In the PEF-RP study presented here, two feeds are used:

- For the salmonids a feed based on the average feed composition of the Norwegian salmon industry in 2017. The full presentation of this feed model can be found in Table 3-10. The vegetable feed ingredients are included with Agrifootprint (v5.0 and economic allocation) and the marine ingredients are included with data presented in the report by Winther et al (2020) *[14]*.

- For the bass and sea bream the Agribalyse (version 3) data sets "Sea bass or sea bream,fattening feed 1,conv prod, at farm gate/FR U" and "Sea bass or sea bream,fattening feed 2,conv prod, at farm gate/FR U" are used.
    - These two data sets will be remodelled or replaced with a model that is according to the "PEFCR Feed for Food-producing Animals" [3].

Table 3-10 Salmonid feed composition. Table and all data from report by Winther et al (2020) [14].

Ingredient group	Ingredient	Scientific name of fish species	Volume (ton)	Proportion of feed (%)
Micro ingredients (3%)	Amino acids		4,763	0.35%
	Medicine		3	0.00%
	Micro ingredients - undefined		17,888	1.30%
	Phosphate		6,980	0.51%
	Pigments		218	0.02%
	Pigments natural		1,438	0.10%
	Pigments synthetic		227	0.02%
	Vitamins and minerals		4,493	0.33%
Crop-based oil (20%)	Rapeseed		274,695	20.03%
Crop-based protein (40%)	Faba beans		41,589	3.03%
	Guar		12,656	0.92%
	Horsebeans		2,823	0.21%
	Legume		37,903	2.76%
	Maize		14,674	1.07%
	Pea		13,192	0.96%
	Soy		281,824	20.55%
	Sunflower		18,687	1.36%
	Wheat		124,786	9.10%
Crop-based starch/carbohydrates (10%)	Pea		12,630	0.92%
	Tapioka		35	0.00%
	Wheat		124,123	9.05%
Fish meal - Reduction Fishery (12%)	Argentine / Silver Smelt	*Argentina sphyraena*	152	0.01%
	Blue Whiting	*Micromesistius poutassou*	77,888	5.68%
	Capelin	*Mallotus villosus*	6,909	0.50%
	Fish meal - Undefined	*Unknown*	139	0.01%
	Atlantic herring	*Clupea harengus*	5,846	0.43%
	Atlantic horse mackerel	*Trachurus trachurus*	75	0.01%
	Jack Mackerel	*Trachurus japonicus*	1	0.00%
	Krill	*Euphausia superba*	12,464	0.91%
	Mackerel	*Scomber scombrus*	727	0.05%
	Gulf menhaden	*Brevoortia patronus*	1,803	0.13%

	Peruvian Anchoveta	*Engraulis ringens*	15,501	1.13%
	European pilchard (Pilchard)	*Sardina pilchardus*	383	0.03%
	Norway pout	*Trisopterus esmarkii*	5,902	0.43%
	Sandeel	*Ammodytes sp.*	22,014	1.61%
	European pilchard (Sardine)	*Sardina pilchardus*	103	0.01%
	Silvery lightfish	*Maurolicus muelleri*	2	0.00%
	Sprat	*Sprattus sprattus*	9,166	0.67%
Fish meal - By-products (5%)	Capelin	*Mallotus villosus*	3,510	0.26%
	Fish meal - Undefined	*Unknown*	4,698	0.34%
	Atlantic herring	*Clupea harengus*	34,742	2.53%
	Atlantic horse mackerel	*Trachurus trachurus*	10	0.00%
	Atlantic mackerel	*Scomber scombrus*	7,616	0.56%
	Whitefish	*Gadus morhua (e.g.)*	11,676	0.85%
Fish oil - By-products (4%)	Capelin	*Mallotus villosus*	2,876	0.21%
	Fish oil - Undefined	*Unknown*	5,441	0.40%
	Atlantic herring	*Clupea harengus*	13,507	0.98%
	Atlantic herring	*Clupea harengus*	7,597	0.55%
	Atlantic horse mackerel	*Trachurus trachurus*	392	0.03%
	Atlantic mackerel	*Scomber scombrus*	9,594	0.70%
	Atlantic salmon	*Salmo salar*	6,873	0.50%
	Whitefish	*Gadus morhua (e.g.)*	2,902	0.21%
Fish oil - Reduction Fishery (8%)	Blue Whiting	*Micromesistius poutassou*	8,896	0.65%
	Capelin	*Mallotus villosus*	6,652	0.49%
	Fish oil - Undefined	*Unknown*	625	0.05%
	Atlantic herring	*Clupea harengus*	6,516	0.48%
	Atlantic horse mackerel	*Trachurus trachurus*	188	0.01%
	Atlantic mackerel	*Scomber scombrus*	1,178	0.09%
	Gulf menhaden	*Brevoortia patronus*	26,989	1.97%
	Peruvian Anchoveta	*Engraulis ringens*	18,348	1.34%
	Norway pout	*Trisopterus esmarkii*	2,337	0.17%
	Sandeel	*Ammodytes sp.*	10,783	0.79%
	Sardine	*Sardina pilchardus*	3,784	0.28%
	Sprat	*Sprattus sprattus*	18,649	1.36%
Algae oil (0.02%)	Algae oil		241	0.02%
	Total		**1,371,322**	**100%**

3.3 Preparation

Preparation is included for all products.

For all preparation, the following is included (in addition to the use of energy as presented in Table 3-11):

- Infrastructure (building hall of steel)

- Materials that are used in maintenance, etc. This input is included to balance the waste flows that are reported. These materials do not cover packaging, which is presented in section 3.4.
- Cleaning agents
- Water consumption
- Waste flows:
  - materials to waste handling and wastewater flows.
  - Fish biomass that is not sold as a commercial product (a co-product) is included as a waste flow according to section 3.6.

