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

2025

PEF-RP study for the Marine Fish PEFCR development

Version 1

2025

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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
EF3.1	Environmental Footprint database version 3.1
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
RER	Region Europe
RF	Reference Flow
RP	Representative Product
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
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 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 aquatic 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].

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

[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. 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.

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 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[3] - 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.

[3] Based on GHG protocol Scope 3 definition from the Corporate Accounting and Reporting Standard (World resources Institute, 2011).

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 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[4] - 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

[4] Based on GHG protocol Scope 3 definition from the Corporate Accounting and Reporting Standard (World resources Institute, 2011).

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, 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).

Preface

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 relevant impacts and the stages, processes and flows that causes them. These results are presented in a separate Excel sheet.

1 Introduction

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). It was conducted according to the guidelines for PEFCR development [1].

The report presents the Product Environmental Footprint study of two virtual marine fish products (representing the two sub-categories of Marine fish for human consumption, namely *wild marine fish* and *farmed marine fish*) that represent the wild caught and farmed marine fish marketed unprocessed for human consumption, in the EU market. In addition, the results of the overarching product category are calculated for the RP of *marine fish*, which is a weighed combination of the RP of the sub-categories *wild marine fish* and *farmed marine fish*.

2 Method description

2.1 Goal

2.1.1 Intended application and reason for carrying out the study

This study was 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 [1]:

- 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

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 was performed by Andrea Arntzen Nistad (Asplan Viak AS) and Erik Skontorp Hognes (Asplan Viak AS former employee) 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)[5].

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 [1].

Table 2-1 Members of the PEFCR review panel

Category	Name	Affiliation
Industry expert	Tom Maidment	Hilton Foods
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. (Note that “Consumed” fish means fish eaten by the consumer. The Use phase of the consumer might include all kinds of processing by the end-user.)

Section 2.2.4 presents the representative products that are studied.

[5] 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 is based on statistics that embraces marine fish products placed on the EU market for human consumption during the years 2020-2022 (as this is the latest available data). This includes all geographical sources and marine fish species for the unprocessed marine fish consumed in the EU (i.e. all freshwater species are excluded).

Regulation (EC) no 852/2004[6] 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 feed production 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, sea bass and sea bream feed according to the stated biological feed conversion ratio (BFCR) and the corresponding fish mass balance.

[6] 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
Feed production	Growing, fishing and other production of feed raw materials. Processing of feed ingredients and compound feed production and packaging.	N/A
Production	Juvenile production and grow out of fish (including onsite killing/preparation).	Fishing (including on-board preparation).
Preparation	Harvest (slaughter), gutting, filleting, refrigeration and/or freezing.	Gutting, filleting, refrigeration and/or freezing.
Distribution	Packaging materials and transport from preparation to retailer, including cooling and losses (fish waste).	
Consumption (Use)	Chilled storage at retailer, transport retail to consumer, use phase at consumer. Losses (fish waste) included.	
End of life	Handling of fish mass that is not sold as a commercial product, or not consumed. Handling of packaging and other material flows.	

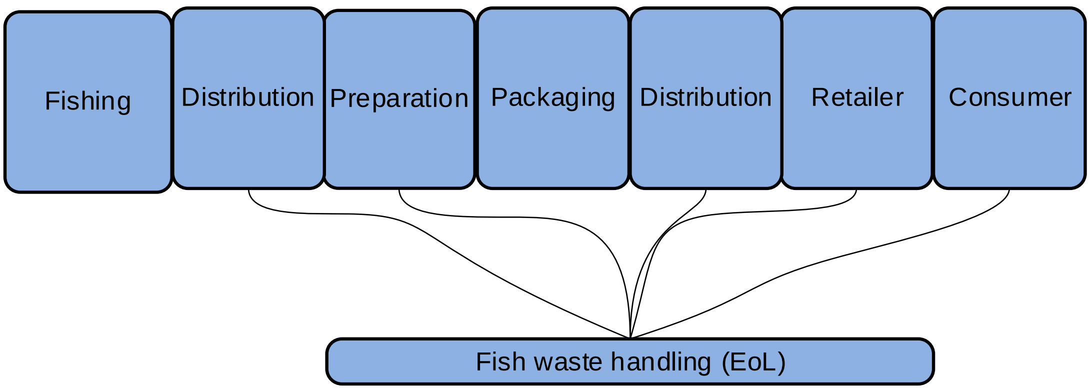

Figure 2—1 System scope wild marine fish product

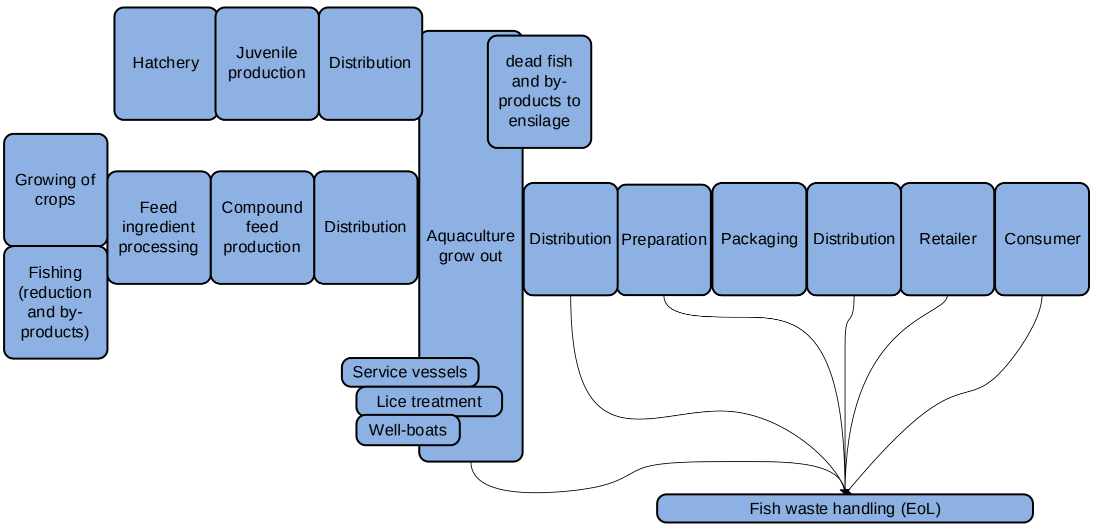

Figure 2—2 System scope farmed marine fish product

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 of the sub-categories 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.

Additionally, results of the overarching product category are calculated for the RP of *marine fish*, which is a weighed combination of the RP of the sub-categories wild marine fish and farmed marine fish. The RP values of the marine fish allows comparative assertion between the sub-categories via the benchmark of the overarching product category.

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 does not include 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[7] for wild and farmed marine fish.
    - In these data the marine fish consumption are split into the commodity groups flatfish, groundfish (other demersal), salmonids, small pelagics and tuna and tuna-like species.
    - The years 2020-2022 were used as these are the latest data available.
2. The state in which the products are distributed (e.g. fresh/frozen, filet/head on gutted, etc.) was retrieved from import-export data collected by EUMOFA [5]. The years 2021-2023 were used as these are the latest data available.

The different species and methods used are not traced back to origin (country or region)
This is a limitation of the PEF-RP study. 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 purchased. 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. Moreover, data for production (fishing/farming) could not be found region, species, type of fishery/farming.

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

Table 2-4 EU marine fish apparent consumption per commodity group for 2020-2022. This present consumption of both wild and farmed products). Source of data: https://www.eumofa.eu/supply-balance

Commodity Group	Apparent consumption (tonne)	% of marine fish apparent consumption	% of wild caught	% of farmed
Flatfish	595 004	3 %	93 %	7 %
Groundfish	7 273 766	36 %	100 %	0 %
Other marine fish excl. seabass and seabream	2243867	8 %	61 %	39 %
Salmonids	4 063 023	15 %	6 %	94 %
Seabass and seabream	818189	1 %	13 %	87 %
Small pelagics	3 642 677	19 %	100 %	0 %
Tuna and tuna-like species	4 082 131	17 %	87 %	13 %
Total	**22 718 657**	**100 %**	**78 %**	**22 %**

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 2020-2022 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 by the TS members and data on how these species were landed by Norwegian fisheries [6].

The group “groundfish” dominates consumption, followed by “small pelagics” and “tuna and tuna like".

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 was modelled.

Table 2-5 The Wild RP model presenting the apparent consumption of wild marine fish in the EU for 2020-2022 and how these species were caught. (Source: [https://www.eumofa.eu/supply-balance)](https://www.eumofa.eu/supply-balance) [4]. See Annex 1 for the full data including species included in each commodity group.

