Marine Fish PEFCR: Screening and recommendations

Authors

This is the Product Environmental Footprint (PEF) screening report that supports the development of PEF Category Rules (PEFCR) – Marine Fish for human consumption.

Members of the Technical Secretariat are EU and national associations (FEAP, FEFAC, EMPA, NSF), fish companies (Marine Harvest ASA, Pelagia AS, Norway Seafoods AS, Lucas perches, Leroy Fishcut and Marine Harvest, VAP – Boulogne) and SINTEF Fisheries and aquaculture (LCA consultant)

Contact info:

For questions regarding this report and the LCA work please contact: Erik Skontorp Hognes, mail: erik.hognes@sintef.no, phone: +47 40 22 55 77.

For questions regarding the ongoing work of developing a PEFCR for Marine Fish products please contact Henrik Stenwig, henrik.stenwig@sjomatnorge.no , phone: +47 91 82 00 72

Preface

The application applying for acceptance as a pilot as part of the Environmental Footprint (EF) pilot phase, was submitted in March 2014, and the Fish pilot was accepted as one of 11 pilots to be part of the 2nd wave of pilot cases in May 2014.
The motivation of the Norwegian Seafood Federation (NSF) to take an active role in the PEF pilot phase, was based on the preceding work regarding pilot testing of the ENVIFOOD Protocol by participating in a consortium established by FEFAC, on the ambition to make seafood visible in the PEF pilot phase and to show interest and initiative in the forthcoming policy making regarding the follow up of the building of a Single Market for Green Products.

Most of the financial resources to cover the costs of the Fish Pilot were granted by the Norwegian Seafood Research Fund (FHF - www.fhf.no/about-fhf) and by the NSF.

The work of the pilot
The work carried out by the Marine Fish pilot followed the time schedule according to *Guidance for the implementation of the EU PEF during the EF pilot phase* until the end of the first public consultation of the draft screening report and the first draft PEFCR. Due to various circumstances, the TS came to the conclusion that, due to lack of time, it would not be possible to finish the pilot in compliance with the Product Environmental Footprint Pilot Guidance in time. The TS is of course very disappointed by this, and we also regret that the TS will not be able to meet the expectations of the Environmental Footprint Team to the Marine Fish pilot.

However, we have achieved new knowledge, and we consider the work done as valuable experience that should be shared with Commission as well as the rest of the Steering Committee.
Based on this, we have prepared this report to the Commission and the Steering Committee for scrutiny, the aim being to give valuable input to the coming development of relevant policy, rules and regulations including PEFCRs for food based on aquatic organisms in general and more specific for products of marine fish, both wild caught as well as farmed.

The current report
Status of this report is based on the following:

- The public stakeholder consultation of the scope and representative product and the assessment of the alignment of existing Product Category Rules (PCR) which took place between November 4th 2014, and December 2nd 2014.
- The face-to-face consultation meeting held in Brussels on November 20th, 2014.
- The scope and the representative product definition approved by the Steering Committee meeting held on February 15h, 2015.
- The amended scope and the representative product approved by the PEF Steering Committee at the meeting the 18 November 2015. At the same time, the name of the pilot was changed to the PEFCR Pilot: Marine Fish for human consumption.
- The public consultation of a draft Screening Report and a draft PEFCR document from February 9th, 2016 to March 8th, 2016.

The screening study has been conducted according to the requirements of the PEF Guide (Annex II to Recommendation (2013/179/EU) and the Product Environmental Footprint Pilot Guidance (version no.5). There was no deviation regarding applied impact categories, except that, as additional information,

the screening includes the exploration of a new method to address biotic impacts from fishing on wild stocks in a PEF.
The current report is prepared on basis of the above mentioned process, but deviate from the formal requirements prescribed in the Product Environmental Footprint Pilot Guidance as it contains

- Results from the screening of caught marine fish and farmed marine fish, respectively
- Conclusions from the screening presented in one chapter
- Recommendations for Marine Fish PEFCR based on the above parts

Thus, the report presents a screening PEF of two products: One fished product and one marine net pen aquaculture product. The screening uses Norwegian data as a proxy, but these data is controlled and complimented with data from literature. Based on the results of these two screenings the report presents recommendations for what requirements a future marine fish PEFCR should contain and point out important issues that need to be solved for a Marine Fish PEFCR. This includes issues such as the development of fish LCI databases and the development of relevant impacts assessment methods. It is a major challenge that marine and ecological impact assessment methods are lacking or weak as of today. This report is not in full compliance with all the requirements for a PEFCR development (as described in the PEFCR guidance v 5.2).

One of the findings is that the lack of secondary data (LCI databases) for marine resources production systems makes it impossible for seafood producers and compound feed producer using marine resources to use the PEF method. As long as there are no relevant databases, that cover the numerous different technologies and regions that provide the EU market with marine resources it is impossible to reach the representability that is required to develop a PEFCR that cover the entire marine fish sector. It will also be impossible for producers to perform PEFS without the support of secondary data as primary data collection form complete life cycles will be both to costly and time consuming or, even, in practice, impossible.

EXECUTIVE SUMMARY

This report presents a Product Environmental Footprint (PEF) screening of two marine fish products, a fished product and one from aquaculture. Based on this screening and the collective competence of the Marine Fish Technical Secretariat a set of recommendations for a Marine Fish PEFCR is also presented.

The goal of the screening was to identify environmental hot spots and study methodical choices to provide recommendations for a product environmental footprint category rules (PEFCR) for marine fish products.

The assessment was performed from fishing and growing of crops for feed and up to where the fish is delivered to retailer - a cradle to gate assessment. The functional unit was 1 kg of edible fish. The impact assessment method used was the latest ILCD method.

The screening confirmed existing knowledge from LCAs and PEFs performed on seafood products. All life cycle stages are relevant, especially important is the fishing activities (for wild caught products), the feed production (for aquaculture products), the transport of the fish and packaging materials. The screening process highlight the need for development of better impacts assessment methods. As of today the established impact assessment method are weak at covering emissions to the marine environment and most important there are no established impact assessment methods to cover the different types of biotic impacts associated with marine fish production systems. One method to address biotic impacts from fishing is presented in this report.

The screening process identified several considerable challenges for the development of a sector wide PEFCR for marine fish products. The current guidelines for the development of a PEFCR require that all of the different productions systems constituting the sector have documented their life cycle inventor data (mass- and energy balances). Such databases does not exist for the marine fish sector. This lack is a challenge both for the development of a PEFCR and for the whole application of the PEF method within the seafood sector. A life cycle inventor database covering all of the different technologies, methods and regional differences should be established for the seafood sector.

Chapter 1 presents the background for this report and why this screening was performed
Chapter 2 presents the methodology used in the screening study
Chapter 3 presents the data that was used in the screening, the life cycle inventory
Chapter 4 presents the results of the screening and identification of environmental hots spots
Chapter 5 presents the conclusions from the screening
Chapter 6 presents the recommended requirements for a marine fish PEF

Table of Contents

List of tables

List of figures

Abbreviations and Units

COD	= Chemical Oxygen demand
DQA	= Data Quality Assessment
DQS	= Data Quality Score
EF	= Environmental Footprint
EFCR	= Economic Feed Conversion Ratio
ELCD	= European reference Life Cycle Database
EPD	= Environmental Product Declaration
ESP	= Expanded Polystyren
Feed Pilot	= PEF pilot feed for food producing animals
FEFAC	= European Feed Manufacturers Federation
GHG	= Greenhouse Gases
GWP	= Global Warming Potentials
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 Organization for Standardization
kWh	= kilowatt hour
LCA	= Life Cycle Assessment
LCI	= Life Cycle Inventory
LCIA	= Life Cycle Impact Assessment
LUC	= Land Use Change
NACE	= Statistical classification of economic activities in the European Community
NPK	= Nitrogen (N), Phosphorus (P) and Potassium (K)
OEF	= Organisation Environmental Footprint
OW	= One Way
PCR	= Product Category Rules
PEF	= Product Environmental Footprint
PEFCR	= Product Environmental Footprint Category Rules
RER	= Region Europe
RUaEP	= Resource Use and Emission Profile
ReCiPe	= Impact assessment method
Scope 1	= referring to the GHG protocol nomenclature, direct emissions
Scope 2	= referring to the GHG protocol nomenclature, emissions from purchased electricity, heat land cooling
SC	= Steering Committee
TS	= Technical Secretariat

1 Introduction

The background for this work is that the European Commission is proposing EU-wide methods to measure the environmental performance of products and organizations, and encouraging Member States and the private sector to take them up. Today, companies willing to highlight the environmental performance of their products have to choose between several methods promoted by governments and private initiatives. Providing environmental information often comes with high costs of mapping the environmental performance and developing communication means. Companies also face the distrust of consumers confused by too many labels with information that makes products difficult to compare.

The European Commission is proposing two methods to measure environmental performance throughout the lifecycle, the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF). They announced a three-year testing period to develop product- and sector-specific rules through a multi-stakeholder process, including provision for organisations with other methods to have them assessed as well. An open call for volunteers was published by the Commission, inviting companies, industrial and stakeholder organisations in the EU and beyond to participate in the development of product-group specific and sector-specific rules.

The Product Environmental Footprint methodology has been drafted by the European Commission's Joint Research Centre. The methodology is based on Life Cycle Assessment, thus basically covers the environmental impacts and point to improvement opportunities from the extraction of raw materials to the disposal of a product. The methodology was developed building on the International Reference Life Cycle Data System (ILCD) Handbook as well as other existing methodological standards and guidance documents. Product Environmental Footprint Category Rules (PEFCRs) aim at providing detailed technical guidance on how to conduct a product environmental footprint study for a specific product category. PEFCRs complement the general methodological guidance for environmental foot- printing by providing further specification at the product level. They will increase reproducibility and consistency of product environmental footprint studies.

1.1 Examples of other guidelines etc. for environmental assessment of seafood products

The guidelines for a PEFCR development require that it is studied if it already exist guidelines etc. for environmental assessment of the product that can be used as a starting point for a PEFCR. Our investigation concluded that it did not exist anything to use a as start for a Marine fish PEFCR, but some documents were found that are relevant, see Table 1-1.

Table 1-1 Documents providing guidance for LCA of fish and seafood products

Document	Type of document
BSI PAS 2050-2:2012 Assessment of life cycle greenhouse gas emissions[1].	This Publicly Available Specification (PAS), PAS 2050-2, contains requirements for the assessment of life cycle greenhouse gas (GHG) emissions specifically associated with seafood and other aquatic food products. The requirements are supplementary to those specified in PAS 2050:2011, which provides a generic method for assessing the life cycle GHG emissions of goods and services [1].
NS 9418:2013 Carbon footprint for seafood - Product category rules (CFP-PCR),	Developed by Standards Norway [2]. This is the only one published in Norwegian.
PRODUCT CATEGORY RULES ACCORDING TO ISO 14025:2006. PRODUCT GROUP: UN CPC 2124 FISH, OTHERWISE PREPARED OR PRESERVED; CAVIAR AND CAVIAR SUBSTITUTES[2]	This is a PCR document developed in the framework of the International EPD System, operating in accordance with ISO 14025:2006; 9001; 14001; 14040 and 14044. The International EPD® System is a system of voluntary environmental declarations applicable to any type of goods and services.

1.2 Relation between the Marine Fish Pilot and the Feed Pilot

Feed is known to be a major environmental aspect in the life cycle of aquaculture fish products [3-14]. This screening include feed based on the results from the Feed Pilot that develop a PEFCR for "feed for food producing animals"[15].

There are several reasons why feed production should be covered by its own PEFCR. One is to ensure future comparability between feed products used for food as beef, farmed fish, poultry and swine. Another reason is the complexity of global feed production systems. Modern feed production includes numerous different ingredients, established and emerging ingredients. To cover all of these different ingredients and all of their potential environmental aspects, according to the PEF guide, will require a wide-ranging set of rules.

The European feed and livestock industry faces the global challenge of meeting the growing global demand for animal and fish products with limited availability of resources and with the need to reduce pressure on the environment. LCA is acknowledged as a helpful tool in reducing the environmental impact of food producing animals. Feed has a significant contribution in the LCA impact of these animals and without a sound analysis of the feed environmental performance; it is difficult to draw robust conclusions from the LCA of any animal product.