Table 3-11 presents the energy use of the different preparation stages that are included. This covers all energy used by the preparation itself and all other activities at the preparation facility, which includes storage of the fish and ice production. These data are based on information from the Norwegian seafood industry. The data presented in Table 3-11 are energy use reported by industry for their total consumption and production over time and does not include details on how the energy is used.

Table 3-11 Preparation energy use

Preparation	Groundfish and flatfish preparation – same for fileting and gutting	Flatfish gutting and head off	Pelagic preparation, same for filleting and round freezing	Tuna and tuna-like filleting	Farmed products preparation
Electricity (kWh/tonne fish input)	363	363	216	363	107
Electricity source	European average	European average	European average	European average	European average
Diesel fuel (l/tonne input)	0,13	0,13	0,13	0,13	0,13

Table 3-12 presents the mass yield and the value ratios used for the different wild caught commodity groups in the preparation stage. The co-product utilization rate also includes loss in the preparation stage (e.g. fish that is withdrawn because of quality issues). Fish mass that does not have a net value is considered a waste flow and handled according to section 3.6.

Table 3-12 Wild fish yield and values at preparation

Preparation step	Round to Head off gutted		Round to Fillet		kg co-product utilized/kg co-product total
Commodity group	Yield (kg product out/kg lwe inn)	Value ratio (main:co-product)	Yield (kg product out/kg lwe inn)	Value ratio (main:co-product)	

Groundfish	0,67	100:5	0,38	100:4	0,6
Small pelagic			0,48	100:17	1,0
Flatfish	0,67	100:5			0,6
Tuna and tuna like			0,38	100:14	0,6

Table 3-13 presents the yield and value ratios used in the preparation stage for the farmed RP. The co-product utilization rate also includes loss in the preparation stage (e.g. fish that is withdrawn because of quality issues). Fish mass that does not have a net value is considered a waste flow and handled according to section 3.6.

Table 3-13 Farmed fish yield and value at preparation

Property	**Unit**	**Salmonids**	**Bass and bream**
Yield in preparation	Live to head on gutted (kg fish out/kg fish in)	0,83	---
	Live to fillet (kg fish out/kg fish in)	0,59	0,44
Co-product utilization in preparation	kg co-product utilized/kg co-product total	0,9	0,9
Value ratio fillet: co-product	fillet: co-product	100:4	100:4
Value ratio head on gutted: co-product	head on gutted: co-product	100:4	

The parameters presented here will be improved based on data from FAO and inputs from industry experts. For the time being they are based on simple assumptions in order to demonstrate how the assessment will include these very important data.

Table 3-14 presents data on how the different commodity groups are distributed. These products are distributed in many product forms, but the RP modelling only includes the options fillet or gutted and frozen. These data[14] are based on trade data and does not only include the fish that is consumed in the EU. Some of it can also be products that are exported. The data does not separate between gutted or round and between gutted and gutted head on and off. Thus, it is assumed that all gutted/round fish is head off gutted.

[14] EUMOFA

Table 3-14 Product state of commodity groups, data for 2017-2019

Presentation and preservation		Groundfish	Small pelagics	Tuna and tuna like species	Flatfish	Salmonids
Whole/gutted	**Fresh**	25 %	39 %	12 %	59 %	48 %
	Frozen	20 %	55 %	75 %	24 %	14 %
Fillet	**Fresh**	5 %	0 %	3 %	3 %	23 %
	Frozen	50 %	6 %	10 %	14 %	15 %

3.4 Packaging

Transport and consumer packaging is included:

- Transport packaging. Two types: Expanded Polystyrene (EPS) box and cardboard box.
- Consumer packaging. Two types: Aluminium with plastic film lid and EPS with plastic film lid.

Table 3-15 Packaging data

Packaging	**Description**
EPS transport packaging	1 box can carry 20 kg fish plus 4-5 kg ice. Weight of 1 box is 600 g and it is composed of Expandable Polystyrene (EPS). The production of the box is included with the EF2.0 data “Polystyrene production, high impact {EU-28+EFTA} | polymerisation of styrene | production mix, at plant | 1.05 g/cm3 | LCI result” (UUID: e4de5167-6a0c-4cb6-a670-138309cc85c5) The waste handling of this box is included with the EF3.0 data “Waste incineration of plastics (unspecified) {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | unspecified plastic waste | LCI result” (UUID: 8137b889-a1d8-4109-8aa7-e2aaee38fa5f)
Cardboard box	1 box that weighs 2 kg can carry 25 kg fish. The cardboard box is only used for frozen products and ice is not included. The cardboard box is composed of 1,8 kg cardboard and 0,2 kg plastic liner. Production of the cardboard is included with the EF3.0 data “Corrugated board, uncoated {EU+EFTA+UK} | 'virgin' Kraft Pulping Process, pulp pressing and drying | production

	mix, at plant | flute thickness 0.8- 2.8 mm, R1=0% | LCI result” (UUID: 574bdb1e-2ed3-46f1-bd14-bb76f739bb71) Production of the plastic liner is included with the EF3.0 data “Packaging film, High barrier {EU+EFTA+UK} | raw material production, lamination process | single route, at plant | thickness: 12 µm PET, 12µm alu, 75µm PE; grammage 115 g/m2 | LCI result” (UUID: 52ce6985-95af-47f4-87a5-d60ebcf3341e)
Aluminium consumer packaging	A box of 30 g aluminium and 5 g PE packaging film holds 500 g fish. End of life for the aluminium is recycling and for the PE market mix.
EPS consumer packaging	A box of 50 g EPS and 5 g PE packaging film holds 500 g fish. EoL of the EPS and the PE with market mix.

In the transport, the mass that is transported (the transport work) takes into account the weight of the packaging and ice. The following factors are used for moving 1 kg of fish:

- Fresh products on ice in EPS box on Euro-pallet: 1,43 kg transported/kg fish.
    - 1 box of 600 g holds 20 kg fish and 5 kg ice. 27 boxes are placed on 1 Euro-pallet that weighs 25 kg: (0,6+5)/20+25/(27*20)=0,43 kg packaging/kg fish
- Frozen products in cardboard box: 1,12 kg transported/kg fish
    - 1 box that weigh holds 25 kg. 27 boxes are placed on 1 Euro-pallet that weighs 25 kg: 2/25+25/(27*25)=0,12 kg packaging/kg fish.