Commodity group	**Apparent consumption (tonne) 2020-2022**	**% of wild marine fish**	**% of commodity group**	**Fishery**						
				Coastal conventional	**High sea demersal**	**High sea demersal**	**Coastal seines**	**Purse seiners**	**Pelagic trawlers**	**Pelagic fishing (>30**
Flatfish	543 924	3 %	100 %	38 %	9 %	45 %	7 %	1 %	0 %	0 %
Groundfish	7 272 174	43 %	100 %	38 %	9 %	45 %	7 %	1 %	0 %	0 %
Other marine fish	1 353 383	8 %	100 %	38 %	9 %	45 %	7 %	1 %	0 %	0 %
Small pelagic	3 642 676	21 %	100 %	10 %	0 %	0 %	22 %	58 %	10 %	0 %
Tuna and tuna-like species	4 046 873	24 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	100 %

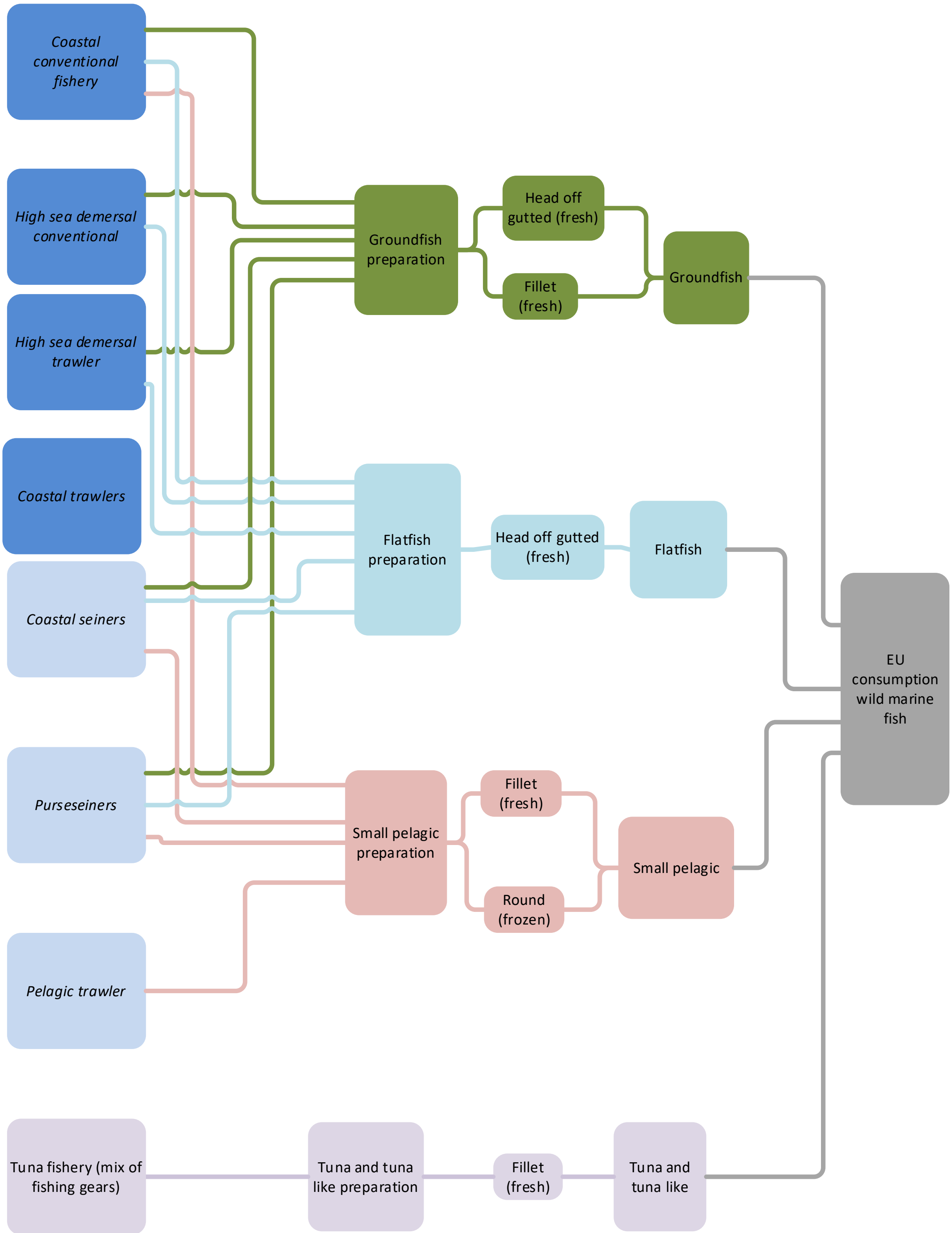

Figure 2—3 The Wild fish RP model: key building blocks.

Figure 2—4 illustrates a conceptual model of how the Wild RP was 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 RP is constructed for the PEF-RP.

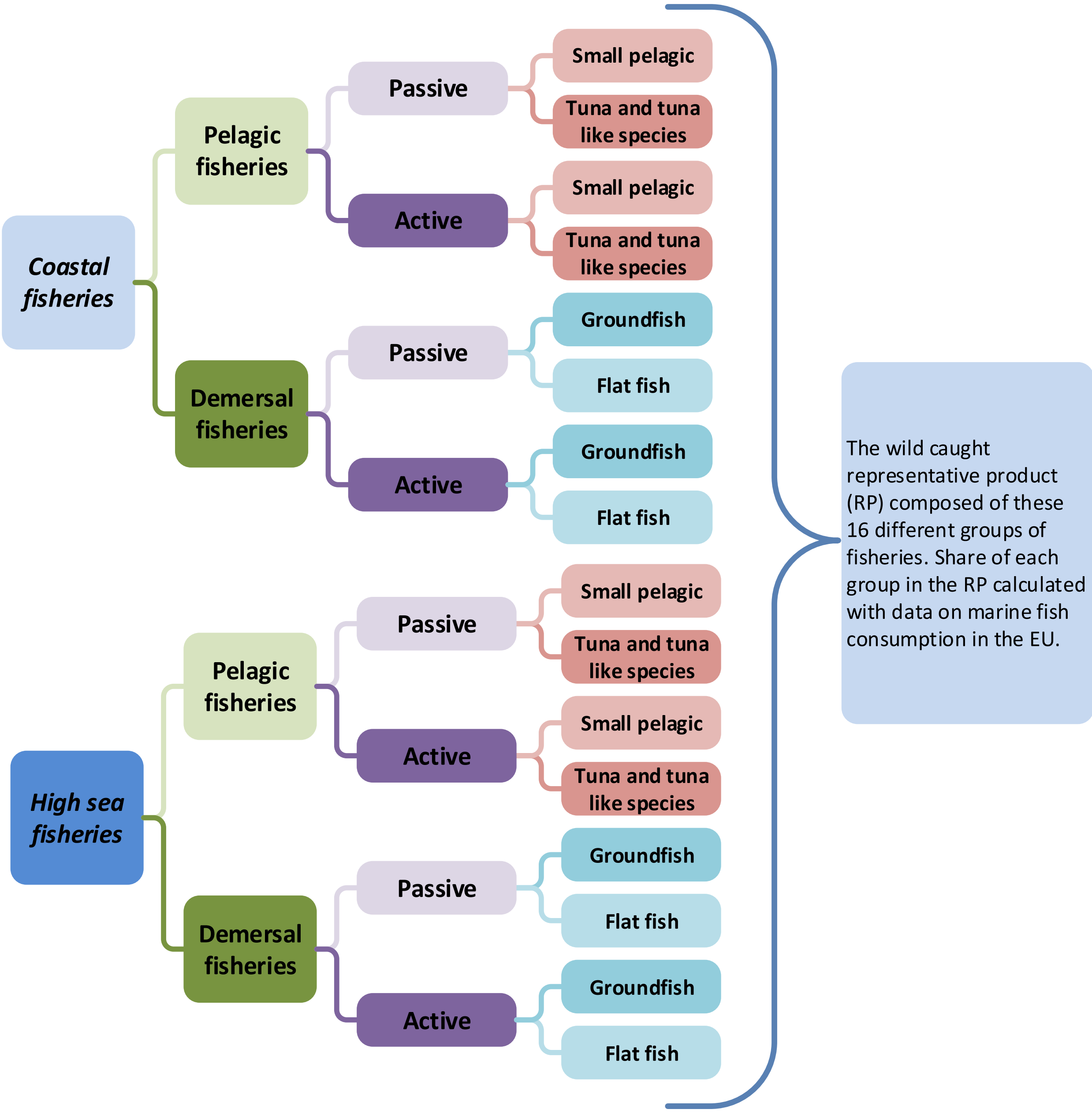

Figure 2—4 Model for the wild marine fish representative product. The terms active/passive refer to the fishing gear. A trawl is a typical example of active fishing gear and a longline is an example of a passive fishing gear.

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. This reflects the main production systems used today, which are open net pen in sea for salmonids or sea bass/sea bream and production in seawater in land-based systems for salmonid or sea 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 production systems used. It is assumed that species other than salmonids or sea bass/sea bream are represented by sea bass/sea bream aquaculture. This assumption was based on expert judgements by the TS. Full grow out in freshwater is not included according to the product scope of this study.

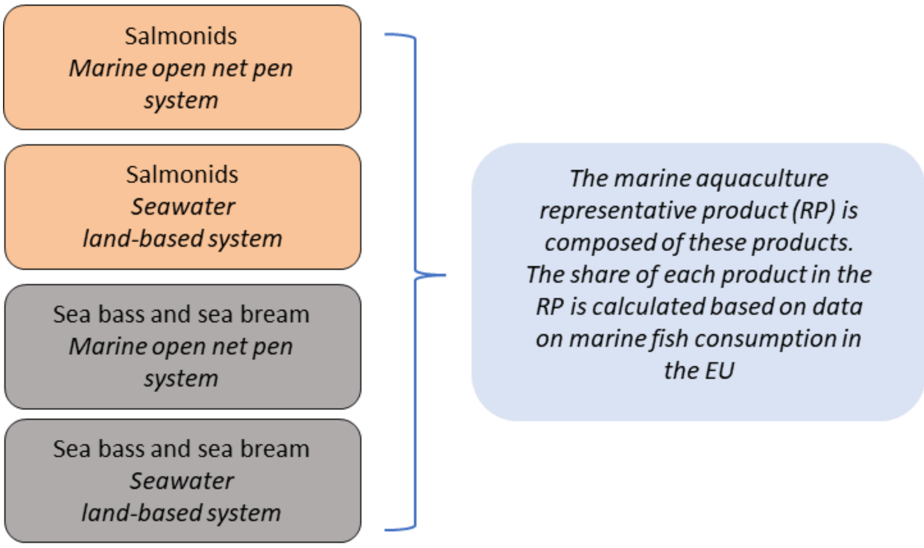

Figure 2—5 Model for the farmed marine fish representative product.