The relative importance of feed in the environmental footprint of animal products also justifies the need to harmonize the methodology across all food producing animals. There is no reason to develop separate methodological approaches for the production of feed in lifecycle studies for pork, poultry meat, milk, fish etc. PEFCRs for food-producing animals should therefore use the same LCA method in relation to the feed that is used.

Measuring the impacts of the production of feed, as well as the feed performance on the farm is necessary in order to achieve meaningful LCAs of food-producing animals. The feed performance in terms of production per unit of feed is closely linked with farm management practices.

[1] Link to the BSI web page: http://shop.bsigroup.com/en/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2050/PAS-2050-2/
[2] Link to web page with the PCR: http://www.environdec.com/en/PCR/Detail/?Pcr=9006#.VEiz8PmsWQA

This basically means that to conduct an LCA at fish farm level, information is needed on the environmental impact of producing the feed and parameters of this feed are needed. The Feed PEFCR is meant to define the rules for deriving PEF compliant LCA information as an input for LCAs on food-producing animals. The Feed PEFCR is seen as a "module" to support the assessment of the environmental footprint of animal products in a harmonized "cradle to plate" way.

As a consequence of the cradle to gate approach chosen for the Feed pilot, the 'on farm' feed efficiency will have to be measured when conducting the LCA of animal products rather than predicted when assessing the feed. The marine fish pilot collaborates with the feed pilot in order to define the appropriate recommendations for this measurement.

Allocation is one example of a methodical choice that has to be harmonized between the PEFCRs for food products. One practical example is how the use of by-products from fisheries is treated when it is used in feed for aquaculture. Also how trimmings from fish farming are treated when used in feed for agricultural meat production.

For marine fish production that use feeds, the results from the Feed Pilot will be used to calculate the PEF of the feed input. At the same time the parts of the fish for human consumption that address fishing activities and fish preparation can be used by the Feed Pilot to guide their inclusion of marine ingredients, from reduction fisheries and by-products, to the feeds.

1.3 Intended product scope of screening and recommendations

The scope of this screening is marine fish for human consumption, in compliance with the adoption of the PEF Steering Committee on 18 November 2015.

With reference to the NACE/CPA classification, the goal is that this screening is representative for the following classes:

- 03.0 Fish and other fishing products
  - 03.00 Fish and other fishing products
    - 03.00.1 Fish, live
      - 03.00.12 Live fish, marine, not farmed
      - 03.00.14 Live fish, marine, farmed
    - 03.00.2 Fish, fresh or chilled
      - 03.00.21 Fresh or chilled fish, marine, not farmed
      - 03.00.23 Fresh or chilled fish, marine, farmed

In addition to these stages, also the following classes under C Manufactured products 10.20 Processed and preserved fish, crustaceans and mollusks will be covered:

- 10.20.1 Fish, fresh, chilled or frozen
  - 10.20.11 Fish fillets and other fish meat (whether or not minced), fresh or chilled
  - 10.20.12 Fish livers and roes, fresh or chilled
  - 10.20.13 Fish, frozen
  - 10.20.14 Fish fillets, frozen
  - 10.20.15 Fish meat, (whether or not minced), frozen
  - 10.20.16 Fish livers and roes, frozen

The products cover by the scope will be comprised by the definition of prepared fishery products as defined in Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin (OJ L 226, 25.6.2004, p. 22)

'*Prepared fishery products'* means unprocessed fishery products that have undergone an operation affecting their anatomical wholeness, such as gutting, heading, slicing, filleting, and chopping.

Products that are <u>not</u> included in the scope:

- 03.00.13 Live fish, freshwater, not farmed
- 03.00.15 Live fish, freshwater, farmed
- 03.00.22 Fresh or chilled fish, freshwater, not farmed
- 03.00.24 Fresh or chilled fish, freshwater, farmed
- 03.00.31 Crustaceans, not frozen, not farmed
- 03.00.32 Crustaceans, not frozen, farmed

- 03.00.4 Mollusks and other aquatic invertebrates, live, fresh or chilled
- 03.00.5 Pearls, unworked
- 03.00.6 Other aquatic plants, animals and their products
- 03.00.7 Support services to fishing and aquaculture
- 03.00.11 Live ornamental fish
  - 10.20.2 Fish, otherwise prepared or preserved
    - 10.20.21 Fish fillets, dried, salted or in brine, but not smoked
    - 10.20.22 Fish livers and roes dried, smoked, salted or in brine
    - 10.20.23 Fish, dried, whether or not salted, or in brine
    - 10.20.24 Fish, including fillets, smoked
    - 10.20.25 Fish, otherwise prepared or preserved, except prepared fish dishes
    - 10.20.26 Caviar and caviar substitutes
- 10.8 Other food products
  - 10.85.1 Prepared meals and dishes,
    - 10.85.12 Prepared meals and dishes based on fish, crustaceans and mollusks

This means that *processing* of marine fish is out of the scope.

Processing as defined in *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:*
'*processing*' means any action that substantially alters the initial product, including heating, smoking, curing, maturing, drying, marinating, extraction, extrusion or a combination of those processes;

In difference from '*unprocessed products'* which means 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;

For fish that goes into other types of processing than what is her included in *preparation* a Marine Fish PEFCR should work as a module for the life cycle from cradle to processing gate.

2 Screening: Method

2.1 Goal

The screening is intended as a preparatory step in a PEFCR development. The main aim is to identify hotspots in the life cycle of marine fish products, and thus understand what the most important life cycle stages are what should be included for a complete PEF of marine fish products. The intention of the screening is NOT to make statements about the product group impacts as such, nor is the intention to use the screening in the context of comparison or for comparative assertions to be disclosed to the public.

The target audience is limited, and determined in line with the goal of this screening study. Thus, the study is intended for the European Commission, the members of the Technical Secretariat of the Marine Fish PEF pilot, the stakeholders registered at the Wiki page of the PEF pilot and the Steering Committee of the Environmental Footprint pilot initiative from the European Commission (including reviewers).

The objective of the screening is to pre-identify the following key information:

- Most relevant life cycle stages;
- Most relevant processes and elementary flows;
- Preliminary indication about the most relevant life cycle impact categories;
- Data quality needs;
- Preliminary indication about the definition of the benchmark for the product category/sub-categories in scope.

2.2 Functional unit

What:	Marine fish products for human consumption and the packaging needed to deliver 1 kg edible product to the retailer
How much:	1 kg edible marine fish
How good:	The product should be appropriate for human consumption
How long:	For products where durability or shelf-life is established

2.3 Explanation of different subdivisions of the screening model/life cycle

In the explanation of the model and the presentation of the results, different conceptions are used to specify what parts of the life cycle/model that is addressed:

- The system boundaries define what part of the life cycle of the product that is included in the assessment

- The part of the life cycle that is covered by the system boundaries are broken down into: 1) life cycle stages and 2) processes. One life cycle stage will typically consist of several processes, e.g. the life cycle stage "distribution" can consist of processes such as "transit of truck" and "production and end of life treatment of transport packaging".

- Further, all of the process that construct the model of the life cycle is divided into a foreground- and a background system.

2.4 System boundaries

The screening covers the life cycle of the products from fishing and feed production and up to the stage where the fish is delivered to retailer. The retailer and stage is also included in a sensitivity study. This system boundary is indicated in Figure 2-1. In this screening feed production is included only with the results from the Feed Pilot, please refer to chapter see chapter 1.2 for the relationship to the feed pilot.

The screening divides the life cycle of the fish product into the following stages:

- Production: Fishing, feed production, aquaculture juveniles production and aquaculture grow out
- Preparation: Gutting, filleting and refrigeration
- Distribution: Transport from preparation to retailer and packaging materials

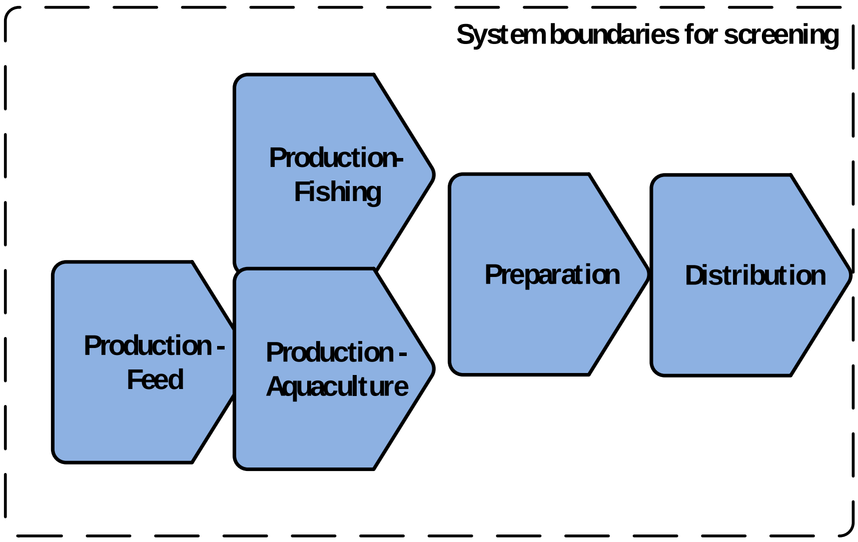


Figure 2-1 System boundaries for PEFCR Marine Fish for human consumption.

2.5 Screening cases

The screening is performed for two different seafood production systems:

A. 1 kg edible product from open pen marine fish aquaculture represented by Norwegian salmon production. Preparation in Norway and consumption in Europe (Figure 2-2). All transport on road.
    - ➢ Starts with juvenile production in a water recycling system. Feed is included with characterized data from the Feed Pilot [15]. Live fish from the fish farm is transported with well boat to preparation where head on and gutted salmon is produced. By-products are stored intermediate as ensilage and later utilized for other products. The head-on-gutted fish is transported fresh (in EPS boxes with ice) to retailer in Europe where skin and boneless fillet is produced by the retailer. Cut-offs etc. from this filleting is not utilized and considered a waste flow. The results for a case where the by-products are utilized is also presented.

B. 1 kg edible product from demersal and pelagic fisheries. Norwegian data used as a proxy and adjusted with data from other big fisheries. Preparation in Norway and consumption in Europe. All transport on road and sea (Figure 2-3).
    - ➢ The demersal fish enters preparation head off and gutted. Assumed that head and guts from demersal fisheries are not utilized, but this might vary between vessels and catches. At preparation the head off and gutted fish is filleted to skin and boneless fillet and by-

products. By-products are stored intermediate as ensilage and later utilized for other products. Fresh fillet transported in EPS boxes to retailer in Europe on road.
- The pelagic fish is landed round and is then filleted and frozen. By-products go directly to meal/oil production and utilized for other products. Frozen fillets are transported in card board boxes to retailer in Europe with boat.

The fish mass balance for each case correspond to the yield and loss rates presented in Table 2-1.