3.5 Fish loss in transport, retail and consumer

Table 3-16 presents the loss rates of products from distribution, retailer and at consumer. These rates are the default rates presented by the PEF method [2]. Loss in fishing, farming and preparation is already accounted for in the previous stages/processes. Note that the loss at consumer (11 %) is the percentage of fish that becomes waste before preparation. The yield from the different product forms to edible parts is presented in Table 3-17.

Table 3-16 Loss rates and coproduct utilization at retailer and consumer

Property	Unit	Value	Comment
Loss during distribution	kg lost/kg distributed	0,04	All products
Loss at retailer	kg fish lost/kg delivered to retailer	0,04	All products
Loss at consumer	kg fish lost/kg bought from retailer	0,11	All products
Co-product utilization at retailer and consumer	Mass of fish not sold and not eaten that is somehow utilized	0%	All products

Table 3-17 Yield at consumer

Product (commodity group)	**Transformation**	**Value** (kg fish out/kg fish in)
Salmonids	Head on gutted to edible	0,54
	Fillet to edible	0,71
Groundfish	Head off gutted fresh to edible	0,46
	Fillet fresh and frozen to edible	0,86
Small pelagic	Fillet to edible	1,0
	Round frozen to edible	0,41
Tuna and tuna-like	Fillet to edible	1,0
Flatfish	Head off gutted fresh to edible	0,46

3.6 Fish End of Life handling (Fish waste handling)

Fish leave the system as waste flows (not products) all the way through the system (Figure 2-1 and Figure 2-2) from raw material acquisition through final consumption. All these flows are included in this PEF study.

The following parameters are used for the CFF formula: R1=R2=R3=0. This leaves the CFF formula to: CFF=Ev +Ed. Where

- Ev is the specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of the RPs and
- Ed is the specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.

The following scenarios are used for Ed:

- Fish waste flows from distribution, retailer and consumer are modelled as going 45% to landfill and 55% to incineration, based on average EU data for municipal waste.
- Fish waste flows from fishing, farming and preparation are modelled as going 100% to incineration, based on TS expert judgement.

3.6.1 Data used in the fish waste modelling

Landfill of fish waste is included with the EF3.0 data *"Landfill of biodegradable waste {EU+EFTA+UK} | LCI result"*. This data is used based on the following consideration:

- Fish biomass has a dry weight (dw) C content of around 0,5 kg C/kg dw. The water content of fish is around 0,335 kg water/kg wet weight (ww). With this the theoretical mass of C that can be emitted from degradation at the landfill is 0,17 kg C/kg ww fish. If all of this C is emitted as methane (CH4) the theoretical intensity is

0,224 kg CH_4/kg ww fish. That is if the fish is completely degraded under anaerobic conditions.

- The dataset "*Landfill of biodegradable waste {EU+EFTA+UK} | LCI result*" includes a biogenic emission intensity of **0,11 kg** biogenic methane per kg biodegradable waste. That is 50% of the theoretical maximum and it is considered a fair assumption the 50% of the fish mass that is landfilled will degrade under anaerobic conditions and emit biogenic methane.

Incineration of fish waste is included with the EF3.0 data "*Waste incineration of untreated wood {EU+EFTA+UK} | waste-to-energy plant with dry flue gas treatment, including transport and pre-treatment | production mix, at consumer | wood waste | LCI result*". While this dataset represents handling of wood, the biogenic carbon content of the waste matches that of fish biomass: 0,44 kg biogenic C per kg waste.

As this incineration process seem to include energy recovery the R3 factor of the CFF formula is not zero. The implications of this and how it can be fixed will be clarified.

3.7 Distribution transport

Transport is included for all product flows and the different inputs and outputs that their life cycle involves. For most of the material inputs to the system these transports are part of the generic datasets that are used. All transport is included as refrigerated transport.

All fish products are attributed a transport scenario as presented in Table 3-18. These preliminary distances are set based on the default data presented by the PEF method [2] in section 4.4.3.

Table 3-18 Transport scenario

Transport	Vehicles	Distance (km)	Dataset (all EF3.0)
From landing to preparation in Europe	Truck (>32 t, EURO 4	130	Articulated lorry transport, Euro 4, Total weight >32 t {EU+EFTA+UK} | diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight / 24,7t payload capacity | LCI result (UUID: e1ded83e-a02f-42cd-92f9-81cce21a3a98)
	Train (average freight train)	240	Freight train, average {EU+EFTA+UK} | mix of electricity driven and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity | LCI result (UUID: 4cedf877-89c5-4b4d-8014-5b7d099a2095)
	Ship (barge)	270	Barge {EU+EFTA+UK} | technology mix, diesel driven, cargo | consumption mix, to consumer | 1500 t payload capacity | LCI result (UUID: 4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae)
From preparation to retailer	Truck (>32 t, EURO 4	2 800 (3500*0,7)	Articulated lorry transport, Euro 4, Total weight >32 t {EU+EFTA+UK} | diesel driven, Euro 4, cargo | consumption mix, to consumer | more than 32t gross weight

			/ 24,7t payload capacity | LCI result (UUID: e1ded83e-a02f-42cd-92f9-81cce21a3a98)
	Ship (transoceanic container)	3 600 (18000*0,2)	Transoceanic ship, containers {GLO} | heavy fuel oil driven, cargo | consumption mix, to consumer | 27.500 dwt payload capacity, ocean going | LCI result (UUID: 6ca61112-1d5b-473c-abfa-4accc66a8a63)
	Train	1800 (18000*0,1)	Freight train, average {EU+EFTA+UK} | mix of electricity driven and diesel driven, cargo | consumption mix, to consumer | average train, gross tonne weight 1000t / 726t payload capacity | LCI result (UUID: 4cedf877-89c5-4b4d-8014-5b7d099a2095)

These distances will be changed as data on the source (country) for the different species are quantified. **Air transport will be included.**

3.8 Retailer

The retail stage is included with data from the PEF method [2] and the retail OEFCR ”Organisation Environmental Footprint Sector Rules (OEFSR) Retail» [15].