Table 2-6 Apparent consumption of farmed marine fish for the years 2020-2022. (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	Land-based system full grow out salmonids	Land-based system full grow out bass and sea bream
Salmon	3 179 438	67 %	100 %			
Trout	636 433	13 %	100 %			
Seabream, gilthead	401 588	8 %		100 %		
Seabass, European	299 552	6 %		100 %		
Other marine fish	157 189	3 %		100 %		
Tuna, bluefin	35 258	1 %		100 %		
Turbot	33 123	1 %		100 %		
Other salmonids	19 603	0 %	100 %			
Seabream, other	11 157	0 %		100 %		
Sole, other	4 013	0 %		100 %		
Halibut, Atlantic	890	0 %		100 %		
Sum	4 778 244	100 %				
Farmed RP			**80 %**	**20 %**	**0 %**	**0 %**

2.2.5 Impact assessment

The impact assessment was done using the EF3.1 method[8]. Table 2-7 presents 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 EF3.1 impact assessment method

EF Impact category	Impact category indicator	Unit	Characterisation model	Robustness
Climate change, total	Global warming potential (GWP100)	kg CO_2 eq	Bern model - Global warming potentials (GWP) over a 100-year time horizon (based on IPCC 2013)	I
Ozone depletion	Ozone depletion potential (ODP)	kg CFC-11 eq	EDIP model based on the ODPs of the World Meteorological Organisation (WMO) over an infinite time horizon (WMO 2014 + integrations)	I
Human toxicity, cancer	Comparative toxic unit for humans (CTUh)	CTUh	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Human toxicity, non-cancer	Comparative toxic unit for humans (CTUh)	CTUh	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Particulate matter	Impact on human health	Disease incidence	PM model (Fantke et al., 2016 in UNEP 2016)	I
Ionising radiation, human health	Human exposure efficiency relative to U^{235}	kBq U^{235} eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	II
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (Van Zelm et al, 2008) as applied in ReCiPe 2008	II
Acidification	Accumulated exceedance (AE)	mol H^+ eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, terrestrial	Accumulated exceedance (AE)	mol N eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe	II
Eutrophication, marine	Fraction of nutrients reaching freshwater end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe	II
Ecotoxicity, freshwater	Comparative toxic unit for ecosystems (CTUe)	CTUe	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018	III
Land use	Soil quality index	Dimensionless (pt)	Soil quality index based on LANCA model (De Laurentiis et al. 2019) and on the LANCA CF version 2.5 (Horn and Maier, 2018)	III
Water use	User deprivation potential (deprivation- weighted water consumption)	m^3 water eq of deprived water	Available Water Remaining (AWARE) model (Boulay et al.,2018; UNEP 2016)	III
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	van Oers et al., 2002 as in CML 2002 method, v.4.8	III
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	van Oers et al., 2002 as in CML 2002 method, v.4.8	III

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

[9] EF reference package spreadsheet, link as above

2.2.6 Biogenic carbon modelling

Fish do not include the storage of biogenic carbon and thus a simplified modelling approach was 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 EF3.1 method.

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

1) from anaerobic degradation of fish biomass going to waste handling, and
2) from anaerobic degradation of sludge collected from production of juveniles in land-based systems

The inventory for the biogenic methane modelling is presented in section 2.2.6.

Sludge from open net pen farming can potentially build up and lead to methane emissions. As anaerobic conditions usually not occur this is not included. See section 3.2.5.

2.2.7 Environmental limitations and candidates for additional environmental information

Marine fishing and marine aquaculture are highly relevant for several environmental impacts not captured by the current impact assessment method (EF3.1). Among these other impacts, biodiversity impacts (biotic impacts) are the most relevant. Marine fish production has direct impact on marine ecosystems and indirect impacts through the different inputs. Feed used for farmed products is the most relevant input in regard of indirect impacts, 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 EF3.1 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.**

2.2.8 Consideration of relevance for biodiversity

According to section A.3.2.7.1 of the PEF method [1] the TS shall make an assessment about the relevance of biodiversity for the products in scope of the PEFCR. 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. See the PEFCR for further considerations and details regarding biodiversity. The PEFCR specifies what a PEF study shall take into consideration.

No assessment of the impact on biodiversity has been done for the RP. It is important to note that this report does not purport to cover all known environmental aspects of marine fish products.

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 [1]) the first versions of the 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)." The second PEF-RP study can however make cut-offs, if the first PEF-RP identified that they can be cut-off within the rules defined for cut-off.

For the second PEF-RP the inclusion of capital goods was limited to fishing vessel and fishing gear construction (fishing), infrastructure and equipment for the open-net pen stage (farmed) and infrastructure for juvenile production (farmed).

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 LCA impact method or inventory data. These impacts are included as additional environmental information in the PEFCR.

- Plastic waste lost to sea: no impact assessment method for impact of plastic pollution in EF3.1
- Impacts to seabed: no LCA impact assessment method in EF3.1, but we have included an indicator (see PEFCR section 3.10)
- Biodiversity/biotic impacts: no biodiversity indicator in EF3.1
- The impact of emissions of anti-fouling agents to sea: no marine ecotoxicity indicator in EF3.1

2.3 Modelling choices

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

These are the most important modelling choices:

- Capital goods are included. This includes construction, maintenance and end-of-life handling of fishing vessels and gear, and the fish farm and equipment during grow-out and juvenile production.
- 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.

- 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.
- Biogenic carbon emissions are included with the simplified approach option (section 2.2.6).

2.4 Allocation

For processes with multiple outputs (co-products) and where it is not possible to separate 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 net 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:

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

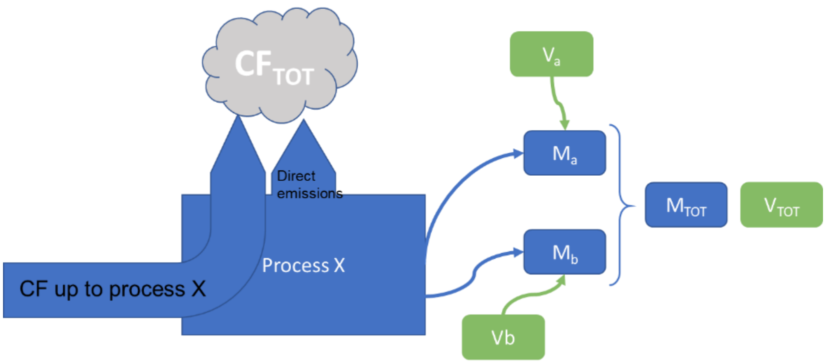

Figure 2—6 Example of economic allocation.

2.5 Data sources and primary and secondary data

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 data are included using data from the EF3.1 database:

- The footprint of materials, energy carriers and transports are included with generic data.
- The retail and consumption stage includes generic data, as suggested by the PEF method.

The activity data (e.g. amount of fuel spent, transport distances, etc.) is generally primary data. This data is either collected based on literature data from previously published LCA studies of marine fish products or expert judgements. For the wild caught products, the fuel use intensity is calculated based on data from the different fisheries that source the products.

Section A.2.4 of the PEF method [1] provide instructions on the data sources that can be used:

- An EF compliant proxy is available for free: it shall be included in the list of default processes of the PEFCR and stated within the limitations section of the second draft PEFCR.
- An ILCD-entry level (EL) compliant dataset as proxy is available for free: A maximum of 10 % of the single overall score may be derived from ILCD-EL compliant datasets.
- If no EF compliant or ILCD-EL compliant dataset is available for free: it shall be excluded from the model. This shall be clearly stated in the second draft PEFCR as a data gap and validated by the PEFCR verifiers.

Data that could not be found in the EF3.1 data or in other datasets in line with the abovementioned requirements were left out of the assessments (see data gaps and impact assessment gaps section 2.2.10).

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, maintenance, and end-of-life handling of fishing gear
- Production, maintenance, and end of life handling of fishing vessel
- Antifouling, production of the chemical
- 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 2.2.4.1). The intensities in Table 3-1 are set based on data from global fisheries [9], [10]. 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	litres 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, fish farms and by the vessels included in the fish grow out for farming is modelled as diesel. The combustion of the fuel is modelled with the EF3.1 data set "*Diesel combustion in construction machine {GLO} | diesel driven | production mix, at plant | LCI result*" (UUID: 6f06614d-fd12-4072-89ff-909caf1d744f) as no dataset for combustion of fuel in fishing vessels are available in the EF3.1 database.

3.1.3 Fishing refrigerant emissions

Emissions of refrigerants from the refrigeration systems on-board the fishing vessels are included. Based on previous studies on the carbon footprint of seafood products these emissions can be significant.