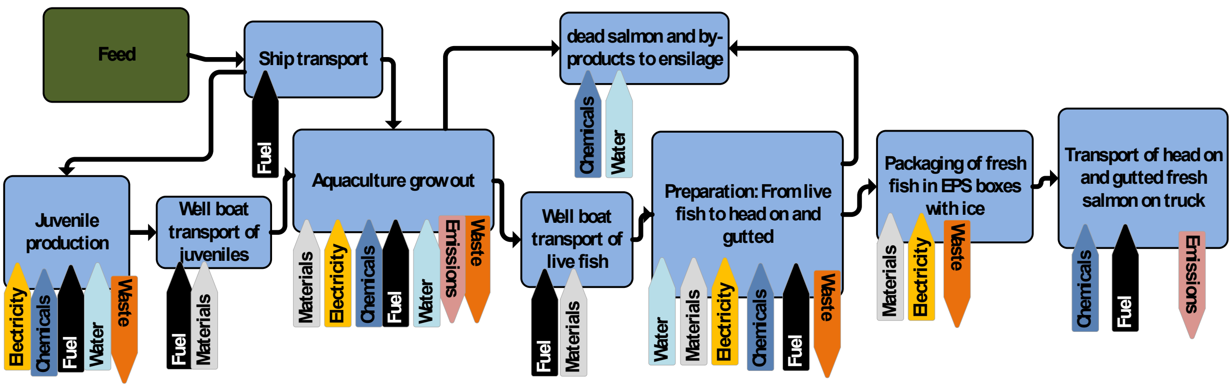


Figure 2-2 Flow sheet for aquaculture case

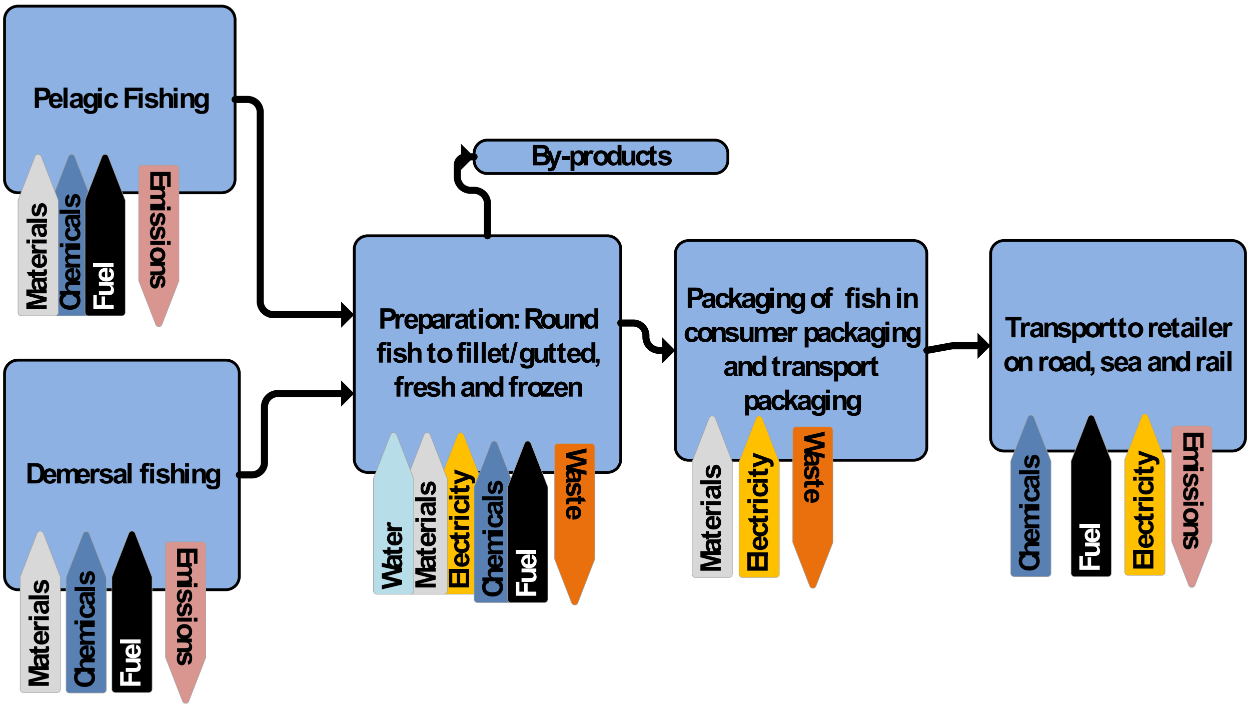


Figure 2-3 Flow sheet fished case

2.6 Allocation procedure for multi-functionality

According to ISO 14044:20065, the PEF guidelines and ENVIFOOD protocol, when co-product allocation is required, the allocation method should be selected based on the following hierarchy:

- Step 1. Allocation should be avoided by 1) dividing the unit processes to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or by 2) expanding the product system to include the additional functions related to the co-products.
- Step 2. The inputs and outputs should be partitioned between each of its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products of functions delivered by the system.
- Step 3. Other relationships, including economic allocation. According to the EVIFOOD protocol, economic allocation shall be used as a default option in Step 3 using a price average over a three year period.

Mass allocation is used as the default option in this screening, but the effect of economic allocation is also shown. Where generic data from the Ecoinvent database is used economic allocation is inherent in that data. As the Feed Pilot has primarily used economic allocation as the default option for feed in the screening study, but also applied mass allocation, this will be done in the current screening study.

The screening is based on the assumption that all intestines, cut offs etc. that are produced in preparation plants (or not at fisher, retailer or consumer) are somehow utilized. Many marine fish products are distributed to retailer and consumer as gutted-head-on or round, then these parts of the fish will not be utilized, therefore they are not considered by-products, but waste.

Table 2-1 Fish mass flow: Yields

Marin open pen product	Round salmon to head on and gutted	0,83
	Head on and gutted salmon to skin and boneless fillet	0,54
Demersal product	Round demersal fish to head off and gutted	0,75
	Head off and gutted demersal fish to skin and boneless fillet	0,60
Pelagic product	Round pelagic fish to fillet	0,50

2.7 End of life modelling of packaging materials

The Resource Use and Emissions Profile (RUaEP) - or End Of Life (EOL) formula - was considered useful for the different packaging materials that are used in the fish life cycles. Thus it was investigated if it was possible to find the necessary data and parameters this formula includes. For the end of life of the fish product itself the EoL approach was not considered useful since there is no type of recycling (generation of by-products is handled through allocation). The fish that is lost is waste and this waste treatment is included with data from the EcoInvent database, see chapter 3.18.

This investigation showed that with the current availability of data and parameters for the relevant packaging materials the use of the EoL formula was not viable. Together with the PEFCR help desk and Pre consultants the Ecoinvent and ELCD database was investigated, but it was not found data that made it possible to use the complete RUaEP formula. To cope with this data gap a Packaging Working Group was established as a part of the PEFCR pilot: "The goal of the Cross-cutting Packaging Working Group (PWG) is to provide guidance on packaging related modelling and data issues in the running Environmental Footprint pilot phase". Until better data is available it was concluded that the safest way was to make some simple assumptions: All packaging material inputs was modelled with the data considered most reliable (and thus with the input of virgin and non-virgin materials inherent in that data set). The end of life treatment of the materials was modelled with data on the treatment of municipal waste. This approach means that this screening does not include any credits from the potential substitution of materials and energy that can be achieved if the packaging materials go to energy- and material recovery. Thus the results connected to packaging materials should be considered worst case and this contribution can be considerably lowered if good recycling is achieved.

2.8 Data quality, uncertainties, value judgements and assumptions

The following lists assumptions, value judgments and data gaps that are important for the outcome of the screening

- As a general rule Norwegian data is used as a proxy for this screening.
- The impacts that are addressed in the assessment are those covered by the ILCD method, thus this screening does not cover all known environmental impacts of marine fish life cycles.
- Electricity is not modelled specific to the region where it is used. All use of electricity in the foreground system is modelled with data from Ecoinvent (v3) on European electric production and distribution mix. See chapter 3.17.

- Water inputs are not regionalized, thus water depletion models are not precise. See chapter 3.16.
- It is assumed that all cut offs, intestines and etc. from the preparation of the fish is somehow utilized and these flows are considered by-products and not waste.
- Assumption and uncertainties specific for each unit processes are described in the description of the life cycle inventory (chapter 3).

2.8.1 Comments on the use of Norwegian data as a proxy

Today it does not exist comprehensive databases with inventory data from seafood production systems. In this screening Norwegian marine fish production systems are used as a proxy. The consideration of the Marine Fish Pilot TS is that this is a robust approach to reach the main goals of the screening, except the ones of benchmarking. We repeat these goals (also presented in chapter 2):

The objective of the screening is to pre-identify the following key information:

- ***Most relevant life cycle stages;***
- ***Most relevant processes and elementary flows;***
- ***Preliminary indication about the most relevant life cycle impact categories;***
- ***Data quality needs;***

When considering the robustness of this approach it is utterly important to keep in mind what the ILCD can actually translate into environmental impacts. The PEF assess the sum of material and energy in- and outputs. What actually happens between what goes in and out is not important, as long as the mass- and energy balances are maintained. This is often referred to as the black box thinking of LCA. This means that even though there are obvious differences in how both fishing (including the choice of fishing gear) and aquaculture is performed, these differences are not captured by the PEF unless they are reflected in significantly different types and amounts of material and energy in- and outputs.

Table 2-2 The proportion of the Norwegian export out of the total EU volumes[3]

	Exported from Norway to EU	Total EU market tonne	% of market covered by Norwegian export
Marine aquaculture fish	650 581	**1 113 546**	58
Demersal fisheries	523 414	**3 979 346**	13
Pelagic fisheries	340 972	**3 236 771**	11

2.8.2 Fishing

Fishing technologies range from artisanal fisheries with relatively primitive lines and spears up to ocean-going ships that carry the most modern engines, hull designs and ICT systems that marine technologies can offer. These vessels can also process the fish on board and deliver products ready for consumption as they enter shore.

There are many ways of dividing fisheries into different groups but two of the most important are the pelagic and demersal fisheries.

- Pelagic fisheries target species that live in the pelagic zone, in the middle of the water body of oceans and lakes. These species typically live in schools.
- Demersal fisheries target species living close to the sea floor; a typical example is cod.

[3] Source of Norwegian export statistics: The Norwegian Seafood Council (http://en.seafood.no/News-and-media/Key-figures)

Further pelagic and demersal fishers can be divided into ocean-going fleets and coastal fleets, depending on what areas the vessel is equipped, designed and allowed to operate in.

The Fisheries and aquaculture department of the FAO provides the following categories of fishing gears[4] (the links leads to individual fact sheets on each gear). It is developed as an international Standard Statistical Classification of Fishing Gear (ISSCFG)[5].

- Surrounding nets (including purse seines)
- Seine nets (including beach seines and Boat, Scottish/Danish seines)
- Trawl nets (including Bottom: Beam, Otter and Pair trawls, and Midwater trawls: Otter and Pair trawls)
- Lift nets
- Falling gears (including cast nets)
- Gillnets and entangling nets (including set and drifting gillnets; trammel nets)
- Traps (including pots, stow or bag nets, fixed traps)
- Hooks and lines (including hand-lines, pole and lines, set or drifting longlines, trolling lines)
- Grappling and wounding gears (including harpoons, spears, arrows, etc.)
- Stupefying devices

The most important gears, based on their share of European fisheries, are the different types of surrounding nets, seine nets, trawls, gillnet and lines.

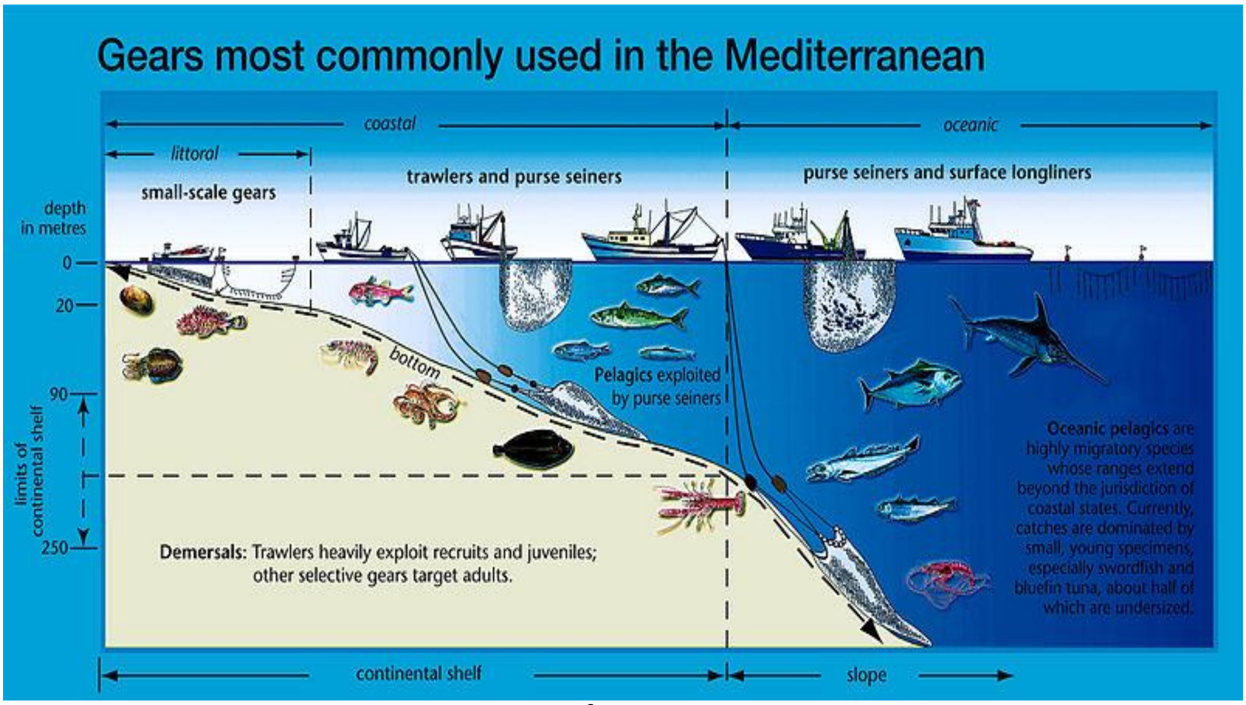


Figure 2-4 Illustration of various important gears[6]