Table 3-19 Data per day the product is in the store and volume of the product in litre

Process or input	Unit	Value	Comment
Output			
Products stored refrigerated at retailer	Days*litre	7,3e8	2000*0,5*2*1000*365. Total capacity of retail centre is 2 000m3.
Inputs			
Electricity	kWh/l*day	1,75e6	400*2000+1900*2000*1/4
Refrigerant production and emission (134a)	Kg/l*day	14,5	0,29*2000*1/4*0,1
Freshwater	m3/l*day	3 650	
Electricity data	The electricity used in the use stage is average European grid mix.		

3.9 Use stage

The use stage is included using the data provided in Annex D of the PEF method [2]. This includes chilled storage, cooking the fish and cleaning the cooking equipment. Table 3-20 presents the details.

The use stage did not include the infrastructure/equipment such as the refrigerator, the pan and the dishwasher. Only the energy and material used are included.

Table 3-20 Inventory data use stage

Process or input	Modelling
Chilled storage	7 days in refrigerator. Electricity intensity 0,0037 kWh/L occupied storage*day. Volume of occupied storage is 3x that of the volume of the fish. It is then assumed that 1 kg fish is equal to 1,5 L (from the assumption that fish meat is around 70% water), leading to the factor 7 days*1,5 L/kg fish *3 *0,0037 kWh/L*day=**0,117 kWh/kg fish product**.
Cooking – energy	10 minutes in frying pan (75% on gas and 25% electricity). Energy intensity 1 kWh/h use.
Cooking - oil	5 g sunflower oil/kg product cooked.
Dishwashing	Per dishwasher cycle: 15 L water, 10 g soap and 1,2 kWh electricity. Washing of frying pan, etc. is assumed to occupy 10% of one cycle.
Electricity data	The electricity used in the use stage is average European grid mix.

3.10 Electricity

Until the RP models are regionalized all use of electricity is include with the EU+EFTA+UK grid mix and the EF3.0 data "Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result".

4 Results

The results are presented per the instructions regarding the hotspot analysis in section "A.6.1. Identification of hotspots" in the PEF method [2]:

- **Most relevant impact categories.** The identification of the most relevant impact categories is based on the normalised and weighted results. The most relevant impact categories are identified as all impact categories that cumulatively contribute to at least 80% to the total environmental impact, starting from the largest to the smallest contributions. The following analysis of most important stages and processes is performed for all categories since the identification of the most relevant impact categories will change as the PEF-RP analysis is improved and the Technical Secretariat of the PEFCR can decide to include other categories than only those that are identified through the "80% rule".
- **Most relevant stages.** The most relevant life cycle stages are the ones that together contribute to at least 80% to any of the most relevant impact categories identified, starting from the largest to the smallest contributions. If the use stage accounts for more than 50% of the total impact, the procedure shall be re-run with the exclusion of the use stage. In this case, the list of most relevant life cycle stages shall be those selected through the latter procedure plus the use stage. This procedure will be followed once the selection of most relevant impact categories is done, while all 28 categories of the EF3.0 method are included, the use stage contributes with >50% to some categories.

- **Most relevant processes.** The most relevant processes are those that collectively contribute to at least **80%** to any of the most relevant impact categories identified. This shall be done only for the most relevant impact categories. Identical processes taking place in different life cycle stages (e.g. transportation, electricity use) shall be accounted for separately. Identical processes taking place within the same life cycle stage shall be accounted for together.
- **Dealing with negative numbers.** The PEF Method can return negative numbers where, for example, process like recycling introduce credits from substitution. When identifying the percentage impact contribution for any process or elementary flow **the absolute values shall be used**. This procedure does not apply to the identification of the most relevant life cycle stages. The procedure to use absolute values includes that the total is recalculated with the absolute values and the percentage impact contribution for any process or elementary flow is assessed to this new total.

The preliminary results are presented in the Excel file, "**Marine Fish PEF-RP Results - 17 07 2022**". This section of the study provides a brief overview.

The short summery of the preliminary results is that the whole life cycle and all processes and flows that are included so far show importance for one of the impact categories.

4.1 PEF results and analysis wild representative product

4.1.1 Normalised and weighted results wild representative product

Table 4-1 presents the normalised and weighted results per 1 kg consumed wild marine fish representative product.

*Table 4-1 Normalised and weighted results for the wild representative product, **all values per 1 kg consumed wild representative product***

Damage category	Unit	Total
Total	µPt	622,76
Acidification	µPt	43,90
Climate change	µPt	144,61
Ecotoxicity, freshwater	µPt	34,95
Particulate Matter	µPt	113,00
Eutrophication, marine	µPt	25,37
Eutrophication, freshwater	µPt	8,86
Eutrophication, terrestrial	µPt	37,31
Human toxicity, cancer	µPt	4,55
Human toxicity, non-cancer	µPt	10,61
Ionising radiation	µPt	3,63
Land use	µPt	5,38
Ozone depletion	µPt	4,72
Photochemical ozone formation	µPt	55,39
Resource use, fossils	µPt	71,47

Resource use, minerals and metals	µPt	34,11
Water use	µPt	24,92

4.1.2 Characterised results of all EF impact categories wild representative product

Table 4-2 presents the characterised results per 1 kg consumed wild marine fish representative product.