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). In the model, all refrigerants are presented by a mix of R22, ammonia and CO_2. 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 data from the Norwegian fishing fleet. All of these parameters will show considerable variation, thus these are very rough estimates. 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

Fishery	Load in vessel (kg/vessel)	Annual emission rate	Annual catch rate estimate	Emission rate	Expected lifetime of refrigerant not lost	Waste rate	Refrigerant mix		
	kg/vessel	kg emitted/kg in system/yr	tonne biomass fished/yr/vessel	kg refrigerant emitted/tonne biomass fished	years	kg waste/tonne biomass fished	Ammonia	CO_2	R22

Coastal conventional	400	0,1	238	0,17	5	0,34	33 %	33 %	33 %
High sea demersal conventional	2000	0,2	3382	0,06	5	0,12	33 %	33 %	33 %
High sea demersal trawlers	2000	0,3	8385	0,02	5	0,05	33 %	33 %	33 %
Coastal seines	2000	0,4	1735	0,12	5	0,23	33 %	33 %	33 %
Purse seiners	400	0,5	11183	0,00	5	0,01	33 %	33 %	33 %
Pelagic trawlers	400	0,6	15617	0,00	5	0,01	33 %	33 %	33 %
Pelagic fishing (>30 cm)	2000	0,7	10000	0,02	5	0,04	33 %	33 %	33 %

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

	Data set
Production	
R22	EF3.1 (UUID: acfe37e4-37e8-4d95-8354-157f09f6e37c): Tetrafluoroethane production {GLO} | technology mix | production mix, at plant | 100 % active substance | LCI result
Ammonia	EF3.1 (UUID: 6a9dbc0a-5245-551c-87ad-915153204a34): Ammonium chloride {EU+EFTA+UK} | technology mix | production mix, at plant | 100 % active substance | LCI result
CO2	EF3.1 (UUID: f418d090-af36-4aac-a593-206e9cc3141c Version: 03.00.009): Carbon dioxide, liquid production {EU+EFTA+UK} | technology mix | production mix, at plant | 100 % active substance | LCI result
Waste handling	
All refrigerants	EF3.1 (Process UUID: 71e54c33-b815-4489-8c87-a3f93c872201): 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:

- The model is simplified, and in the model all fish is landed as round. The split into main and co-products occurs in the preparation stage (section 3.3)[10].
- 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.

[10] In practice, wild fish can often be landed as gutted or as killed but not gutted. It is modelled as round to be able to use the fuel use estimates (which are given as litre fuel per live weight landed).

- 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. Data is based on expert judgements from companies in the TS and literature[11]

Property	Ground fish	Small pelagics	Flatfish	Tuna and tuna like
Ratio targeted catch vs by-catch of the landed fish	90:10	93:7[12]	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

Limited data have been available on the ratio between targeted catch and by-catch. It is well known that the ratio between targeted catch and by-catch show large variation between species and sources.

3.1.5 Bait

The bait contributes to < 0,5 % to all impact categories[13]. It was decided to exclude the bait from the model in the second PEF-RP. For some species it may still be important, which is highlighted in the PEFCR.

3.1.6 Fishing vessel and gear

Construction of the fishing vessel is included based on: 1) data on the ship lightweight[14] of fishing vessels; 2) yearly catch rate for these vessels and assumption of their lifetime; and 3) data on the construction and end of life handling from the EF3.1 database and the dataset "*Fishing vessel, steel, 56 m, 486 t {EU+EFTA+UK} | solid fishing vessel assembly | production mix, at plant | ocean going, 56 m, 486 t | Unit process, single operation*". Table 3-5 presents the data that is used to estimate the vessel "use" per unit of fish landed.

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 considered a rough simplification (to use the same data for all fisheries), but acceptable for the development of the RP.

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

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[11] report-carbon-footprint-norwegian-seafood-products-2017_final_040620.pdf (sintef.no)

[12] Data from Pelagia for herring and mackerel (2021).

[13] The input factor was based on data from the Norwegian Directorate of Fishery; 50 to 60 g bait per kg fish. The fisheries, "coastal conventional" and "high sea conventional" are attributed with bait. Fuel intensity of 0,1 l fuel/kg lwe landed. Preparation (freezing), storing, packaging and distribution (500 km by road) of the bait was included.

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

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)
Length of demersal trawler (tonne)	Ca. 70-80 meter [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 production of antifouling paint is modelled based on the EF 3.1 dataset, *"Chemicals for maintenance fishing vessel (antifouling) {EU+EFTA+UK} | production mix, at plant | Antifouling coating for use on ships to prevent unwanted organism growth. | LCI result"*, was used. An intensity of 0,035 g antifouling paint/kg lwe landed catch is assumed. The same intensity is used for all fisheries.

The EF impact assessment method does not cover Marine Ecotoxicity which means that emissions from anti-fouling agents to sea cannot be included in the PEF-RP. Regardless, emissions for anti-fouling agents are included in the PEFCR under additional environmental information.

3.2 Marine net pen farming (aquaculture)

The farmed marine fish representative product is modelled as a mix of salmonids and sea bass/sea bream (Table 2-6).

3.2.1 Feed input

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 the feed is modelled based on feed composition data for each species combined with datasets from EF3.1.

The production of feed dominates the environmental footprint of most farmed fish and thus the Feed Conversion Ratio (FCR) is a key parameter. In this assessment, the Biological Feed Conversion Ratio (BFCR) is used as it includes the mass of all the fish that is produced, not only the mass that is sold for harvesting.

The salmon feed is based on the average feed composition of the Norwegian salmon industry in 2019[15]. A simplification is made to the full feed model and is used in the analysis. The feed model used is shown in Table 3-6.

[15] https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3044084

Table 3-6 Feed model for salmon.

Main ingredient group	Ingredient	Share of feed	EF3.1 Dataset used for modelling
Crop based protein 36,90 %	Corn Gluten protein	0,2 %	Maize gluten meal, dried {GLO} | from wet milling (gluten drying) | production mix | LCI result
	Guar Protein	5,9 %	Soybean meal (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Pea protein	1,6 %	Pea, protein-concentrate {EU+EFTA+UK} | from pea protean-concentrate production | production mix | LCI result
	Soy Protein Concentrate (SPC)	16,9 %	Soybean protein concentrate {EU+EFTA+UK} | from crushing (solvent, for protein concentrate) | production mix | LCI result
	Sunflower Protein	2,7 %	Sunflower seed meal (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Wheat Gluten	9,6 %	Wheat gluten feed {EU+EFTA+UK} | from wet milling | production mix | LCI result
Micro-ingredients & Other	Sum of all micro-ingredients	4,1 %	Enzymes production {EU+EFTA+UK} | technology mix | production mix, at plant | 100 % active substance | LCI result
Crop based oil 20,90 %	Rapeseed oil	20,6 %	Crude rapeseed oil (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Soybean oil	0,3 %	Crude soybean oil (pressing) {EU+EFTA+UK} | from crushing (pressing) | production mix | LCI result
Carbohydrates 12,80 %	Peas	2,60 %	Pea, starch (from protein-concentrate) {EU+EFTA+UK} | from pea protean-concentrate production | production mix | LCI result
	Tapioca	0,0 %	Tapioca starch (processing with use of co-products) {TH} | from processing with use of co-products | production mix | LCI result
	Wheat	5,30 %	Wheat starch {EU+EFTA+UK} | from wet milling | production mix | LCI result
	Beans	5,00 %	Broad bean, meal {EU+EFTA+UK} | from broad bean crushing | production mix | LCI result
Marine oil 10,40 %	Sum	10,40 %	Fish oil {GLO} | from fish meal and oil production | production mix | LCI result
Marine protein 14,80 %	Sum	14,80 %	Fish meal {GLO} | from fish meal and oil production | production mix | LCI result

The feed for sea bass and sea bream is based on the feed composition from two major producers with a total market share of 65 %. The feed composition is thereafter compared to data reported by AZTI[16], which in general shows alignment with a few exceptions (lower share of micro ingredients than reported by feed producers, use of pea protein). The feed model applied is shown in Table 3-7.

Table 3-7 Feed model for sea bass and bream.

Main ingredient group	Ingredient	Share of feed	EF Dataset used for modeling
Crop based protein 30,2 %	Guar protein	1,2 %	Soybean meal (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Corn Gluten protein	5,2 %	Maize gluten meal, dried {GLO} | from wet milling (gluten drying) | production mix | LCI result
	Soy Protein Concentrate (SPC)	1,2 %	Soybean protein concentrate {EU+EFTA+UK} | from crushing (solvent, for protein concentrate) | production mix | LCI result

[16] https://www.azti.es/en/

	Rape seed meal	7,5 %	Rapeseed meal (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Soybean dehulled	8,0 %	Soybean meal (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Sunflower seed meal	6,9 %	Sunflower seed meal (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Wheat gluten	0,2 %	Wheat gluten feed {EU+EFTA+UK} | from wet milling | production mix | LCI result
	Pea	0,0 %	Pea, protein-concentrate {EU+EFTA+UK} | from pea protean-concentrate production | production mix | LCI result
Micro Ingredients & other 2,6 %	Sum of all micro-ingredients	2,6 %	Enzymes production {EU+EFTA+UK} | technology mix | production mix, at plant | 100 % active substance | LCI result
Crop based oils 4,8 %	Rapeseed oil	3,8 %	Crude rapeseed oil (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
	Soybean oil	1,0 %	Crude soybean oil (solvent) {EU+EFTA+UK} | from crushing (solvent) | production mix | LCI result
Carbohydrates 14,4 %	Wheat	14,4 %	Wheat starch {EU+EFTA+UK} | from wet milling | production mix | LCI result
Marine oil 7,0 %	Sum of marine oil	7,0 %	Fish oil {GLO} | from fish meal and oil production | production mix | LCI result
Marine Protein 13,2 %	Sum of marine protein	13,2 %	Fish meal {GLO} | from fish meal and oil production | production mix | LCI result
LAP`s 27,7 %	Feather meal	6,8 %	Animal meal, poultry {EU+EFTA+UK} | from dry rendering | production mix | LCI result
	Animal protein meal	16,0 %	Animal meal, poultry {EU+EFTA+UK} | from dry rendering | production mix | LCI result
	Bloodmeal	4,9 %	Animal meal, pig {EU+EFTA+UK} | from dry rendering | production mix | LCI result

For production of feed and transport the same data is used for both salmon and sea bass/sea bream. The production of feed is included based on average data from the industry. It includes 230 kWh/kg electricity, 0,5 l/kg diesel, 115 kWh/kg heat, as well as mixed materials and water use, and corresponding waste treatment. Transport from feed pellets production site to production location is included assuming 100 km lorry transport and 500 km ship transport.