What the PEF can capture today is materials and energy going into the fishing vessel together with the outputs these inputs are translated to: Emissions to air and water, generation of waste and delivered

[4] Link to web page: www.fao.org/fishery/topic/1617/en
[5] Link to web page: www.fao.org/fishery/cwp/handbook/M/en
[6] https://en.wikipedia.org/wiki/File:Mediterran_fishing_gear.jpg#filehistory

product together with packaging. However, if one consider that biotic impacts on how the fishery is performed is important, we present a novel approach to include this, but today none of the methods included in the ILCD method include these environmental aspects. Thus, concerning the fishing gear itself, Figure 2-4above also illustrates that, except from the material of the gear itself, the environmental impacts that can be assessed by the ILCD method, can only be measured by the emissions and energy use of the vessel. However, the gears involved might have significantly influence on the emissions and energy use during the fishing. The screening, as basis for the drafting of the PEFCR, will therefore focus on the performance of the vessels, but the recording of the kind of gear actually used, will always be important. In spite of the fact that there are a large numbers of different fishing gears used, their effect on the impacts assessed by the current ILCD method, can only be assessed indirectly by recording of the emissions and energy use of the vessel using the specific gear. However, there are several environmental impacts that are directly linked to the gear itself irrespective of the vessel used (example bottom trawlers versus surrounding nets or longlines and their potential impact on the benthic biodiversity), but the specific impacts of these gears are not captured by the ILCD method or any other well established impact assessment methods (see section 3.12). Based on this, we argue that Norwegian demersal and pelagic, high sea and coastal, fisheries involve the same major in- and outputs as any other fishery. And thus that using Norwegian data as a proxy is a robust approach for the above presented goals.

2.8.3 Aquaculture

Equal to fishing the environmental aspects of aquaculture that can actually be captured by the ILCD method are only the ones associated with the materials and energy going into the aquaculture processes together with the outputs these inputs are translated to: Emissions to air, water and ground; generation of waste and delivered product together with packaging. The current PEF and ILCD methods will not capture the impacts that are actually different from one marine aquaculture system to another. We argue that Norwegian marine net pen aquaculture systems include the same major material and energy in- and outputs as any other marine aquaculture system. Thus the use of Norwegian data as a proxy is a robust approach for the above presented goals.

2.9 Data sources and data gaps

It does not exist any available databases with relevant data for fish PEF/LCAs and thus this screening is based on the collection of primary data.

Data used and data gaps are presented in detail for each unit process in chapter 4. Some general remarks:

- To model the foreground system, data was gathered from Norwegian industry actors; research projects; public surveys; industry organisations and journal articles
- To model the input of commodities; capital investments and infrastructure to the foreground system: The EcoInvent database (v3 recycled content) and the ELCD v3.0 (European reference Life Cycle Database).

2.10 Impact assessment method

The ILCD 2011 Midpoint + method (v1.09)[7] was used for the impact assessment, the 15 impact categories that were used are presented in Table 2-3. More detail on this set of impact assessment methods can be found in the document "International Reference Life Cycle Data System (ILCD)

[7] Method released by the EC and JRC 08.06.2016 (http://eplca.jrc.ec.europa.eu/?page_id=140). Imported to Simapro with datafile distributed by Pre consultants.

handbook Recommendations for Life Cycle Impact Assessment in the European context" by European Commission - Joint Research Centre (2011)[8].

Table 2-3 ILCD v1.07 impact categories[9]

Impact category	Recommended default LCIA method	Indicator	Classification
Climate change	Baseline model of 100 years of the IPCC	Radiative forcing as Global Warming Potential (GWP100)	**I**
Ozone depletion	Steady-state ODPs 1999 as in WMO assessment	Ozone Depletion Potential (ODP)	**I**
Human toxicity, cancer effects*	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTUh)	**II/III**
Human toxicity, non-cancer effects*	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTUh)	**II/III**
Particulate matter/Respiratory inorganics	RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007	Intake fraction for fine particles (kg PM2.5- eq/kg)	**I**
Ionising radiation, human health*	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	Human exposure efficiency relative to U235	**II**
Photochemical ozone formation	LOTOS-EUROS (Van Zelm et al, 2008) as applied in ReCiPe	Tropospheric ozone concentration increase	**II**
Acidification	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	**II**
Eutrophication, terrestrial	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	**II**
Eutrophication, aquatic	EUTREND model (Struijs et al, 2009b) as implemented in ReCiPe	Fraction of nutrients reaching freshwater end compartment (P)/ marine end compartment (N)	**II**
Ecotoxicity (freshwater)*	USEtox model, (Rosenbaum et al, 2008)	Comparative Toxic Unit for ecosystems (CTUe)	**II/III**
Ecotoxicity (terrestrial and marine)	No methods recommended		
Land use	Model based on Soil Organic Matter (SOM) (Milà i Canals et al, 2007b)	Soil Organic Matter	**III**

[8] European Commission - Joint Research Centre. 2011. International Reference Life Cycle Data System (ILCD) Handbook Recommendations for Life Cycle Impact Assessment in the European context. First edition November 2011. EUR 24571 EN. Luxemburg. Publications Office of the European Union; 2011

[9] Pre consultants database manual on impact assessment methods: https://www.pre-sustainability.com/download/DatabaseManualMethods.pdf

Resource depletion, water*	Model for water consumption as in Swiss Ecoscarcity (Frischknecht et al, 2008)	Water use related to local scarcity of water	**III**
Resource depletion, mineral, fossil and renewable* *	CML 2002 (Guinée et al., 2002)	Scarcity	**II**
Levels: “I” (recommended and satisfactory), level “II” (recommended but in need of some improvements) or level “III” (recommended, but to be applied with caution); “interim” indicates that a method was considered the best among the analysed methods for the impact category, but still immature to be recommended. * See chapter 2.10.1 on impact categories that are not considered sufficiently reliable.			

2.10.1 ILCD impact categories not considered sufficiently reliable

The PEFCR guidance document (v5) and Annex B, chapter B.6 on Benchmark and classes of environmental performance point out that some of the 15 impact assessment methods are currently not sufficiently reliable for the use in communication of single scores and may be excluded for this purpose. These categories are:

- **human toxicity - cancer effect**
- **human toxicity - non-cancer effect**
- **ecotoxicity for fresh water**
- **water depletion**
- **resource depletion**
- **ionizing radiation HH**
- **land use**

2.11 Data quality assessment

The PEFCR guide require that a semi-quantitative data quality assessment is performed according to the PEF guide chapter 5.6 [16] and chapter 3.5 in the PEFCR guide: "The PEF screening can be based on readily available generic data (life cycle inventory databases, e.g. from commercial databases) fulfilling the data quality requirements as defined in the most updated version of the PEF Guide. In particular, for the screening step a minimum “fair” quality data rating is required for data contributing to at least 90% of the impact estimated for each EF impact category, as assessed via a qualitative expert judgement".

The screening presented here have not gone through a complete data quality assessment according to these requirements.

This qualitative expert judgement is also described in the PEFCR pilots wiki page, the steps to follow are :

1. Sort the datasets for each EF impact category according to their impact contribution, from the biggest contribution to the smallest

2. Identify the group of datasets that together contribute to at least 90% of the total results of each EF impact category, starting from the datasets with the highest contribution.

3. Assess the data quality of the datasets identified via qualitative expert judgment from very poor to very good (very poor, poor, fair, good, very good), taking into account the data quality criteria of table 3 in the PEF/OEF guide (chapter 5.6 in the PEF The expert can be the practitioner of the PEF screening study. The quality criteria are (table 3 and chapter 5.6 in the PEF guide [16]):
    - Technological-, Geographical- and Time-related representativeness
    - Completeness
    - Parameter uncertainty
    - Methodological appropriateness and consistency

4. If each dataset is at least “fair” quality then data quality requirements for the PEF/OEF screening are met

5. If not, refine the data collection to meet the “fair” quality level OR identify for each EF impact category the following datasets with large contribution (some datasets not considered initially at step 2) to complete at least 90% of the impact and repeat the exercise

The overall data quality, the Data Quality Rating (DQR), is calculated by summing up the achieved quality rating (from 1-5 where 1 is very good and 5 is very poor) for each of the quality criteria, divided by the total number of criteria (i.e. six). Fair quality means an average DQR of less than 4.

3 Screening: Life cycle inventory analysis

This chapter describes the data/processes used in the screening model. Each unit process is presented with: Description of the process; data collection procedure; quantified mass and energy in- and outputs (inventory results); assumptions and data gaps.

3.1 Marine net pen fish farm: Construction and operation

The biological life cycle of farmed fish starts with the brood stock and production of roe, then hatching and growth via the juvenile stage (which is “smolt” in salmonids) to the "grow out" phase until slaughter. Fish farming, also known as "grow out", is here defined as the process where the salmon is grown from smolt, typically weighing 100 – 150 gr, to salmon ready for slaughter at around 4-5 kg. This grow out is undertaken during a period of 18 months, one production cycle. Between each production cycle the farming location will rest for at least 2 months.

The fish farming consists of numerous different activates, some of them are:

- Net operations: Mounting the fish farm, maintaining and exchanging nets, cleaning nets, moving equipment from one farm site to another, inspection and repair. Net is operated during several of the following activities.
- Feeding the fish, this is now a highly automated process. Includes receiving and storing of feed
- Vaccination of the fish.
- Various treatments adapted to the diseases that occur.
- Receiving and storing feed.
- Removal of dead fish.
- Harvest of fish ready for slaughter. This process involves use of the well boat.

Many of these activities, and often the most energy intensive ones, are not performed by the farming company, but sub-contractors that operate on numerous different production sites. This makes it difficult to connect their activities to the mass of salmon produced (the functional unit).

Fuel is used to operate the fish farm, mainly generation of electricity to run feeding robot, other electric systems, lightning and fuel to transport of personal and goods between the site in the sea and the corresponding base/contact spot of the company on land. Based on reports from Norwegian companies this **fuel consumption was included with 13,3 litres of diesel per tonne of salmon produced in live weight**.

Net operation was included based on a scenario describing the activities and their frequency in a typical production cycle. This scenario was developed with an expert panel from the biggest salmon producers and their equipment suppliers and sub-contractors. Once theses scenario was defined the energy, material and chemical inputs associated with them was estimated through data on the fuel consumption used in the net operations; interview with net producers (they also perform cleaning and impregnation of the nets) and suppliers of the other equipment used in the open pen fish farm.

Important assumptions in this scenario was:

- Economic feed factor of 1,2. One tonne of salmon in live weight is sold per 1.2 tonnes of feed delivered to the farm
- Production performed in open net cages with a circumference of 60 m and depth of 20 meters (30 m in the centre). Giving a net surface of 5390m2. The nylon net material weigh 300-500 gr/m2.
- Each net can contain a maximum number of 200 000 fish and never a biomass of more than 780 tonne of fish. This means that each net can handle 1 salmon farming licence. It is assumed that the salmon farmer continuously grade and harvest the fish and that each production cycle (18 months) yield 1 200 tonne of fish in live weight. How much fish that is produced per production cycle is depending on the strategy of the producer and losses. 1 200 tonne per production cycle per licence is considered to be representative for the biggest and most efficient producers, but some achieve up to 1 300 tonne and more.
- The nets are cleaned once per month in water and disinfected, dried and impregnated/coated between each production cycle.
- Other than the net steel, concrete and steel for the floating ring and mooring was included. For a 160 m circumference net: 15 000 kg PP plastic; 5 900 kg Chromium steel; 5 250 kg reinforcing steel; 2 322 kg PE plastic. Waste treatment for each of these materials was included with Ecoinvent data on PE, PP and steel and iron recycling.
- Life time of equipment other than the net 10 years
- Each production cycle uses two nets, one smolt net and one grow out net
- Each net is inspected with diver once per month

Equipment or capital investments that were not included in the fish farm model:

- The feeding system and the barge, due to lack of data.