Table 4-2 Characterised results for the wild representative product, ***all values per 1 kg consumed wild representative product.*** *The "results direct output" presents the values before all flows are converted to absolute values.*

Results all impact categories.	Unit	Result absolute values	Result direct output
Acidification	mol H+ eq	3,93E-02	3,93E-02
Climate change	kg CO2 eq	5,09E+00	5,56E+00
Climate change - Biogenic	kg CO2 eq	2,10E-02	3,93E-01
Climate change - Fossil	kg CO2 eq	5,01E+00	5,11E+00
Climate change - Land Use and LU Change	kg CO2 eq	5,42E-02	6,08E-02
Ecotoxicity, freshwater - part 1	CTUe	6,87E+01	7,03E+01
Ecotoxicity, freshwater - part 2	CTUe	5,52E+00	7,42E+00
Ecotoxicity, freshwater - inorganics	CTUe	3,79E+01	3,83E+01
Ecotoxicity, freshwater - metals	CTUe	3,50E+01	3,48E+01
Ecotoxicity, freshwater - organics	CTUe	1,57E-10	1,57E-10
Particulate Matter	disease inc.	7,49E-07	7,51E-07
Eutrophication, marine	kg N eq	1,61E-02	1,68E-02
Eutrophication, freshwater	kg P eq	4,78E-04	5,08E-04
Eutrophication, terrestrial	mol N eq	1,76E-01	1,78E-01
Human toxicity, cancer	CTUh	3,30E-09	3,61E-09
Human toxicity, cancer - inorganics	CTUh	0,00E+00	4,51E-22
Human toxicity, cancer - metals	CTUh	2,24E-09	2,56E-09
Human toxicity, cancer - organics	CTUh	1,06E-09	1,05E-09
Human toxicity, non-cancer	CTUh	9,66E-08	1,32E-07
Human toxicity, non-cancer - inorganics	CTUh	2,58E-08	2,62E-08
Human toxicity, non-cancer - metals	CTUh	6,86E-08	1,03E-07
Human toxicity, non-cancer - organics	CTUh	2,64E-09	3,41E-09
Ionising radiation	kBq U-235 eq	3,45E-01	3,06E-01
Land use	Pt	4,73E+01	5,55E+01
Ozone depletion	kg CFC11 eq	3,98E-06	4,02E-06
Photochemical ozone formation	kg NMVOC eq	4,68E-02	4,70E-02
Resource use, fossils	MJ	6,20E+01	5,58E+01
Resource use, minerals and metals	kg Sb eq	2,85E-05	2,88E-05
Water use	m3 depriv.	3,09E+00	3,36E+00

4.1.3 Most relevant impact categories wild representative product

Table 4-3 presents the impact categories identified as most important, that is the impact categories that cumulatively contribute to at least 80% to the total environmental impact, starting from the largest to the smallest contributions.

Table 4-3 Identification of most important impact categories for wild representative product

WILD MOST RELEVANT IMPACT CATEGORIES	
Impact categories	**% of normalised and weighted results**
Climate change	23,2 %
Particulate Matter	18,1 %
Resource use, fossils	11,5 %
Photochemical ozone formation	8,9 %
Acidification	7,0 %
Eutrophication, terrestrial	6,0 %
Sum of selected categories to total normalized and weighted result	**80 %**

4.1.4 Most relevant stages wild representative product

Figure 4-1 presents how the different life cycle stages contribute to the impact categories identified as most important (section 4.1.3)

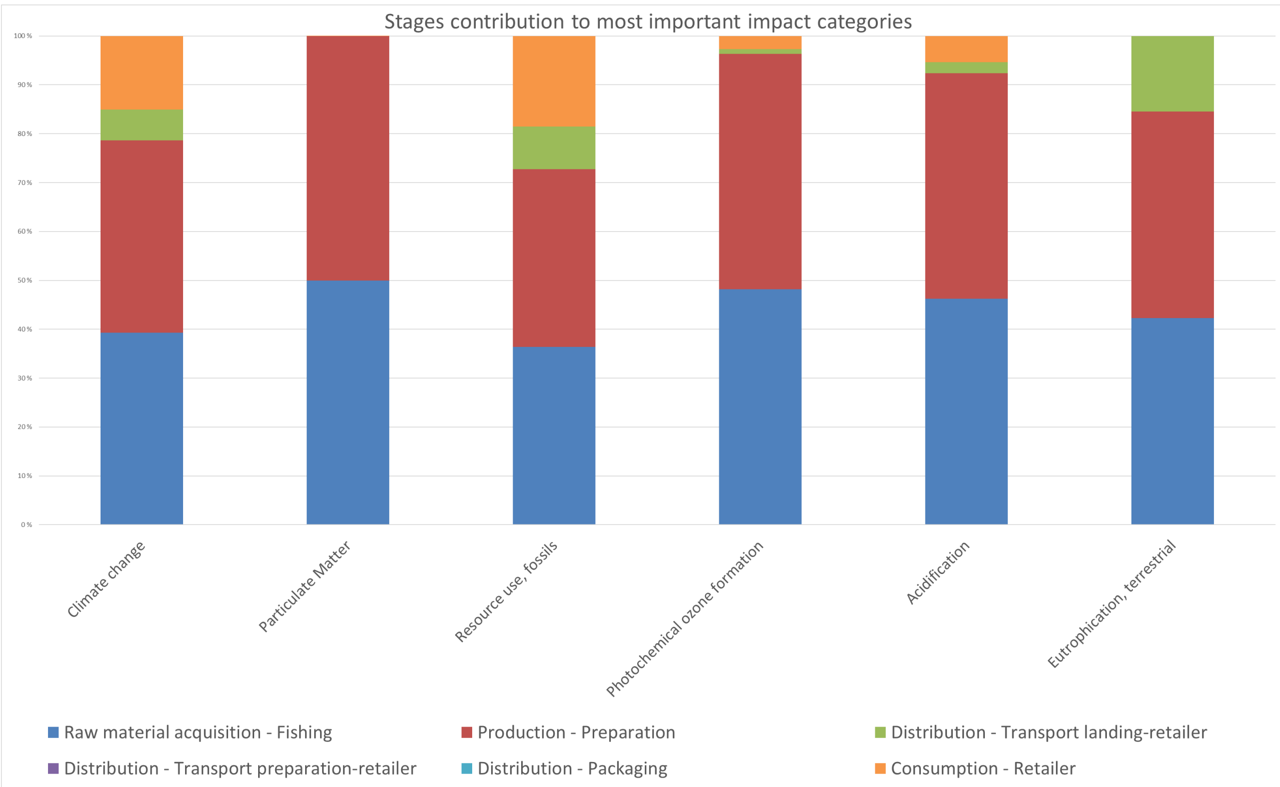


Figure 4-1 Contribution of each life cycle stage to the impact categories identified as most important, for the wild representative product.