3.2.2 Sea bass and sea bream production (grow-out)

The sea bass and sea bream production up to the preparation stage is included based on data from a meta-study of LCAs on sea bass and sea bream production by Zoli et al. (2023)[17] and data from the dataset *"Sea bass or sea bream, 200-500g, conventional, in cage, at farm gate/landing/FR U"* from Agribalyse [18]. The input data for the grow-out phase is shown in Table 3-8 below.

Fry enter the grow-out phase at 35 g. Data for the production of fry is scarce and only one study is previously published[19], showing similar values to salmon juvenile production for the

[17] https://www.sciencedirect.com/science/article/pii/S004484862300354X
[18] https://doc.agribalyse.fr/documentation-en/agribalyse-data/data-access
[19] https://www.sciencedirect.com/science/article/pii/S004484862300354X

major inputs. This stage is therefore modelled in the same way as the production of salmon juveniles (see section 3.2.4), but the feed input is changed to the same feed as used during the grow-out of sea bass and sea bream.

Table 3-8 Yield and values fish farming of bass and sea bream based on data.

Property	Unit	Value Bass and sea bream	Comment/reference
Mortality rate	kg dead fish/kg biomass production	0,15	Based on data from Zoli et al. (2023).
Utilization rate dead fish	kg utilized dead fish/kg dead fish total	0	Assume no utilisation
Sea bream fry	Pieces / kg biomass produced	2,75	The fry is assumed to be 35 g based on dataset from Agribalyse.
BFCR (biological feed conversion ratio)	kg feed/kg biomass produced	2	Based on average of seabass and bream from multiple studies[20]
Electricity	kWh/kg biomass produced	0,005	Based on dataset from Agribalyse
Diesel	litre/kg biomass produced	0,05	Zoli et al. (2023)

3.2.3 Salmon production (grow-out)

Table 3-9 (salmonids) present the most relevant input data for the grow-out of salmonids in marine open net-pen systems.

Table 3-9 Yield and values fish farming of salmonids (per calendar year)

Property	Unit	Value	Comment/reference
Mortality rate	kg dead fish/kg biomass production	0,09	Based on data from Norwegian aquaculture[21]. This corresponds to 15-20% of the number of salmon and trout in sea farming lost.
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 2021.

[20] https://www.sciencedirect.com/science/article/pii/S004484862300354X
[21] https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/3044084/Rapport_klimafotavtrykk.pdf?sequence=1&isAllowed=y.

Juvenile input	kg /kg biomass produced	0,022	Assume a start weight of 100 g[22].
Energy use fish farm, electricity	kWh/kg biomass produced	0	The fish farm can be connected to the power grid by a cable. As a conservative estimate[23] it is assumed that a diesel generator supplies the fish farm.
Energy use fish farm, diesel	l/kg biomass produced	0,05	[24]
Value dead fish vs fish sold to human consumption		4:100	

3.2.4 Juvenile production

The juvenile production is included with data from Table 3-10 for both salmonids and seabass / sea bream. This process is included based on data from Norwegian aquaculture and includes energy use, water input, infrastructure, and sludge handling and is based on data from a recirculating aquaculture system (RAS)[25]. Flow-through systems generally shows the same characteristics with exception of higher water use.

The production of eggs in the hatchery is included based on data from a leading producer of fertilized eggs sold to the salmon aquaculture industry. 0,005 kWh electricity/egg and 17 litre freshwater/egg were assumed. The process contributed < 0,02% to all impact categories.

Table 3-10 Data for juvenile production. The data is used to model fry/juvenile production for both salmonids and sea bass / sea bream.

Property	Unit	Value	Comment
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	It is assumed that 16 kWh electricity is required to dewater and dry the sludge to 90 % dry matter, and transported 500 km.
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.

[22] Greenhouse gas emissions of Norwegian salmon products
[23] In Norway more than 50 % of the sites for aquaculture production are connected to the onshore power grid. To have a conservative assumption, it was decided to assume only diesel use.
[24] SINTEF Open: Greenhouse gas emissions of Norwegian salmon products (unit.no)
[25] *idem*

3.2.5 Emission of feed nutrients to water

Emissions of feed nutrients to water either from fish farms in sea or at land are included by a mass balance model. The model and the factors going into the model are presented in the Excel file "Marine Fish PEFCR Feed emission mass balance model". Figure 3—1 illustrates the basic building blocks of the model.

For the production of juveniles in the RAS plant, a collection efficiency for particulates of 50 % was assumed.

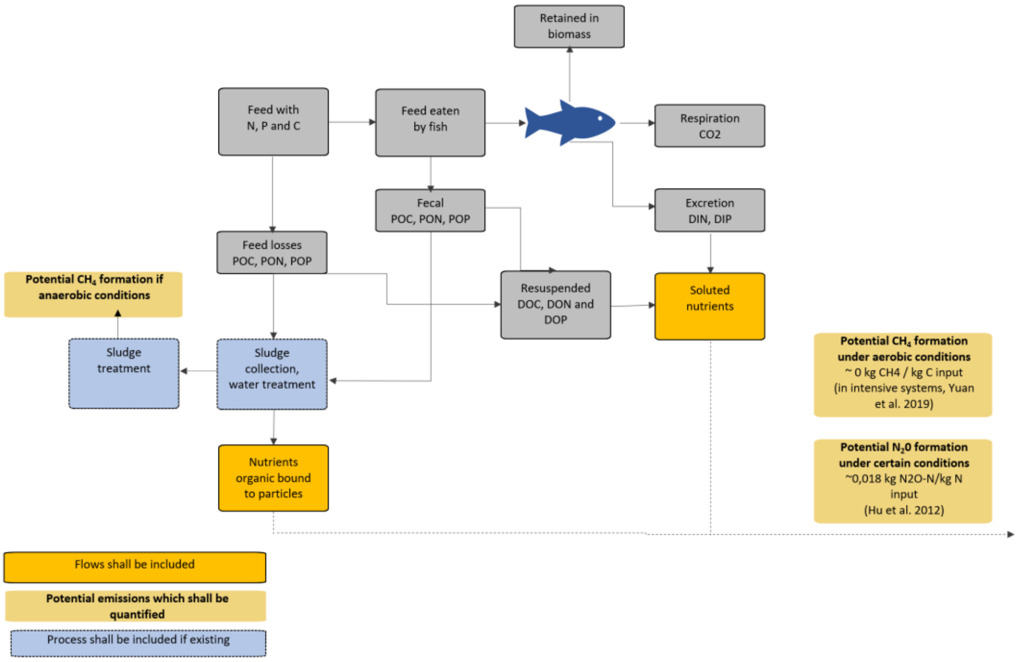

Figure 3—1 Feed nutrient mass balance model.

The subsequent potential degradation of carbon to methane emissions and nitrogen to N_2O because of accumulation under the net-pens is uncertain and depend on the specific conditions. The potential emissions are included based on factors in the feed emission model; where methane emissions are assumed to be zero, as anaerobic conditions are not likely occurring.

Carbon emissions from respiration is not included.

3.2.6 Antifouling production and emission from open net-pens

The net pens are treated using antifouling chemicals. These chemicals leave 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.

In the recent years copper-based treatments are to some degree replaced by other chemicals such as thioyanate, tralopyril, etc. The share of different chemicals is still unknown[26].

[26] Risk report Norwegian fish farming (2024) HAVFORSKNINGEN NR. 2024-4

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.

An estimate for the use of anti-fouling agents used per tonne lwe fish produced is done based on data from the Norwegian salmon farming industry. In 2013, 1 016 tonnes of copper were used to produce antifouling coatings for net pens in Norwegian salmon farms alone[27]. Fish production in 2013 was 1 239 876 tonnes, assuming a copper density of ca. 30% this yields a consumption of anti-fouling agents of ca. 2,5 kg/tonne lwe fish produced. Based on[28], the consumption is 3,5 kg/tonne lwe fish produced. Based on these estimates, 3 kg of anti-fouling chemicals is assumed per tonne lwe fish produced.

To model the production the EF 3.1 dataset "*Net impregnation chemicals {EU+EFTA+UK} | technology mix | production mix, at plant | Antifouling chemicals used for the impregnation of nets used in aquaculture. | LCI result*" was used.

Expert judgements state that 20-30% of the anti-fouling agents is collected by onshore washing of nets, while 80% is emitted to sea[29]. As the impact assessment method does not include marine ecotoxicity, emissions from the use of antifouling agents to sea are not included. This is listed under section 2.2.10 Data gaps and impact assessment gaps.

3.3 Preparation

Preparation is included for all products.