Emissions to water of nitrogen, phosphorus, dissolved organic carbon and carbon from the salmon cage was included with emission factors found in the paper [Wang et al 2012]. This paper provided data to give the following emission (to water) factor as a function of the feed efficiency (the EFCR):

- Nitrogen: EFCR*0,072*0,62
- Phosphorus: EFCR*0,012*0,7
- Dissolved Organic Carbon: EFCR*0,51*0,03
- Carbon: EFCR*0,51*0,19

Emissions of net impregnation chemicals was included with data from SINTEF report (SFH80 A066083): In 2004 total input of copper to the Norwegian salmon aquaculture industry was 250 tonnes, here it is assumed that this input is in the form of Cu_2O. The same year this industry produced 600 000 tonnes of salmon and trout. This gives a input factor of 0,41 kg Cu/tonne fish. Further it is assumed that 20-30% of this cupper is retrieved by the onshore net cleaning. In addition to this it is assumed that the feed emit 16 mg/kg feed [17] [Wang et al 2012]. These data on Cu emissions from the net to the water was controlled against data gathered for an Aquaculture Stewardship Council (ASC) certification of two production sites (2014 data). Her two nets that had been used 15 months and cleaned (in water) with high pressure 16 times showed a Cu content of 9 200 – 11 000 mg Cu/kg net material (0,92-1,1w%), the

content in freshly content nets are typically 8,5%. Thus around 7,5% of the Cu in the nets are lost at sea. With the case above was used, this gives that for a net weighting 2,7 tonne and loosing 7,5 w% of the CU over a production cycle yielding 1 2000 tonne salmon, the emission factor would be 0,17 kg CU per tonne salmon produced in live weight.
In this analysis an emission factor of 0,31 kg Cu per tonne salmon produced in live weight.

Fish farming can also include emissions of chemicals from treatment of parasites. This screening includes the input and emissions of peroxide. Data from Marine Harvest (Figure 3-1) was used: **24,1 litres peroxide per tonne fish produced.** Production of the peroxide is modelled with the Ecoinvent data "Hydrogen peroxide without water in 50% solution state". This data is per kg and it is assumed that 1kg = 1liter.

LICE MEDICINE USE: ACTIVE SUBSTANCE (GRAM OR LITER)
PER TONNE BIOMASS PRODUCED

	ORAL (G/T)	TOPICAL (G/T)	PEROXIDE (LTR/T)*
2011	3.5	2.0	2.8
2012	0.8	4.8	10.9
2013	4.1	2.8	17.7
2014	1.6	3.3	24.1
2015	4.8	2.5	42.3

* Hydrogen peroxide also used for the control of Amoebic Gill Disease (AGD)

Figure 3-1 Data on the input of lice medicine from 2015 Marine Harvest annual report[10]

3.2 Feed input

The feed input was modelled with system process data on fish feed from the PEF Feed pilot. See chapter 1.2 on the relation between this screening and the PEF Feed pilot

[10] Link to 2015 Marin Harvest Annual Report: www.marineharvest.com/investor/annual-reports/

3.3 Juvenile production

The juvenile production is modelled with data from Norwegian salmon smolt producer, all of them using recycling aquaculture systems (RAS). The infrastructure is included based on data from a conceptual RAS model developed by the Freshwater institute [18].

The juvenile process included input of:

- Feed (used same data as for the grow-out feed, chapter 3.2): 1 kg feed per kg smolt produced. Big producer report a EFCR as efficient as 0,95 for smolt production.
- Electricity: 8 kWh electricity per kg smolt produced
- Fuel: 0,004 litre per kg smolt produced
- Hydrated lime 0,1 kg per kg smolt produced
- Liquid oxygen: 0,76 kg per kg smolt produced
- Water: 14,6 litre per kg smolt produced
- Formic acid: 0,002 kg per kg smolt produced
- Formaldehyde: 0,0011 kg per kg smolt produced
- Soap and disinfection chemicals;
- Emissions to water: Dissolved organic carbon (DOC)
- Treatment of sludge: 0,5 kg sludge to sludge treatment per kg smolt produced.

3.4 Sludge treatment

The sludge treatment simply includes drying of the sludge. It is assumed that the sludge from the juvenile RAS production have a dry content of 20% and that it is dried down to 100% dry matter. With a vaporization heat of water: 2260 kJ/kg this process include an electricity input of 0,8*2260= 1,810 kJ electricity per kg of sludge dried.

In addition to the drying of the sludge a transport of 500 km with truck is included.

It is known that in real life sludge treatment would be partly self driven e.g. by burning the dry matter to dry the next batch of sludge. There are also numerous different ways of utilizing the sludge that would not involve the drying of the sludge. The way sludge treatment is included here must be considered a worst case, but ensures that this part of the system is included in the screening.

3.5 Transport distances

This presents transport distances used in the foreground system. Transport distances included in the background data (Ecoinvent, Agrifootprint and ELCD database) is not presented here.

Table 3-1 Transport distances used in foreground system of screening analysis.

Transport	Distance	Reference/comment
Salmon feed from pellets factory to grow out farm	2 000 km	Used distance Stavanger-Mo I Rana as a case (1000 km each way). (www.sea-distances.org)
Salmon feed from pellets factory to juvenile production	2 000 km	
Transport of fish from preparation plant in Norway to city in Europe on road	2 274 km	Distance Norway (Hitra)-Paris, with ferry Oslo-Hirtshals. Return transport of truck is not included.
Well boat transport of smolt	500 km	Assumed distance
Well boat transport of salmon from fish farm to preparation	500 km	Assumed distance
Transport of frozen pelagic products from Norway to Europe	1 875 km	Distance from Narvik to Rotterdam
Transport of sludge from juvenile production to sludge treatment	500 km	Assumed distance

3.6 Packaging

Packaging are included for all products twice: Once during transport and then as consumer packaging:

Two types of transport packaging materials are included: Expanded polystyrene (EPS) boxes for transport of fresh fish on ice and cardboard boxes for transport of frozen fish.

Transport packaging and ice is included with: Production of EPS material; production of ice (electricity) and waste handling of EPS boxes. **See chapter 2.7 on the attempt to use the end-of-life formula on these packaging materials.**

The range of consumer packaging for fresh and frozen products are numerous. This screening included three types of packaging, all of them can contain 500 gr of fish:

- Made of card board, same type as card board used for transport packaging. 125 gr of card board per unit.
- Made of EPS with a PE film. 50 gr EPS and 5 gr polyethylene film per unit.
- Made of aluminium with a PE film. 30 gr Al plus 3 gr PE per unit.

The different packaging materials was modelled with the following generic data:

- Card board:
    - material input: ELCD v3.1 "Corrugated board boxes, technology mix, prod. mix, 16,6 % primary fibre, 83,4 %"
    - waste handling: ELCD v3.1 "Waste incineration of paper fraction in municipal solid waste (MSW), EU-27 Part l"

- Expanded Polystyrene
    - Material input: ELCD v3.1 " Polystyrene expandable granulate (EPS), production mix, at plant RER Partly term"
    - Waste handling: ELCD v3.1 "Waste incineration of plastics (PE, PP, PS, PB), EU-27"

- Polyethylen film
    - Material input: Ecoinvent v3 "Packaging film, low density polyethylene {GLO}| market for | Alloc Rec, S"
    - Waste handling: ELCD v3.1 "Waste incineration of plastics (PE, PP, PS, PB), EU-27"

- Aluminium
    - Material input: ELCD v3.1 "Aluminium sheet, primary prod., prod. mix, aluminium semi-finished sheet product RER S"
    - Waste handling: ELCD v3.1 "Aluminium (waste treatment) {GLO}| recycling of aluminium | Alloc Rec, S"

The following was not included for the packaging:

- Processing from materials to finished container/box
- Capital investments

3.7 Fish feed transport

Transport of feed is included in the categorized results from the feed pilot, in the screening

Transport from the feed mill to the smolt producing unit and fish farm is typically operated by sub-contractor to the feed producer (in some cases the salmon farmer and feed producer are same company). These transports supply several farm sites. The whole transport can be divided into:

- Loading of feed. Energy use will normally come from electricity grid.
- Steaming to fish farm.
- Unloading of feed at fish farm. Energy for this activity from the ship. Dynamic positioning may be involved.
- Data from two feed transporting vessels gave the following fuel factors:
    - 0,4 l/kg feed was used during unloading of the feed. This from a range of 0,29-0,76 l/kg depending on how much time the unloading took.
    - 0,0129 litre of diesel per tonnes*km for the transport. This was considered a representative average for the whole fleet of the reporting company.

Feed transporting ships also operate on natural gas, but here only diesel fuel is considered.

The following was not included for the feed transport with ship:

- Construction and end of life treatment of ship and on-board equipment
- Harbour activities
- Maintenance of ship, e.g. paint and grease
- Chemicals used in refrigeration system

3.8 Well boat transport

Well boats are used to:

- Transport juveniles to the farm site
- Handle fish during treatment of diseased fish and splitting/grading
- Transport fish ready for slaughter to primary preparation.

Well boat operation include pumping large volumes of water and fish.

Data on the fuel use of well boats was retrieved from an internal project at SINTEF. This is for one single vessel. Fuel use during crossing was in the range of 300-350 litres per hour at a speed of 10 kn. Fuel use during operations such as loading and unloading 195 l/hr. With a capacity of 1950 m3 and a fish density of 75 kg salmon/m3 this gave the following fuel factors:

- Crossing of vessel (same with and without fish): 0,13 l/t*km.
- Loading, unloading and waiting at farm site: 16 l/tonne salmon

Construction and maintenance of the well boat; port facilities; emission from anti fouling paints was included copying data from the EcoInvent process "Transport, freight, sea, transoceanic ship| processing | Alloc Rec, U".

3.9 Fishing

Fishing is included with data on

- fuel use
- emission of refrigerant
- Emissions to water from the use of antifouling agents on the fishing vessel.
- construction and end of life handling of vessel
- production and waste handling of fishing equipment.

Fuel consumption in open seas and coastal fishing of pelagic and demersal products is retrieved from a dataset containing a statistically representative selection of vessels from the Norwegian fishing fleet in the years 2009 -2013. These data and all known data from other LCA and energy/fuel studies of both European and global fisheries show that the catch specific fuel factor of fisheries is in the range of less than a 0,1 to several litres per kilo of fish landed.

For the pelagic case a fuel consumption of 0,095 litre diesel per kg fish landed in round weight was used as a baseline. During the screening a sensitivity analysis on the fuel intensity for fisheries lead to the decision to adjust the fuel intensity for pelagic fisheries with literature data on fuel use in important tuna fisheries. Tuna is an especially important species in the EU consumption, around 42% of the pelagic marine fish species consumed was tuna or tuna like fishes. Available literature showed a considerably higher fuel consumption in tuna fisheries than in the average for Norwegian pelagic fisheries (that mainly target smaller and more abundant species). Journal articles report fuel intensities in global purse sein Tuna fisheries in the range of 195 to 527 litres per tonne, Parker et al suggest an average for tuna purse seiners of 368 litre/tonne [19, 20]. This fuel intensity is used for the tuna share of the pelagic fishery, this resulted in a fuel intensity for the pelagic fishery of:

- **0,42*0,368 + 0,58*0,095 = 0,22 litre/kg landed.**

For the demersal fishing a fuel intensity of 0,245 litre diesel per kg landed in round weight was used.

Refrigerant emissions was included with emission rates of refrigerant of 0,023 and 0,224 gr per kg landed for pelagic and demersal fishing. Emission factor of refrigerants is based on a study if the carbon footprint of Norwegian fisheries in 2009 [21].

See chapter 3.19 for data on the production and combustion of fuel.

3.10 Fishing gears

Fishing gears was included with an input of plastics (nylon and polypropylene) and steel. Just as with fuel consumption it is a waste variation in how long they last and how much the different fishing gears catch through their life span. It was not identified any comprehensive data source for composition and catch capacity for fishing gears. The end of life for the fishing gear is either when it is worn out or for other reasons replaced or when it is lost at sea – see comments on potential impacts from fishing gear in chapter 0.