4.1.5 Most relevant processes wild representative product

See table in the sheet “Wild RP results” in the Excel file “**Marine Fish PEF-RP Results – 17 07 2022”**

4.2 PEF results and analysis farmed marine fish representative product

4.2.1 Normalised and weighted results farmed marine fish representative product

Table 4-4 presents the normalised and weighted results per 1 kg consumed farmed marine fish representative product.

*Table 4-4 Normalised and weighted results for the farmed representative product, **all values per 1 kg consumed farmed representative product***

Damage category	**Unit**	**Total**
Total	mPt	2,05
Acidification	mPt	0,10
Climate change	mPt	0,41
Ecotoxicity, freshwater	mPt	0,28
Particulate Matter	mPt	0,17
Eutrophication, marine	mPt	0,55
Eutrophication, freshwater	mPt	0,03
Eutrophication, terrestrial	mPt	0,08
Human toxicity, cancer	mPt	0,01
Human toxicity, non-cancer	mPt	0,03
Ionising radiation	mPt	0,02
Land use	mPt	0,05
Ozone depletion	mPt	0,00
Photochemical ozone formation	mPt	0,08
Resource use, fossils	mPt	0,11
Resource use, minerals and metals	mPt	0,07
Water use	mPt	0,04

4.2.2 Characterised results of all EF impact categories farmed marine fish representative product

Table 4-5 presents the characterised results per 1 kg consumed farmed marine fish representative product.

Table 4-5 Characterised results for the farmed representative product, all values per 1 kg consumed farmed representative product. The "results direct output" presents the values before all flows are converted to absolute values.

Results all impact categories.	**Unit**	**Result absolute values**	**Result direct output**
Acidification	mol H+ eq	9,32E-02	9,36E-02
Climate change	kg CO2 eq	1,54E+01	1,59E+01
Climate change - Biogenic	kg CO2 eq	1,98E-01	4,40E-01
Climate change - Fossil	kg CO2 eq	1,06E+01	1,08E+01
Climate change - Land Use and LU Change	kg CO2 eq	4,62E+00	4,63E+00
Ecotoxicity, freshwater - part 1	CTUe	2,92E+02	2,94E+02
Ecotoxicity, freshwater - part 2	CTUe	3,19E+02	3,21E+02
Ecotoxicity, freshwater - inorganics	CTUe	6,21E+01	6,27E+01
Ecotoxicity, freshwater - metals	CTUe	7,37E+01	7,40E+01
Ecotoxicity, freshwater - organics	CTUe	4,38E-04	4,38E-04
Particulate Matter	disease inc.	1,12E-06	1,13E-06

Eutrophication, marine	kg N eq	3,66E-01	3,66E-01
Eutrophication, freshwater	kg P eq	1,87E-03	1,89E-03
Eutrophication, terrestrial	mol N eq	3,86E-01	3,89E-01
Human toxicity, cancer	CTUh	8,39E-09	8,69E-09
Human toxicity, cancer - inorganics	CTUh	4,22E-20	4,26E-20
Human toxicity, cancer - metals	CTUh	6,69E-09	6,99E-09
Human toxicity, cancer - organics	CTUh	1,70E-09	1,70E-09
Human toxicity, non-cancer	CTUh	3,71E-07	4,04E-07
Human toxicity, non-cancer - inorganics	CTUh	3,80E-08	3,86E-08
Human toxicity, non-cancer - metals	CTUh	2,35E-07	2,67E-07
Human toxicity, non-cancer - organics	CTUh	9,90E-08	9,96E-08
Ionising radiation	kBq U-235 eq	1,39E+00	1,40E+00
Land use	Pt	5,34E+02	5,42E+02
Ozone depletion	kg CFC11 eq	7,53E-07	7,89E-07
Photochemical ozone formation	kg NMVOC eq	7,06E-02	7,09E-02
Resource use, fossils	MJ	8,99E+01	8,74E+01
Resource use, minerals and metals	kg Sb eq	5,72E-05	5,75E-05
Water use	m3 depriv.	5,22E+00	4,94E+00

4.2.3 Most relevant impact categories farmed marine fish representative product

Table 4-6 presents the impact categories identified as most important for the farmed marine fish representative product, which are the impact categories that cumulatively contribute at least 80% to the total environmental impact, starting from the largest to the smallest contributions.

Table 4-6 Identification of most important impact categories for farmed representative product

FARMED MOST RELEVANT IMPACT CATEGORIES	
Impact categories	% of normalised and weighted results
Eutrophication, marine	27 %
Climate change	20 %
Ecotoxicity, freshwater	14 %
Particulate Matter	8 %
Resource use, fossils	5 %
Acidification	5 %
Photochemical ozone formation	4 %
Sum of selected categories to total normalized and weighted result	84 %

4.2.4 Most relevant life cycle stages farmed marine fish representative product

Figure 4-2 presents the contribution of each life cycle stage to the impact categories identified as most important, for the farmed representative product.