For all preparation, the following is included:

- Energy use (as in Table 3-11)
    - 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.
- 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
    - Wastewater flows. Emissions to water are modelled based on the upper limit from BAT-AEL

[27] O. Floerl, S. LM, and N. Bloecher, "Potential environmental risks associated with biofouling management in salmon aquaculture ," *Aquac. Environ. Interact.*, vol. 8, pp. 407–417, 2016.
[28] https://www.sciencedirect.com/science/article/abs/pii/S0044848615302568?via%3Dihub
[29] report-pdf

- Fish biomass that is not sold as a commercial product (a co-product) is included as a waste flow according to section 3.9.

Table 3-11 presents the energy use of the different preparation stages that are included.

Table 3-11 Energy use for preparation.

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/t fish input)	363	363	216	363	107
Electricity source	European average	European average	European average	European average	European average
Diesel fuel (l/t 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 market price is considered a waste flow and handled according to section 3.9.

Table 3-12 Wild fish yield and values at preparation. The yields are adapted based on SINTEF 2017[30]. The value ratios and the share of co-products utilized are based on expert judgements.

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 market price is considered a waste flow and handled according to section 3.9.

[30] report-carbon-footprint-norwegian-seafood-products-2017_final_040620.pdf (sintef.no)

Table 3-13 Farmed fish yield and value at preparation. Data is adapted based on[31]. For simplicity, the same value ratio is assumed for fillet/co-products and head on gutted/co-products. For sea bass and sea bream the same value ratios as for salmon is assumed in lack of data.

Property	**Unit**	**Salmonids**	**Bass and bream**
Yield in preparation	Live to head on gutted (kg fish out/kg fish in)	0,83	0,9[32]
	Live to fillet (kg fish out/kg fish in)	0,59	0,45
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	100:4

The yields, co-product utilisation and value ratios are highly important for the results. The parameters are set based on the best available data and inputs from industry experts.

All data for the preparation stage (consumption data, emissions, yields, co-product utilisation and value ratios) are subject to high uncertainty and considerable variability, which will affect the results.

Table 3-15 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[33] 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.

Table 3-14 Product state of commodity groups, data for 2021-2023. Data for sea bass and sea bream are estimated based on the following studies[34] [35]

Presentation and preservation		**Groundfish**	**Small pelagics**	**Tuna and tuna like species**	**Flatfish**	**Salmonids**	**Sea bass and sea bream**
Whole/gutted	Fresh	23 %	25 %	19 %	34 %	79 %	85 %
	Frozen	27 %	63 %	63 %	26 %	4 %	0 %
Fillet	Fresh	5 %	0 %	1 %	2 %	10 %	15 %
	Frozen	45 %	12 %	17 %	39 %	7 %	0 %

[31] Greenhouse gas emissions of Norwegian salmon products (unit.no)
[32] Indicative factors for converting product weight to live weight for a selection of major fishery commodities (fao.org)
[33] https://eumofa.eu/
[34] D5_4_approved.pdf (performfish.eu)
[35] WWF_supply_chain_study_2021_seabass_seabream.pdf (fishforward.eu)

3.4 Packaging

Transport and consumer packaging is included:

- Transport packaging. Two types: Expanded Polystyrene (EPS) box and cardboard box. "Small pelagics, frozen" are assumed transported in cardboard boxes, while all other products are assumed transported in EPS.
- Consumer packaging. Two types: Aluminium with plastic film lid and EPS with plastic film lid. Assume 50% aluminium and 50% EPS.

Table 3-15 Packaging data

Packaging	Description
Transport packaging: EPS	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 EF3.1 data "Polystyrene production, high impact {EU-28+EFTA} | polymerisation of styrene | production mix, at plant | 1.05 g/cm3 | LCI result" (UUID: 42affac5-a207-4ec5-bd7d-2dffd85ff50e) The waste handling of this box is included with the EF3.1 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)
Transport packaging: 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 EF3.1 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 EF3.1 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" and "Plastic film, PE wrap {EU+EFTA+UK} | raw material production, plastic extrusion | production mix, at plant | thickness: 25 um, grammage: 0,023575 kg/m2 | LCI result "(UUID: 52ce6985-95af-47f4-87a5-d60ebcf3341e
Consumer packaging: aluminium tray	A box of 30 g aluminium and 5 g PE packaging film holds 500 g fish. The EF3.1 dataset "Aluminium tray {EU+EFTA+UK} | primary aluminium production, processing of foil/ tray | production mix, at plant | 2.7 g/cm3 | LCI result" (UUID: c3c7f8ac-a88a-4bab-a0bc-d32e1cc1c5f4) and "Plastic film, PE wrap {EU+EFTA+UK} | raw material production, plastic extrusion | production mix, at plant | thickness: 25 um, grammage: 0,023575 kg/m2 | LCI result" (UUID: 0d2213f8-a115-4ce0-a1d9-0aa66aaf51ab) are used. End of life for the aluminium is recycling and for PE incineration.
Consumer packaging: EPS	A box of 50 g EPS and 5 g PE packaging film holds 500 g fish. EoL of the EPS and the PE is incineration.

In the transport, the mass that is transported (the transport work) takes into account the weight of the packaging and ice. The following factors were 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 Distribution

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 3-19. These preliminary distances are set based on the default data presented by the PEF method [1] in section 4.4.3.

Table 3-16 Transport scenario

Transport	Vehicles	Distance (km)	Dataset (all EF3.1)
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)

3.6 Retailer

The retail stage is included with data from the PEF method [1] and the retail OEFCR "Organisation Environmental Footprint Sector Rules (OEFSR) Retail" [15].
Data in Table 3-17 is shown for chilled products. For frozen products please refer to the values in retail OEFCR "Organisation Environmental Footprint Sector Rules (OEFSR) Retail" [15].

Table 3-17 Data per day the product is in the store and volume of the product in litre. Data is shown for chilled products.

Process	Unit	Value	Comment
Storage days, distribution and retailer	day	14	Retail OEFSR[36], chilled products
Storage volume per kg fish	litre storage volume/kg fish	4,5	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.
Electricity, retail and distribution	kWh/litre storage volume*day	0,00162	Annex[37]
Refrigerant 134a	kg/litre storage volume*day	7,95E-08	
Construction of refrigerator/cooling unit, retail/distribution/consumer	p/litre storage volume*day	8,70E-07	Data for construction of refrigerator in based on retail OEFSR. 20 kg iron, 1.5 kg aluminium, 7.8 kg compressor, 0.01 kg copper, 0.06 kg cables, 0.3 kg glass, 6 kg plastic, 1 kg oil, 4 kg insulating foam, 1.1 kg water, 0.04 kg pollutant (using mercury as proxy). Packaging: 4 kg cardboard, 0.5 kg plastic film, along with a 50 g paper notice

[36] https://wayback.archive-it.org/org-1495/20221006222603mp_/https:/ec.europa.eu/environment/eussd/smgp/pdf/OEFSR-Retail_15052018.pdf
[37] https://environment.ec.europa.eu/system/files/2021-12/Annexes%201%20to%202.pdf

Construction of chilled storage buildings, retail and distribution	m2/litre storage volume*day	5,48E-08	50 years lifetime. Can use EF datasets: Building, steel frame construction {GLO} | steel frame construction | single route, at plant | material quantities adjustable, 1 m3 gross volume = 125 kg | Unit process, single operation. 125 kg per gross m3. Assume 5 meters high = **625 kg per m2.**
Construction of chilled storage buildings, retail and distribution	m2/litre storage volume*day	1,10E-07	Modelled as paved area. Assuming a lifetime of 50 years.

3.7 Consumer

The consumer / use stage is included using the data provided in Annex D of the PEF method [1]. This includes chilled storage, cooking the fish and cleaning the cooking equipment. Table 3-18 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 3-18 Inventory data for the consumer use stage.

Process or input	Modelling
Product volume	The product volume is estimated to 4,5 litre per kg fish.
Transport from retail to consumer	The allocation shall be done based on the volume of the product divided by 0,2 m3 which is the size of the maximum volume and distance (5 km) from PEF annex II. 62% of the trips are done by car and 5% by van.
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.

3.8 Fish loss in distribution, retail and consumer

Table 3-19 presents the loss rates of products from distribution, retailer and at consumer. These rates are the default rates presented by the PEF method [1]. 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 and is added in addition to the non-edible parts. The yield from the different product forms to edible parts is presented in Table 3-20.

Table 3-19 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 3-20 Yield at consumer. Data adapted based on the following references[38] [39] [40]

Product (Commodity group)	Transformation	Value (kg fish out/kg fish in)
Salmonids, sea bass and bream	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

3.9 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=0. This leaves the CFF formula to:

$$E_V + R_3 (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) + (1-R_3)*E_d$$

Where the *E* values, *X* values and *LHV* values are extracted from the EF compliant datasets. Impacts and benefits of energy recovery is handled by the EF3.1 dataset used for incineration.

Ev is the virgin material input and is the specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.

[38] report-carbon-footprint-norwegian-seafood-products-2017_final_040620.pdf (sintef.no)
[39] Greenhouse gas emissions of Norwegian salmon products (unit.no)
[40] Indicative factors for converting product weight to live weight for a selection of major fishery commodities (fao.org)

The following scenarios are used for *R3*:

- Fish waste flows from distribution, retailer and consumer are modelled as going 55 % to landfill and 45% to incineration, based on average EU28 data provided in annex C of EF.3.1. R3 = 0,45.
- Fish waste flows from fishing, farming and preparation are modelled as going 100 % to incineration, based on TS expert judgement. R3 = 1.