A generic fishing gear was composed based on data from big bottom trawls for demersal fishing: 2 300 kg nylon, 400 kg polypropylene and 42 000 kg chromium steel. Waste handling of these materials was also included (Ecoinvent recycling processes). To relate the input of fishing gears to fish landed it was assumed that the plastic materials of this trawl is used for 2 years, the metal 5 years and have an annual catch of 7 000 tonne.

3.11 Emissions from antifouling paints on ships and fishing vessels

Emissions from the use of antifouling agents on fishing vessels was included with data from Jotun[11] and their product "SDS SeaForce 30". Based on its technical documentation it was assumed that it can cover 2 m2/kg paint and that this lasts for 36 months. The density is 1,6 kg/l. The composition of this paint was based on it's material safety data sheet[12].

To relate the emissions of antifouling paint to the mass of fish landed it was assumed that the fishing vessels paint a surface of 50m2 and have a yearly catch of 9 000 tonne.

3.12 Intermediate treatment of by-products by ensiling

One common way to treat by-products from both fisheries and aquaculture is with formic acid to make ensilage (ref Com Reg. (EU) No 142/2011, Annex IV, chapter III). In this analysis it is assumed that all by-products, except by-products from pelagic, go through this process. A rule of thumb in the industry is that it is used 2 % acid with respect to the mass treated. This was confirmed by data from salmon processing showing that 0,02 kg of formic acid was used per kg by-products treated. The input of acid was included with the ecoinvent v3 data set "Formic acid {RER}| market for | Alloc Rec, S". In addition to the input of acid, an input of water: 3 kg water per kg by-product treated, was included and an electricity input of 0,008 kWh per kg per kg by-products treated.

3.13 Preparation of fish

In this document *preparation* of fish means the way to treat fish to make *prepared fishery products* as defined in Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin (OJ L 226, 25.6.2004, p. 22): "*Prepared fishery products"* means unprocessed fishery products that have undergone an operation affecting their anatomical wholeness, such as gutting, heading, slicing, filleting, and chopping.

[11] Personal communication with Eivind A. Berg

[12] Link to Jotun data sheet seaforce 30: www.jotun.com/Datasheets/Download?url=%2FSDS%2FSDS__1538__SeaForce%2030__Eng__US.pdf

For the information purpose, the following definitions from the 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) are cited to clarify the differences of the concepts:

- "*processing"* means any action that substantially alters the initial product, including heating, smoking, curing, maturing, drying, marinating, extraction, extrusion or a combination of those processes;

- "*unprocessed products"* means 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;

Preparation of the fish is modelled with a compilation of data from pelagic, demersal/white fish and salmon preparation. The goal was to build processes that were specific, but as it was difficult to get good data for all different products it was considered most robust to ensure that the process was as complete as possible, in terms of including as many in- and outputs as possible rather than being very product precise. The data that was available did not make it possible to separate between fresh and frozen products neither. The producers providing that data would over the period of data collection have a mixed production.

The preparation included the following in- and outputs, all per tonne fish into preparation:
- Electricity: 175 kWh
- Freshwater: 4 400 litres
- Infrastructure: Estimated using data from Marin Harvest (Ulvan, factory), 15 000 m2; assumed lifetime 20 yrs and 90 000 tonne annual production.
- Soap and disinfection chemicals: 281 gr and 380 gr
- Waste: Wood, mineral oil, paint, electronic equipment, biodegradable municipal, metals, core board, plastics, and waste water.
- The data on generation of waste of materials and components was balanced with an input of similar commodities.

3.14 Truck transport

Truck transport of the fish from preparation to retailer is modelled with the following inputs and consumption factors:
- Fuel used of engine: 0,0185 litre fuel per t*km.
- Assuming that the truck uses 3,7 litre/10km on European roads and as an average carry 20 tonnes of fish.
- Fuel to run refrigeration system on truck: 0,4 l/hr transport
- Production and emission of refrigerant from the truck: 0,00026 kg 134a/hr transport
- Assumed that the refrigerant 134a is used and an emission rate of 10% per year.
- These time dependent inputs is included using an average speed of 80km/hr
- Use of infrastructure and maintenance and construction of vehicle. Will be included with Ecoinvent data, but must review allocation method.

Numerous different vehicles and engine classes are used in the export of salmon, but most common are semitrailers with isolated boxes that can store around 33 europallets. The load of these trailers are limited by law so maximum load of goods will be around 24 tonnes.

Table 3-2 presents data that was obtained on fuel consumption for these trucks with load. For Norwegian (hilly) roads a fuel use of 0.42 l/km was used and for European (flat terrain) 0.32 l/km.

Table 3-2 Fuel factors for semi-trailer

Norwegian road (hilly) [l/10km]	European road (flat) [l/10km]
5.7*	2.9*
4.2 (4.1-4.3)**	**3.2** (3.1-3.3)**
3.96 (Unspecified rural road. 40ton.)***	3.60 (Unspecified motorway)***
* Personal communication with major semitrailer operator ** Personal communication with logistics department at one of the main salmon producers ***NTM database (The Network for Transport and Environment)	

The load of fish on each transport also vary depending if the fish is fresh or frozen and how good the logistics operator is able to utilize the capacity:

- Fresh fish: 18 tonnes fresh fish per lorry, this fish is transported in expanded polystyrene (EPS) boxes with 20 kg fish and around 4-5 kg ice.
- Frozen fish: 22 tonnes fish per lorry, these products are transported in cardboard boxes with around 25 kg fish in each box (without ice).

The numbers in brackets in Table 3-3 represents the range given from the interviews.

Table 3-3 Product specific load factors for semitrailers

Products	Load factors [Tonne product / lorry]
Fresh fish on ice in EPS boxes	18 (17-19)
Frozen fish in cardboard boxes	22 (21-24)

3.15 Retail and consumer

The retail and consumer stages was presented in earlier versions of the screening. Then these stages was included based on data from the Issue paper: Guidance and requirements for handling the use stage in PEFCRs Version 4.0 – 11 November 2015 [22]

Retail and consumer was modelled including:

- Building and equipment. Retail store with area 4 000 m2 and a "product volume" capacity of 2 000 m3. The store contains 60m2 of freezers and 60m2 of refrigerators.
- Electricity consumption of 400 kWh/m2·year is assumed for the entire building surface. For the freezers and refrigerators 2 700 and 1 900 kWh/yr*m2.
- Emission of refrigerant. Mass inn freezers and refrigerators: 0.29 kg R404A (r134a) per m2. Emission rate 10% per year.
- Loss at retailer was included with 10%
- Transport of the consumer in car 5 km. Assume that consumer bought 20 kg of products in total. This part is included in the life cycle stage distribution according to recommendation from EC (page 2 I use phase document).
- Storage of product in refrigerator for 3 days. Refrigerated storage modelled with data from EC. per kg by-products treated
- Preparation of the fish with induction oven using 0,6 kWh/hr and preparation time of 15 minutes per kg. 75% on gas and 25% electricity), 5 gram sunflower oil (incl. its life cycle) per kg product
- Loss, fish not eaten, but thrown, was included with 20%

3.16 Water input and waste water treatment

Fresh water input to the foreground system is modelled with input of the raw material "Water, fresh".

In the ILCD method v1.08 and the impact category "Water resource depletion" this substance have a characterization factor of 0,162 m3 water eq /m3.

The water input should be regionalized with respect to in which part of the world water is used and the local water scarcity situation. This is not done so fare.

By studying the JRC report "Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods" [23] and the chapter on water depletion, we see that the characterization factors of 0,16 puts the water input used in this screening in the category of moderate scarcity.

In addition, water use in the background system (EcoInvent and ELCD data) is also included.

In processes with a fresh water input, this input is balanced with an output of waste water treatment with the ELCD v3.1 process "Waste water - untreated, organic contaminated EU-27 S".

3.17 Electricity

Electricity input to the foreground system is modelled using the ELCD v3.1 process "Electricity mix, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S".

3.18 Waste treatment of fish products

Handling of fish waste, in this screening, generated at the retailer and the consumer, is included with the ELCD data set "Waste incineration of biodegradable waste fraction in municipal solid waste (MSW), EU-27".

3.19 Production and use of fuels

All process that use fuels in the foreground system use the same data on the production and use (combustion) of the fuel. This includes: The transport processes (ships and trucks); fishing vessels and use of fuel in electricity generation and operation of vessels at the fish farm.
Production and distribution of fuel is included with the ELCD v3.0 process "Diesel, from crude oil, consumption mix, at refinery, 200 ppm sulphur EU-15 S".
Emission factors for the combustion/use of the fuel was included with data from EEA Technical report No 12/2013: "EMEP/EEA air pollutant emission inventory guidebook 2013 Technical guidance to prepare national emission inventories (Table 3-2)". The emission of the sulphur dioxide is modelled as a function of the sulphur content in the fuel, basically SO_2 emitted is two times the mass of S in the fuel. This from the ratio between the molar mass of SO_2 (64gr/mol) and S (32gr/mol). As a baseline it is assumed that the fuels contain 0,1w% S.

Table 3-4 Emission factor for the use/combustion of 1 tonne of fuel in engines

Ammonia	0,02	kg
Arsenic	0,04	g
Benzene	0,0073	kg
Benzene, hexachloro-	0,08	mg
Cadmium	0,01	g
Carbon dioxide, fossil	3190	kg
Carbon monoxide, fossil	7,4	kg
Chromium	0,05	g
Copper	0,88	g
Dinitrogen monoxide	1,22	kg
Dioxins (TEQ)	0,13	µg
Lead	0,13	g
Mercury	0,03	g
Methane, fossil	0,3	kg
Nickel	1	g
Nitrogen oxides	78,5	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	2,8	kg
PAH, polycyclic aromatic hydrocarbons	0,00336	kg
Particulates, < 2.5 um	1,4	kg
Particulates, > 10 um	1,5	kg
Polychlorinated biphenyls	0,038	mg
Selenium	0,1	g
Sulphur dioxide	2	kg
Toluene	0	kg
TSP	1,5	kg
Xylene	0	kg
Zinc	1,2	g

3.20 Biogenic carbon emissions

From the PEF guide, Annex VI: "Biogenic emissions include those resulting from the burning (combustion) or degradation of biogenic materials, wastewater treatment and biological sources in soil and water (including CO_2, CH_4 and N_2O), while biogenic removals correspond to the uptake of CO_2 during photosynthesis". The guideline for the PEFCR development further state that biogenic carbon should be accounted for separately.

The most important parts of the biogenic carbon cycle of fish is presented in Figure 3-2. Uptake in the life cycle of fish is through photosynthesis in the growing of crops for aquaculture feed production and through phytoplankton for wild fish. Emission of biogenic carbon will be through the respiration of the fish, decomposition of non-utilized feed, faeces and wasted fish product and from organisms/humans consuming the fish. In addition to this there are important biogenic carbon emissions from the feed production from land use change. The carbon, nitrogen and phosphorus balance for salmon aquaculture have been studied by several, one of them is Wang et al. [24]. Their work concluded that for salmon around 38% of the carbon in the feed is retained in the fish, 40% was respired as CO2 and the remaining 19% of the carbon was released as particles to the water. These particle being faeces and particulate organic carbon (POC). To our knowledge the ILCD method does not contain any link between the emission of POC to water and climate impacts. Thus this emission is not included in the calculation of biogenic carbon emissions.

Emission of carbon from degradation of fish waste is included in the waste treatment process: "Waste incineration of biodegradable waste fraction in municipal solid waste (MSW), EU-27" from the ELCD database. This process includes emission of biogenic CO2, 630 kg biogenic CO2 per tonne waste handled.

In addition to the biogenic carbon in the fish, biogenic carbon is also a part of the packaging materials, here biogenic methane can be included if waste goes to anaerobe degradation, but in this screening all such waste is assumed to go to incineration, thus only biogenic CO2 is generated here, and this will be a zero balance with uptake in growing of wood.