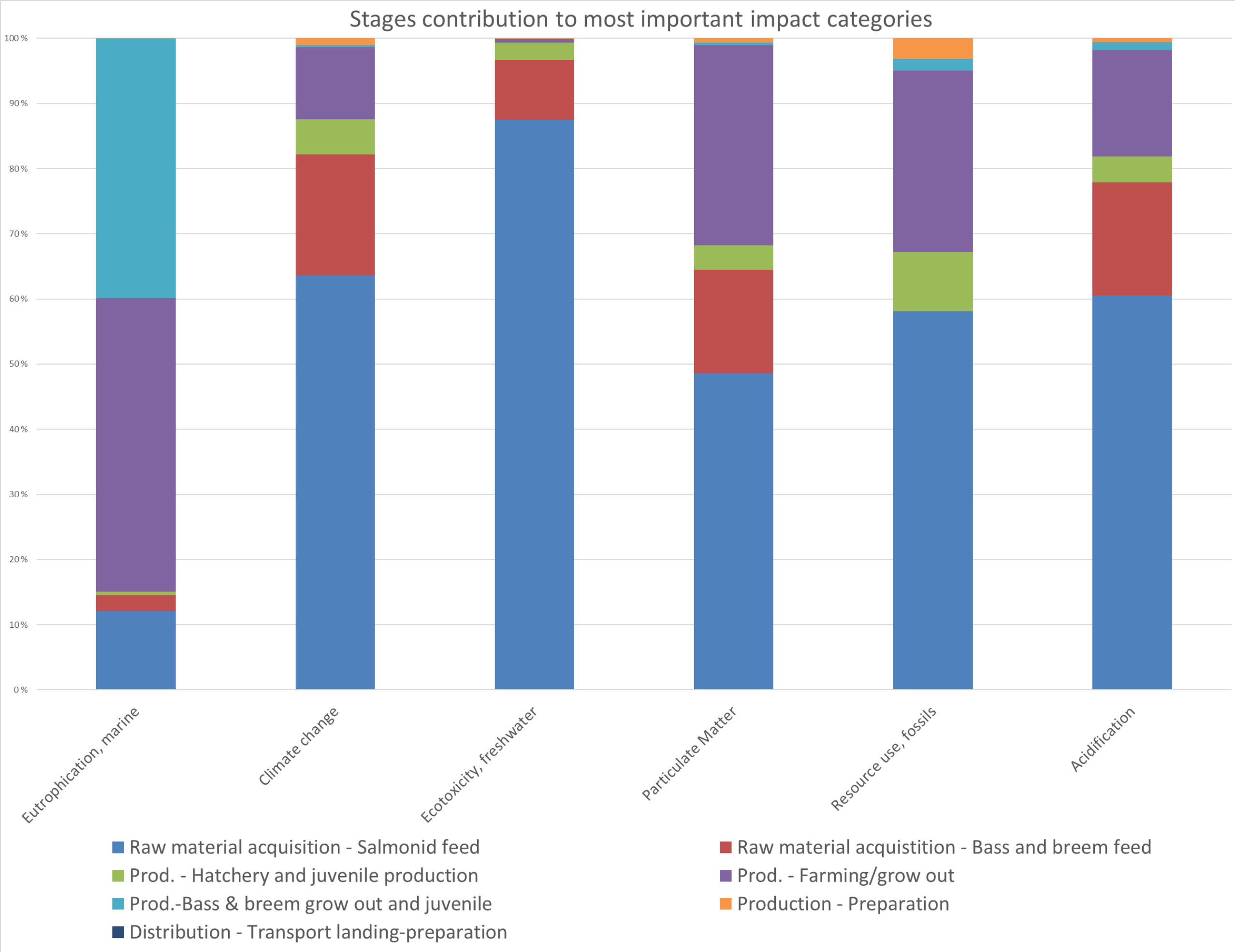


Figure 4-2 Contribution of each life cycle stage to the impact categories identified as most important, for the farmed representative product.

4.2.5 Most relevant processes farmed marine fish representative product

See table in the sheet "Farmed RP results" in the excel file "**Marine Fish PEF-RP Results - 17 07 2022"**

4.3 Additional information

See section 2.2.7.

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6 Annexes

6.1 Annex 1: Commodity groups

Comodity Group	Species (MCS)	Tonne consumed 2016-2018
Flatfish	Plaice, European	250 871
Flatfish	Other flatfish	236 071
Flatfish	Sole, common	81 466
Flatfish	Flounder, European	56 844
Flatfish	Megrim	49 747
Flatfish	Sole, other	23 252
Flatfish	Halibut, Greenland	19 187
Flatfish	Dab	18 841
Flatfish	Flounder, other	17 395
Flatfish	Turbot	17 307
Flatfish	Halibut, other	12 395
Flatfish	Brill	8 745
Flatfish	Plaice, other	6 958
Flatfish	Halibut, Atlantic	5 164
Flatfish Total		**804 243**
Groundfish	Cod	3 499 338
Groundfish	Alaska pollock	2 481 709
Groundfish	Hake	1 498 095
Groundfish	Haddock	477 657
Groundfish	Saithe (=Coalfish)	470 034
Groundfish	Other groundfish	367 433
Groundfish	Blue whiting	243 475
Groundfish	Redfish	227 333
Groundfish	Grenadier	201 755
Groundfish	Whiting	42 182
Groundfish	Ling	41 520
Groundfish	Pouting (=Bib)	25 451
Groundfish	Pollack	20 744
Groundfish	Toothfish	-2 691
Groundfish Total		**9 594 034**
Other marine fish	Other marine fish	798 485
Other marine fish	Monk	292 893
Other marine fish	Other sharks	234 380
Other marine fish	Seabream, other	128 789
Other marine fish	Ray	76 543
Other marine fish	Red mullet	60 853
Other marine fish	Gurnard	49 340
Other marine fish	Scabbardfish	29 915
Other marine fish	Cusk-eel	23 238
Other marine fish	Dogfish	22 474
Other marine fish	Smelt	14 861
Other marine fish	Seabass, European	14 442
Other marine fish	John dory	12 574
Other marine fish	Picarel	12 271
Other marine fish	Seabream, gilthead	12 184
Other marine fish	Ray's bream	5 302
Other marine fish	Weever	4 447
Other marine fish	Cobia	-26
Other marine fish	Seabass, other	-1 910
Other marine fish Total		**1 791 056**
Salmonids	Other salmonids	28 284
Salmonids	Trout	13 157
Salmonids	Salmon	4 701
Salmonids Total		**46 141**
Small pelagics	Herring	1 855 323
Small pelagics	Sardine	942 676
Small pelagics	Mackerel	927 387
Small pelagics	Sprat (=Brisling)	569 059
Small pelagics	Anchovy	446 929
Small pelagics	Horse mackerel, other	234 973
Small pelagics	Horse mackerel, Atlantic	92 245
Small pelagics	Miscellaneous small pelagics	-68 487
Small pelagics Total		**5 000 105**
Tuna and tuna-like species	Tuna, skipjack	2 415 468
Tuna and tuna-like species	Tuna, yellowfin	1 349 468
Tuna and tuna-like species	Tuna, miscellaneous	489 292
Tuna and tuna-like species	Swordfish	147 005
Tuna and tuna-like species	Tuna, albacore	120 131
Tuna and tuna-like species	Tuna, bigeye	100 720
Tuna and tuna-like species	Tuna, bluefin	28 294
Tuna and tuna-like species Total		**4 650 378**
Grand Total		**21 885 956**