3.9.1 Data used in the fish waste modelling

Landfill of fish waste is included with the EF3.1 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 waste. If all of this C is emitted as methane (CH4) the theoretical intensity is **0,224 kg** CH4/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 **0,175 kg** C / kg waste. This yield a potential of 0,23 kg CH4/kg waste, while the Emission of biogenic methane is 0,0196 kg CH4/kg waste based on the data set. This yields 8 % of the theoretical maximum and it is considered a fair assumption.

Incineration of fish waste is included with the EF3.1 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.

3.10 Electricity

All use of electricity is included with the EU+EFTA+UK grid mix and the EF3.1 data "Electricity grid mix 1kV-60kV {EU+EFTA+UK} | technology mix | consumption mix, to consumer | 1kV - 60kV | LCI result" (UUID: 34960d4d-af62-43a0-aa76-adc5fcf57246)

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 [1]:

- **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 relevant 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 categories of the EF3.1 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.

Main results are presented in this chapter. For full results, please refer to the Excel results file.

4.1 PEF results and analysis wild representative product

4.1.1 Normalised and weighted results wild representative product

Table 4-1 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	Value
Total	**µPt**	660
Acidification	µPt	44
Climate change	µPt	166
Ecotoxicity, freshwater	µPt	25
Particulate Matter	µPt	118
Eutrophication, marine	µPt	27
Eutrophication, freshwater	µPt	2
Eutrophication, terrestrial	µPt	40
Human toxicity, cancer	µPt	2
Human toxicity, non-cancer	µPt	8
Ionising radiation	µPt	4
Land use	µPt	7
Ozone depletion	µPt	5
Photochemical ozone formation	µPt	59

Resource use, fossils	µPt	132
Resource use, minerals and metals	µPt	2
Water use	µPt	18

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.

Impact category	Unit	Result absolute values	Result direct output
Acidification	mol H+ eq	4,06E-02	3,96E-02
Climate change	kg CO2 eq	5,95E+00	5,94E+00
Ecotoxicity, freshwater	CTUe	7,49E+01	7,49E+01
Particulate matter	disease inc.	7,92E-07	7,82E-07
Eutrophication, marine	kg N eq	1,81E-02	1,81E-02
Eutrophication, freshwater	kg P eq	1,31E-04	1,31E-04
Eutrophication, terrestrial	mol N eq	1,91E-01	1,90E-01
Human toxicity, cancer	CTUh	1,94E-09	1,91E-09
Human toxicity, non-cancer	CTUh	5,32E-08	5,32E-08
Ionising radiation	kBq U-235 eq	4,83E-01	3,49E-01
Land use	Pt	7,53E+01	7,52E+01
Ozone depletion	kg CFC11 eq	4,36E-06	4,36E-06
Photochemical ozone formation	kg NMVOC eq	5,01E-02	5,00E-02
Resource use, fossils	MJ	1,14E+02	1,03E+02
Resource use, minerals and metals	kg Sb eq	2,04E-06	2,04E-06
Water use	m3 depriv.	2,46E+00	2,46E+00

4.1.3 Most relevant impact categories wild representative product

Table 4-3 presents the impact categories identified as most relevant, 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 Most relevant impact categories for wild representative product

Impact categories	**% of normalised and weighted results**
Climate change	25 %
Resource use, fossils	20 %
Particulate Matter	18 %
Photochemical ozone formation	9 %
Acidification	7 %
Eutrophication, terrestrial	6 %
Sum of selected categories to total normalized and weighted result	**84 %**

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 relevant.

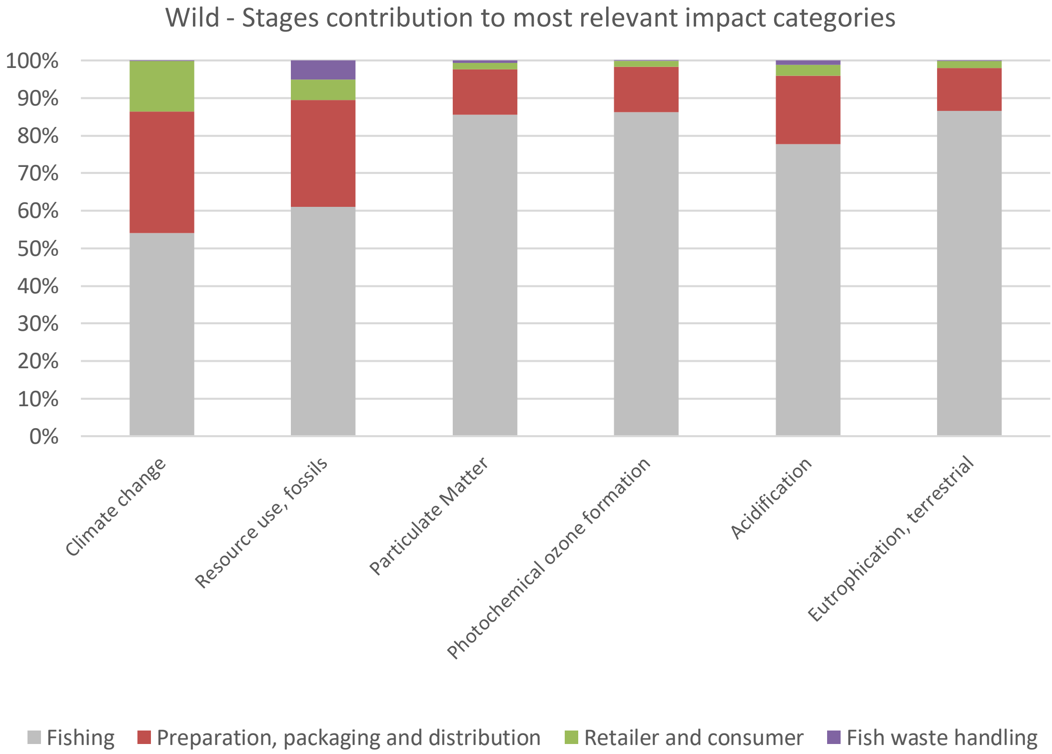

Figure 4—1 Contribution of each life cycle stage to the impact categories identified as most relevant, for the wild representative product.

4.1.5 Most relevant processes wild representative product

See table in the sheet “Wild RP results” in the Marine Fish PEF-RP Results file.

4.2 PEF results and analysis farmed representative product

4.2.1 Normalised and weighted results farmed 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	Value
Total	**µPt**	1774
Acidification	µPt	67
Climate change	µPt	392
Ecotoxicity, freshwater	µPt	371
Particulate Matter	µPt	113
Eutrophication, marine	µPt	361
Eutrophication, freshwater	µPt	21
Eutrophication, terrestrial	µPt	47
Human toxicity, cancer	µPt	10
Human toxicity, non-cancer	µPt	30
Ionising radiation	µPt	14
Land use	µPt	70
Ozone depletion	µPt	0
Photochemical ozone formation	µPt	45
Resource use, fossils	µPt	164
Resource use, minerals and metals	µPt	29
Water use	µPt	39

4.2.2 Characterised results of all EF impact categories farmed 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.

Impact category	Unit	Result absolute values	Result direct output
Acidification	mol H+ eq	6,13E-02	6,02E-02
Climate change	kg CO2 eq	1,41E+01	1,41E+01
Ecotoxicity, freshwater	CTUe	1,10E+03	1,10E+03
Particulate matter	disease inc.	7,64E-07	7,53E-07
Eutrophication, marine	kg N eq	2,38E-01	2,38E-01
Eutrophication, freshwater	kg P eq	1,22E-03	1,22E-03
Eutrophication, terrestrial	mol N eq	2,24E-01	2,23E-01
Human toxicity, cancer	CTUh	8,39E-09	8,36E-09
Human toxicity, non-cancer	CTUh	2,11E-07	2,11E-07
Ionising radiation	kBq U-235 eq	1,36E+00	1,21E+00
Land use	Pt	7,23E+02	7,23E+02
Ozone depletion	kg CFC11 eq	2,97E-07	2,97E-07
Photochemical ozone formation	kg NMVOC eq	3,83E-02	3,82E-02

Resource use, fossils	MJ	1,41E+02	1,28E+02
Resource use, minerals and metals	kg Sb eq	2,45E-05	2,45E-05
Water use	m3 depriv.	5,22E+00	5,22E+00

4.2.3 Most relevant impact categories farmed representative product

Table 4-6 presents the impact categories identified as most relevant 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 relevant categories for farmed representative product

Farmed most relevant impact categories	**% of normalised and weighted results**
Climate change	22 %
Ecotoxicity, freshwater	21 %
Eutrophication, marine	20 %
Resource use, fossils	9 %
Particulate Matter	6 %
Land use	4 %
Sum of selected categories to total normalized and weighted result	**83 %**