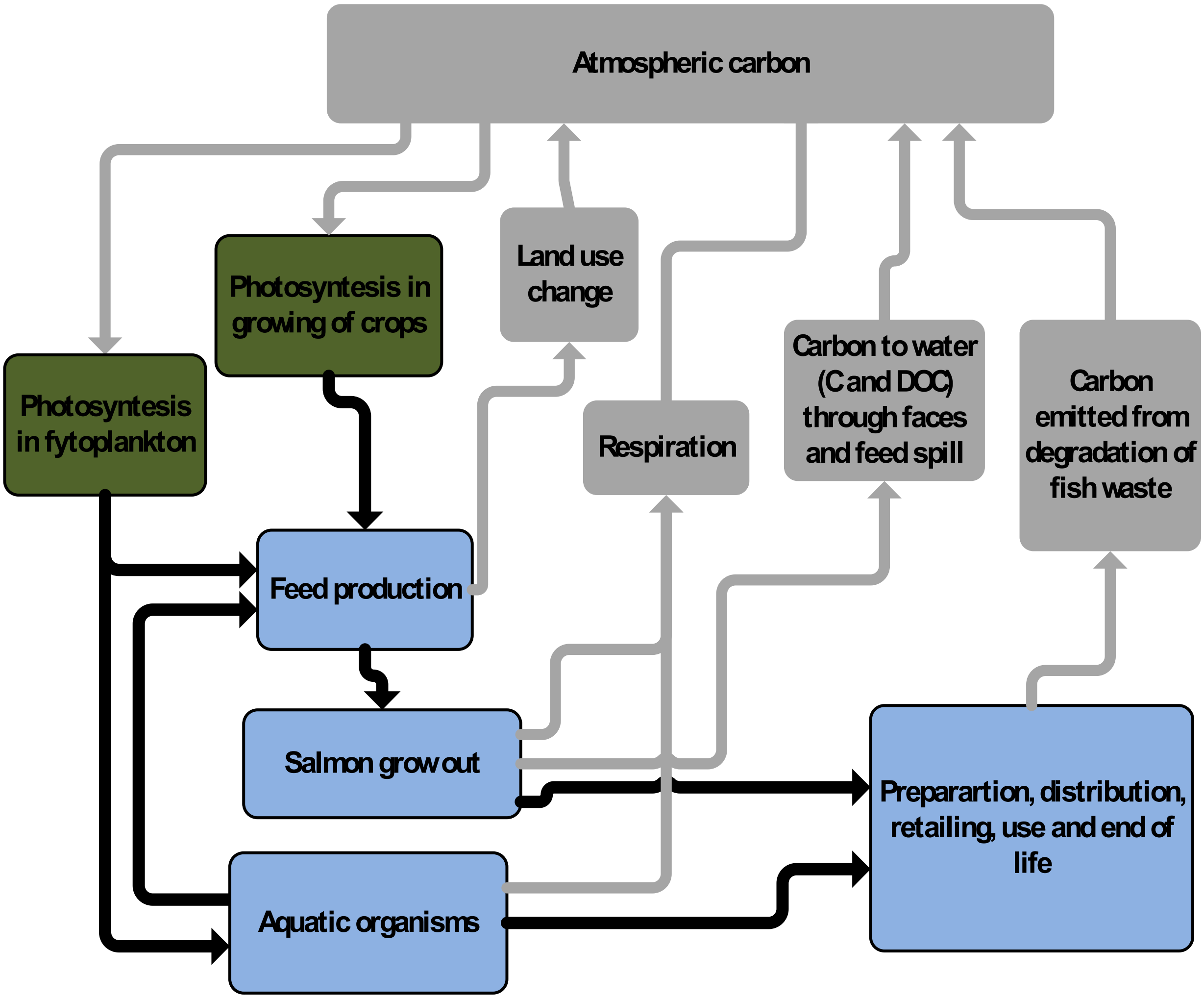


Figure 3-2 Biogenic carbon cycle for fish life cycle

4 Screening: Results

Each impact category was investigated to identify the most relevant life cycle stages; processes and elementary flows. The screening model was updated in an iterative process with the interpretation. For an example data was disaggregated to ensure more precise identification of where and why impact occur (more precise linking between elementary flow; process and life cycle stage).

The following criteria are used to identify most important processes and flows:

- The criteria for being among the most important is that they contribute to reach a minimum of 80% of any impact category.
- processes as most relevant where they collectively contribute at least 80% to any impact category before normalisation and weighting
- Flows are most relevant when they cumulatively contribute more than 80% to the impact category and/or single flows contribute more than 5% to the impact category.

Table 4-1 Summary of requirements to define most relevant contributions and hotspots (Table D-1 in PEFCR Guidance document v5.0)

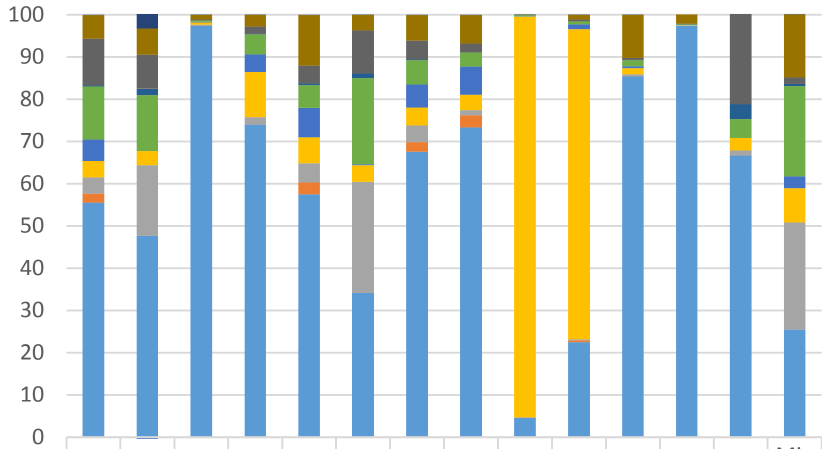
Item	At what level does relevance need to be identified?	Threshold
Most relevant impact categories	In the final results, starting from normalized and weighted results but deviations possible if justified	No threshold. Decision left to TS but subject to stakeholder consultation and TAB opinion
Most relevant life cycle stages	For each impact category, before normalization and weighting. Not relevant for data needs identification	All life cycle stages contributing cumulatively more than **80%** to any impact category
Hotspots	For each impact category, before normalization and weighting	Either (i) life cycle stages, processes, and elementary flows cumulatively contributing at least **50%** to any impact category, or (ii) at least the two most relevant life cycle stages, processes and at least two elementary flows (minimum 6). Additional hotspots may be identified by the TS
Most relevant processes	For each impact category, before normalization and weighting. Essential for data needs identification	All processes contributing cumulatively more than **80%** to any impact category
Most relevant elementary flows	For each impact category, before normalization and weighting. Essential for data needs identification	All elementary flows contributing cumulatively more than **80%** to any impact category and in any case all those contributing more than 5% individually

4.1 Aquaculture results

4.1.1 Aquaculture: Life cycle stages

Table 4-2 present how much (in %) each life cycle stage contribute to each impact category. Table 4-3 presents the same results with absolute values for a case where the salmon is transported as head-on-and-gutted to retailer and none of the by-products are utilized except the intestines from the gutting. Table 4-4 presents the absolute values for a case where the salmon is filleted before transport to the retailer and all by-products are utilized.

Table 4-2 Identification of most important life cycle stage for each impact category. All values % of total impact for each impact category.



	Climate change	Ozone depletion	Human toxicity, non-cancer effects	Human toxicity, cancer effects	Particulate matter	Ionizing radiation HH	Acidification	Terrestrial eutrophication	Freshwater eutrophication	Marine eutrophication	Freshwater ecotoxicity	Land use	Water resource depletion	Mineral, fossil & ren resource depletion
Distribution: Refrigeration in transport	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Distribution: Transport	6	6	1	3	12	4	6	7	0	1	10	2	0	15
Distribution: Packaging, transport and consumer	11	8	0	2	4	10	4	2	0	0	0	0	21	2
Preparation: Chillled storing	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Preparation: Ensilage production	0	2	0	0	0	1	0	0	0	0	0	0	4	1
Preparation: Gutting	13	13	0	5	5	20	6	3	0	1	1	0	4	21
Production: Well boat transport	5	0	0	4	7	0	5	7	0	1	0	0	0	3
Production: Grow out (fish farm)	4	3	1	11	6	4	4	4	95	73	1	0	3	8
Production: Juvenile production	4	17	0	2	5	26	4	1	0	0	0	0	1	25
Production: Feed transport	2	0	0	0	3	0	2	3	0	0	0	0	0	0
Production: Feed (Feed pilot)	56	48	97	74	57	34	68	73	5	22	85	97	67	25

Table 4-3 Impact assessment results for each IA divided into life cycle stages. Results for 1 kg edible salmon at retailer gate when the by-products except the intestines are not utilized.

Impact category	Unit	Total	Production: Feed (Feed pilot)	Production: Feed transport	Production: Juvenile production	Production: Grow out (fish farm)	Production: Well boat transport	Preparation: Gutting	Preparation: Ensilage production	Preparation: Chillled storing	Distribution: Packaging, transport and consumer	Distribution: Transport	Distribution: Refrigeration in transport
Climate change	kg CO2 eq	9,07E+00	5,04E+00	1,91E-01	3,52E-01	3,49E-01	4,56E-01	1,14E+00	3,00E-02	5,64E-04	9,94E-01	5,09E-01	1,24E-02
Ozone depletion	kg CFC-11 eq	3,92E-07	1,87E-07	-7,24E-10	6,55E-08	1,31E-08	-1,07E-09	5,19E-08	6,09E-09	1,40E-10	3,12E-08	2,45E-08	1,47E-08
Human toxicity, non-cancer effects	CTUh	7,56E-06	7,36E-06	2,97E-09	1,82E-08	4,20E-08	1,25E-08	2,77E-08	2,22E-09	1,68E-11	1,02E-08	8,82E-08	1,55E-10
Human toxicity, cancer effects	CTUh	1,18E-07	8,74E-08	1,09E-10	1,95E-09	1,26E-08	4,94E-09	5,63E-09	1,81E-10	3,70E-13	1,98E-09	3,33E-09	5,84E-12
Particulate matter	kg PM2.5 eq	3,76E-03	2,16E-03	1,05E-04	1,70E-04	2,30E-04	2,63E-04	2,02E-04	1,45E-05	2,90E-07	1,60E-04	4,48E-04	5,42E-06
Ionizing radiation HH	kBq U235 eq	2,91E-01	9,93E-02	6,84E-05	7,65E-02	1,14E-02	5,84E-04	5,93E-02	3,24E-03	1,70E-04	2,95E-02	1,08E-02	4,00E-06
Photochemical ozone formation	kg NMVOC eq	4,21E-02	2,24E-02	1,96E-03	8,72E-04	2,63E-03	4,61E-03	2,29E-03	7,36E-05	1,33E-06	2,14E-03	5,08E-03	1,01E-04
Acidification	molc H+ eq	6,93E-02	4,68E-02	1,59E-03	2,70E-03	2,93E-03	3,79E-03	3,99E-03	1,68E-04	4,85E-06	3,05E-03	4,19E-03	8,20E-05
Terrestrial eutrophication	molc N eq	2,72E-01	2,00E-01	7,71E-03	3,36E-03	9,92E-03	1,81E-02	9,08E-03	2,30E-04	4,37E-06	5,55E-03	1,83E-02	3,97E-04
Freshwater eutrophication	kg P eq	2,09E-02	9,63E-04	5,41E-07	2,56E-06	1,98E-02	1,92E-06	6,57E-05	1,71E-06	5,66E-10	1,79E-05	7,48E-06	2,87E-08
Marine eutrophication	kg N eq	1,44E-01	3,23E-02	7,04E-04	2,94E-04	1,06E-01	1,65E-03	1,02E-03	2,02E-05	4,01E-07	5,35E-04	1,67E-03	3,62E-05
Freshwater ecotoxicity	CTUe	1,57E+01	1,34E+01	7,19E-03	6,39E-02	2,28E-01	7,18E-02	2,31E-01	8,94E-03	3,35E-05	7,43E-02	1,61E+00	3,78E-04
Land use	kg C deficit	7,59E+01	7,39E+01	-1,53E-02	6,16E-02	1,00E-01	-1,52E-02	9,04E-02	6,99E-02	0,00E+00	6,10E-02	1,65E+00	-7,74E-04
Water resource depletion	m3 water eq	1,63E-02	1,09E-02	4,40E-06	1,81E-04	4,79E-04	-1,95E-05	7,28E-04	5,85E-04	2,43E-07	3,49E-03	-2,86E-05	2,13E-07
Mineral, fossil & ren resource depletion	kg Sb eq	1,77E-04	4,51E-05	-2,24E-08	4,50E-05	1,44E-05	5,02E-06	3,79E-05	9,11E-07	1,84E-09	2,70E-06	2,64E-05	1,20E-08

Table 4-4 Impact assessment results for each IA divided into life cycle stages. Results for 1 kg edible salmon at retailer gate when all by-products are utilized.