6.2 Annex 2: Review Panel

Industry expert, **Alex Olsen** graduated with a degree in Environmental Management from the Technical University of Denmark in 2009 and received his MSc in Food Science from the Royal Veterinary and Agricultural University (Denmark) in 1986. Mr. Olsen is current self-employed after working as Head of Sustainability for A. Espersen A/S for the past 14 years (2007-2021). Prior to this, he was Manager of McDonald's Europe's Agricultural Assurance program from 2002-2007 and Supply Chain Manger for McDonald's Denmark (1995-2002) after starting his career as Project Leader for Food Manufacturing and Microbiology for the Danish Meat Institute (1987-1995), Food Inspector in Holbaek, Denmark (1986-1987), and Food Policy Officer, Danish Consumer Association (1986). During his career at Espersen, Mr. Olsen managed numerous projects focused on seafood sustainability, including: coordinating an international working group that aims to secure a healthy marine eco-system for the future in the northern-most part of the Northeast Atlantic around the island of Svalbard; developing Disruptive Seafood Harvest design concepts; developing the Espersen Sustainability Program "Our Seas, Our Fish, Our Food"; coordinating MSC certification of the Danish East Baltic cod fishery and providing assistance to Lithuanian and Latvian authorities to support their move towards MSC certification; developing the Issuing Supplier Agreement (a set of rules to avoid buying fish from unregistered catches); presenting the company's revised calculation on illegal, unreported and unregulated fishing (IUU) in Baltic cod fisheries based on industry data to The International Council for the Exploration of the Sea (ICES); actively engaging in the development of the European Fish Processors and Traders Association (AIPCE-CEP); and developing guidelines for the responsible sourcing of fish.

LCA expert, **Dr. Angel Avadí** graduated in Computer Systems Engineering in 2002, from the Catholic University of Guayaquil (Ecuador). He obtained in 2006 a MSc in e-Business (International University of Japan), in 2008 a MSc. in International Cooperation Policy (Ritsumeikan Asia Pacific University - Japan), and in 2010 a MEng. in International Material Flow Management (University of Applied Science Trier - Germany). Between 2011 and 2014, he worked on his PhD thesis (University of Montpellier - France) focused on the sustainability of value chains associated with Peruvian fisheries, including aquaculture. Since 2015, he is a researcher at the French Agricultural Research Centre for International Development (CIRAD). He has contributed to various projects focused on seafood systems, including a project funded by Sustainable Recycling Industries (SRI) in the course of which he provided dozens of LCI datasets to ecoinvent (2018); and two European Value Chain Analysis for Development (VCA4D) projects focused on Zambian aquaculture (2018) and Gambian fisheries and aquaculture (2020). Angel has contributed dozens of life cycle inventory datasets to the French AGRIBALYSE agricultural LCA database. Angel has also reviewed projects and methodological guidelines focused on seafood systems, such as VCA4D projects on Cambodian aquaculture (2017) and Malian inland fisheries (2020), as well as several project proposals submitted to the

German Research Foundation (2017) and the Research Council of Norway (2020). He has published 35 scientific papers to date, with nine additional pieces currently under review.

LCA expert, **Dr. Ian Vázquez-Rowe** graduated in Biology in 2006 at the University of Texas at Arlington. He then continued his graduate studies in Environmental Engineering at the University of Santiago de Compostela – USC (2006-2008), with a short Erasmus period at the University La Sapienza in Rome where he developed his master thesis. In October 2008 he initiated his research career at USC, where he obtained his PhD in Chemical Engineering in July 2012. Currently, Dr. Vázquez-Rowe is an Associate Professor at the Department of Engineering at the Pontificia Universidad Católica del Perú. He has participated in numerous research projects at a European, Spanish, Galician, Luxembourgish and Peruvian level, as well as recent projects with UN Environment. Dr. Vázquez-Rowe has published over 110 articles in international journals. Currently, he is also the editor for Ocean Resources and Marine Conservation at the International Journal of Life Cycle Assessment and for Journal of Environmental Management. One of his main research lines has been linked to analysing the environmental sustainability of seafood products, mainly from wild fisheries. He has contributed to various projects focused on seafood systems, including a project funded by Sustainable Recycling Industries (SRI) in the course of which he provided dozens of LCI datasets to ecoinvent (2018), together with Ángel Avadí. More recently, he has started working on the environmental impacts related to the dissipative release of plastic fragments to the ocean and the associated effects on human health and (ocean) ecosystem quality. Since 2019 he co-chairs the Marine impacts in Life Cycle Assessment (MarILCA) projects, which aims at establishing novel characterization factors and impact categories to compute environmental impacts and damages associated to marine plastics in Life Cycle Impact Assessment.

6.3 Annex 3: Review Report

See Excel file “Marine Fish PEF-RP Report - Review Panel Report 19 07 2021”.