4.2.4 Most relevant life cycle stages farmed representative product

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

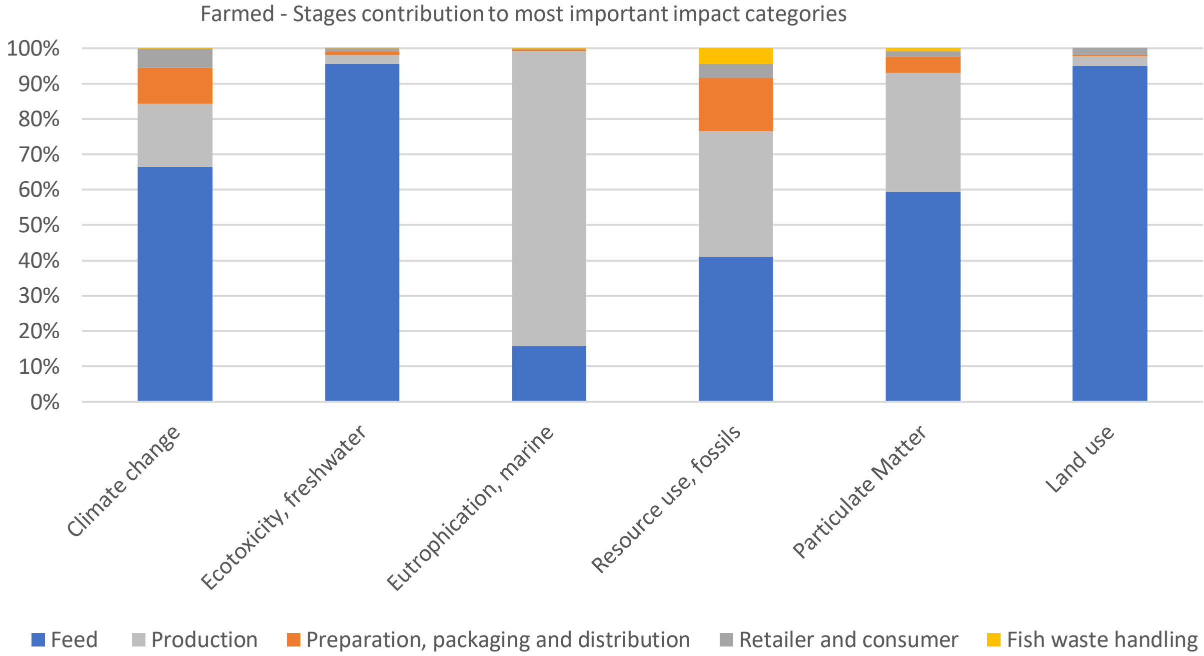

Figure 4—2 Contribution of each life cycle stage to the impact categories identified as most relevant, for the farmed representative product.

4.2.5 Most relevant processes farmed representative product

See table in the sheet "Farmed RP results" in the Marine Fish PEF-RP Results file.

4.3 PEF results and analysis marine fish representative product

The representative product for marine fish is a combination of the wild marine fish and farmed marine fish. The market shares shown in Table 2-4 are used, meaning that the marine fish RP is 78 % wild and 22 % farmed.

4.3.1 Normalised and weighted results marine fish representative product

Table 4-7 presents the normalised and weighted results per 1 kg consumed marine fish representative product.

Table 4-7 Normalised and weighted results for the marine fish representative product, all values per 1 kg consumed marine fish representative product.

Damage category	**Unit**	**Value**
Total	µPt	905
Acidification	µPt	49
Climate change	µPt	215
Ecotoxicity, freshwater	µPt	101
Particulate Matter	µPt	117
Eutrophication, marine	µPt	101
Eutrophication, freshwater	µPt	6
Eutrophication, terrestrial	µPt	41

Human toxicity, cancer	µPt	4
Human toxicity, non-cancer	µPt	13
Ionising radiation	µPt	6
Land use	µPt	21
Ozone depletion	µPt	4
Photochemical ozone formation	µPt	55
Resource use, fossils	µPt	139
Resource use, minerals, and metals	µPt	8
Water use	µPt	23

4.3.2 Characterised results of all EF impact categories marine fish representative product

Table 4-8 presents the characterised results per 1 kg consumed marine fish representative product.

Table 4-8 Characterised results for the marine fish representative product, all values per 1 kg consumed marine fish representative product. The "results direct output" presents the values before all flows are converted to absolute values.

Impact category	**Unit**	**Result absolute values**	**Result direct output**
Acidification	mol H+ eq	4,51E-02	4,41E-02
Climate change	kg CO2 eq	7,73E+00	7,73E+00
Ecotoxicity, freshwater	CTUe	3,00E+02	3,00E+02
Particulate matter	disease inc.	7,86E-07	7,76E-07
Eutrophication, marine	kg N eq	6,65E-02	6,65E-02
Eutrophication, freshwater	kg P eq	3,71E-04	3,71E-04
Eutrophication, terrestrial	mol N eq	1,98E-01	1,98E-01
Human toxicity, cancer	CTUh	3,36E-09	3,33E-09
Human toxicity, non-cancer	CTUh	8,79E-08	8,79E-08
Ionising radiation	kBq U-235 eq	6,76E-01	5,38E-01
Land use	Pt	2,18E+02	2,18E+02
Ozone depletion	kg CFC11 eq	3,47E-06	3,47E-06
Photochemical ozone formation	kg NMVOC eq	4,75E-02	4,74E-02
Resource use, fossils	MJ	1,20E+02	1,08E+02
Resource use, minerals and metals	kg Sb eq	6,98E-06	6,98E-06
Water use	m3 depriv.	3,07E+00	3,07E+00

4.3.3 Most relevant impact categories marine fish representative product

Table 4-9 presents the impact categories identified as most relevant, 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 4-9 Most relevant impact categories for marine fish representative product

Impact categories	**% of normalised and weighted results**
Climate change	24 %
Resource use, fossils	15 %
Particulate Matter	13 %
Ecotoxicity, freshwater	11 %
Eutrophication, marine	11 %
Photochemical ozone formulation	6 %
Sum of selected categories to total normalized and weighted result	**80 %**

4.3.4 Most relevant stages and processes marine fish representative product

See table in the sheet "Marine Fish RP results" in the Marine Fish PRE-RP Results file.

5 References

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6 Annexes

6.1 Annex 1: Commodity groups

The table shows the apparent consumption of wild marine fish per commodity group and species.

Commodity group	Species	Sum apparent consumption (tonne) 2020-2022
Flatfish	Brill	0
Flatfish	Dab	11535
Flatfish	Flounder, European	47681
Flatfish	Flounder, other	11559
Flatfish	Halibut, Atlantic	1480
Flatfish	Halibut, Greenland	0
Flatfish	Megrim	46866
Flatfish	Other flatfish	217930
Flatfish	Plaice, European	122664
Flatfish	Plaice, other	0
Flatfish	Sole, common	56824
Flatfish	Sole, other	15316
Flatfish	Turbot	12069
Flatfish	**Total**	**543924**
Groundfish	Alaska pollock	2265996
Groundfish	Blue whiting	66023
Groundfish	Cod	2275908
Groundfish	Grenadier	135614
Groundfish	Haddock	83119
Groundfish	Hake	1379403
Groundfish	Ling	46572
Groundfish	Other groundfish	260869
Groundfish	Pollack	13836
Groundfish	Pouting (=Bib)	18232
Groundfish	Redfish	207081
Groundfish	Saithe (=Coalfish)	480193
Groundfish	Whiting	39328
Groundfish	Total	7272174
Other marine fish	Cusk-eel	18340
Other marine fish	Dogfish	11129
Other marine fish	Gurnard	27867
Other marine fish	John dory	8240
Other marine fish	Monk	264080
Other marine fish	Other marine fish	631270
Other marine fish	Other sharks	158905
Other marine fish	Ray	64698

Other marine fish	Red mullet	45059
Other marine fish	Scabbardfish	17903
Other marine fish	Seabass, European	12090
Other marine fish	Seabream, gilthead	11166
Other marine fish	Seabream, other	82636
Other marine fish	Total	1353383
Salmonids	Other salmonids	25132
Salmonids	Salmon	193808
Salmonids	Trout	8610
Salmonids	Total	227550
Small pelagic	Anchovy	346842
Small pelagic	Herring	1328007
Small pelagic	Horse mackerel, Atlantic	63462
Small pelagic	Horse mackerel, other	58923
Small pelagic	Mackerel	742240
Small pelagic	Sardine	737942
Small pelagic	Sprat (=Brisling)	365260
Small pelagic	Total	3642676
Tuna and tuna-like species	Swordfish	117495
Tuna and tuna-like species	Tuna, albacore	118621
Tuna and tuna-like species	Tuna, bigeye	80176
Tuna and tuna-like species	Tuna, bluefin	60212
Tuna and tuna-like species	Tuna, miscellaneous	345684
Tuna and tuna-like species	Tuna, skipjack	2116305
Tuna and tuna-like species	Tuna, yellowfin	1208380
Tuna and tuna-like species	Total	4046873
Grand total		17086580

6.2 Annex 2: Review Panel

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.

Industry expert **Tom Maidment** graduated with a MEng degree in Automotive Engineering with Sustainability from the University of Warwick (UK) in 2017 and became a Chartered Engineer in 2022 with the Institution of Engineering and Technology. Mr. Maidment currently works for Hilton Foods as Group Product Sustainability Senior Manager (since 2021) and is an Associate at Oxford Net Zero (since 2023). Prior to this he worked at Jaguar Land Rover (2014-2021) on Environmental Lifecycle Assessment and before that in a number of product development roles and was Technical Director of E.Mission (2018-2023), a business which he founded to improve public understanding of the carbon footprint of food. During his career Tom has worked on a number of lifecycle assessment related projects across sectors including completing a lifecycle assessment for the production of insect derived livestock feed, developing a tool which used natural language processing to automatically calculate the carbon footprint of online recipes and supporting Seafish in the development of a carbon measurement tool.

6.3 Annex 3: Review Report

The suggestions from the Review Panel have been taken into consideration during the update of this report. The following review reports (Excel files) provide comments received and responses from the TS:

1) Review Reports for 1st Draft PEFCR and PEF-RP (August-October 2021)

2) Review Report for 2nd Draft PEFCR and PEF-RP (July-August 2024)

3) Review Report for Final Draft PEFCR and PEF-RP (October 2024)