Impact category	Unit	Total	Production: Feed (Feed pilot)	Production: Feed transport	Production: Juvenile production	Production: Grow out (fish farm)	Production: Well boat transport	Preparation: Gutting	Preparation: Ensilage production	Preparation: Chillled storing	Distribution: Packaging, transport and consumer	Distribution: Transport	Distribution: Refrigeration in transport
Climate change	kg CO2 eq	4,92E+00	2,72E+00	1,03E-01	1,90E-01	1,89E-01	2,46E-01	6,16E-01	3,91E-02	3,05E-04	5,37E-01	2,75E-01	6,68E-03
Ozone depletion	kg CFC-11 eq	2,16E-07	1,01E-07	-3,91E-10	3,54E-08	7,09E-09	-5,80E-10	2,80E-08	7,92E-09	7,56E-11	1,69E-08	1,32E-08	7,91E-09
Human toxicity, non-cancer effects	CTUh	4,09E-06	3,97E-06	1,60E-09	9,83E-09	2,27E-08	6,74E-09	1,49E-08	2,89E-09	9,07E-12	5,51E-09	4,76E-08	8,37E-11
Human toxicity, cancer effects	CTUh	6,40E-08	4,72E-08	5,88E-11	1,05E-09	6,80E-09	2,67E-09	3,04E-09	2,36E-10	2,00E-13	1,07E-09	1,80E-09	3,15E-12
Particulate matter	kg PM2.5 eq	2,04E-03	1,17E-03	5,68E-05	9,20E-05	1,24E-04	1,42E-04	1,09E-04	1,88E-05	1,57E-07	8,62E-05	2,42E-04	2,93E-06
Ionizing radiation HH	kBq U235 eq	1,60E-01	5,36E-02	3,69E-05	4,13E-02	6,17E-03	3,15E-04	3,20E-02	4,22E-03	9,16E-05	1,59E-02	5,83E-03	2,16E-06
Photochemical ozone formation	kg NMVOC eq	2,28E-02	1,21E-02	1,06E-03	4,71E-04	1,42E-03	2,49E-03	1,24E-03	9,56E-05	7,18E-07	1,15E-03	2,74E-03	5,45E-05
Acidification	molc H+ eq	3,76E-02	2,53E-02	8,60E-04	1,46E-03	1,58E-03	2,04E-03	2,16E-03	2,19E-04	2,62E-06	1,65E-03	2,26E-03	4,43E-05
Terrestrial eutrophication	molc N eq	1,47E-01	1,08E-01	4,17E-03	1,81E-03	5,36E-03	9,76E-03	4,91E-03	2,99E-04	2,36E-06	3,00E-03	9,89E-03	2,14E-04
Freshwater eutrophication	kg P eq	1,13E-02	5,20E-04	2,92E-07	1,38E-06	1,07E-02	1,04E-06	3,55E-05	2,22E-06	3,06E-10	9,68E-06	4,04E-06	1,55E-08
Marine eutrophication	kg N eq	7,79E-02	1,75E-02	3,80E-04	1,59E-04	5,72E-02	8,90E-04	5,51E-04	2,63E-05	2,17E-07	2,89E-04	9,01E-04	1,95E-05
Freshwater ecotoxicity	CTUe	8,50E+00	7,26E+00	3,88E-03	3,45E-02	1,23E-01	3,88E-02	1,25E-01	1,16E-02	1,81E-05	4,01E-02	8,70E-01	2,04E-04
Land use	kg C deficit	4,10E+01	3,99E+01	-8,27E-03	3,32E-02	5,42E-02	-8,18E-03	4,88E-02	9,09E-02	0,00E+00	3,30E-02	8,92E-01	-4,18E-04
Water resource depletion	m3 water eq	9,25E-03	5,88E-03	2,38E-06	9,77E-05	2,59E-04	-1,06E-05	3,93E-04	7,60E-04	1,31E-07	1,89E-03	-1,55E-05	1,15E-07
Mineral, fossil & ren resource depletion	kg Sb eq	9,65E-05	2,43E-05	-1,21E-08	2,43E-05	7,79E-06	2,71E-06	2,04E-05	1,18E-06	9,92E-10	1,46E-06	1,43E-05	6,46E-09

4.1.2 Aquaculture: Processes and flows

The results are presented in the **excel file " Marine Fish PEFCR Screening results - Aquaculture - 09 09 2016.xlsx"**:

- The sheet "PIVOT HOTSPOTS" presents the most important processes and flows for each impact category per life cycle stage
- The sheet "Most important processes" and "Most important flows" presents what processes and flows contributed to each impact category.

4.1.3 Aquaculture: Hotspot analysis

The following chapters present the identification of the hot spots for each impact category, based on the results on the most important life cycle stages; processes and flows together with investigation of how these are linked.

Climate change

Life cycle stages: All life cycle stages contributed more than 5%. Feed, preparation and distribution (transport and packaging) are the most important.
Processes: Feed, production and combustion of fuels, waste water treatment, electricity production waste incineration and EPS production.
Elementary flows: carbon dioxide and N2O

Hotspots:
- Use of feed in aquaculture grow out and juvenile production.
- Use and production of fuel used in distribution from preparation to retailer and in transport of feed and live fish.
- Production of electricity used in juvenile production and preparation (including storing)
- Waste water treatment in preparation.

Biogenic climate impacts

Climate impacts from biotic carbon emissions are presented separately (see also chapter 3.20).

For biogenic emissions contribution to climate impact it is concluded that the contribution can potentially be of significance. Even though the screening model did not include perfect, or even good, carbon mass balances for biotic carbon the rough numbers presented here, show that this aspect needs to be addressed in a Marine Fish PEFCR.

Ozone depletion

Life cycle stages: All life cycle stages contribute with more than 5%
Processes: Feed and electricity production
Elementary flows: Refrigerants (see results file for details)

Hotspots: For marine net pen aquaculture this impact category is dominated by emission from the feed production. Other than that the production of electricity used in juvenile production and preparation are important. Emissions from the use of fuel and emission of refrigerants in transports are also important.

Marine and freshwater eutrophication

The results showed that the ILCD method associate emissions to marine water to with freshwater eutrophication. To our knowledge this must be an error in the method. Anyway these two impact categories are interpreted together.

Life cycle stages: Both impact categories are dominated by emissions from the fish grow out (fish farm). Secondly comes feed production and distribution to retailer.
Processes: Net pen farming emissions to water, feed production and combustion of fuels.
Elementary flows: Nitrogen and phosphorus to water
Hotspots:
- Emissions to water of nitrogen and phosphorus from marine net pen, feed spill and faeces.
- Nitrogen emissions from the feed production.
- Use of fuel (NOx emissions) by fishing vessel, feed transport, well boat and transport of fish from preparation to retailer.

Photochemical ozone formation

Life cycle stages:
Processes: Feed production, distribution (packaging and transport), fish farm and preparation.
Elementary flows: Nitrogen oxides and nitrogen dioxide
Hotspots: This impact category is dominated by the feed production and emission from the production and use of fuels in transport processes.

Human toxicity, cancer effects

Life cycle stages: Feed, fish farm and preparation
Processes: Feed, hydrogen peroxide production, waste treatment and steel production
Elementary flows: Chromium emissions to water and soil.
Hotspots: This IA is dominated by chromium emissions from the production of feed (see Feed Pilot for details on what caused these emissions). For the rest of the system chromium emissions arise from the use of chemicals (hydrogen peroxide) in the treatment of salmon lice, steel used in fish farm equipment and waste treatment from preparation.

Human toxicity, non-cancer effects

Life cycle stages: Feed is the most important life cycle stage
Processes: Feed production, production of hydrogen peroxide, waste water treatment and steel production
Elementary flows: chromium emissions
Hotspots: Production of feed, production of hydrogen peroxide used in parasite treatment in fish grow out, wastewater treatment from preparation, steel produced for use in fish farm equipment.

Particulate matter

Life cycle stages: All stages contribute more than 4%. Feed production, distribution and grow out are the most important stages.
Processes: production and use of fuels, electricity production and polystyrene production.
Flows: Particulates, < 2.5 µm, Ammonia and SO2
Hotspots: See feed pilot for detail on how feed production cause particulate, ammonia and SO2 emissions. Except feed the use of fuel in transport vehicles used in distribution for the fish and grow out are important. Electricity used in the juvenile production and preparation of the fish caused SO2 emissions.

Ionizing radiation HH

Life cycle stages: All life cycle stages contributed more than 10% except distribution and grow out (4 and 3%).
Processes: Production of electricity, feed and aluminium.
Elementary flows: Emissions of carbon-14 and cesium-13 to air
Hotspots: Electricity used in the different life cycle stages are the most important hots pots (through carbon and caesium emissions) except feed. See feed pilot for detail on how this impact was caused. Aluminium used in the consumer packaging of the fish is also important.

Acidification

Life cycle stages: All stages contribute more than 3%, but feed and distribution are the most important stages

Processes: combustion of fuels and production of feed and electricity.

Elementary flows: Ammonia, nitrogen oxides and sulphur dioxide

Hotspots: The use of fuel in feed transport and distribution of the fish. Electricity used in juvenile production and preparation. See feed pilot for details on what caused this impact in the feed production.

Terrestrial eutrophication

Life cycle stages: All stages are important except juvenile production and distribution that contribute less than 3%.

Processes: Feed production and combustion of fuels

Elementary flows: Nitrogen oxides and ammonia emissions to air.

Hotspots: The use of fuel in feed transport, grow out and distribution of the fish. See feed pilot for details on what caused this impact in the feed production.

Freshwater ecotoxicity

Life cycle stages: Grow out and feed production dominates this category

Processes: Grow out and feed

Elementary flows: Copper, zinc and chlorpyrifos emissions.

Hotspots: This impact category is totally dominated by Cu emissions from impregnation used in the fish nets.

Land use

Life cycle stages: Feed

Processes: Feed production

Elementary flows: Transformation of land to arable land and transformation for mineral extraction.

Hotspots: See feed pilot for details.

Water resource depletion

Life cycle stages: Feed, distribution (packaging) and preparation

Processes: Feed production, EPS production and fresh water use in preparation

Elementary flows: See results file for complete list

Hotspots: Feed also dominates this category. Other than that the production of expanded polystyrene used in packaging and water used in preparation of the fish are important hotspots.

Mineral, fossil & resource depletion

Life cycle stages: All stages are important except distribution (less than 3%)

Processes: Building hall construction, feed production, electronic components and maintenance of lorries

Elementary flows: Indium, phosphorus, cadmium, Nickel crude ore and sulphur

Hotspots: Extraction of indium dominates this category see own chapter on indium contribution. Other than indium extraction of phosphorus used in feed is a hotspot.

Indium contribution

The issue paper "Indium contribution HOW TO DEAL WITH INDIUM CONTRIBUTION IN SOME DATASETS" by the Technical Helpdesk, 9 March 2015, point at potentially to high values for the contribution of Indium to this impact category.

For this screening Indium show up as a very import contributor to the Mineral, fossil & resource depletion impact category. This Indium mainly enters the system with the use of zinc coat coils in building halls (infrastructure), passenger car and maintenance of transport lorries used in the distribution of fish. All of these process data from the Ecoinvent v3.1 database.

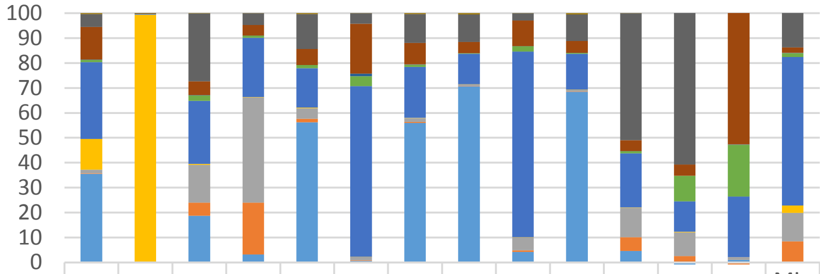
The issue paper recommends to investigate if the input of Indium to the zinc production seems reasonable and recommend data that refer to the Ecoinvent v2.2 database. It was investigated if these recommended data could be implemented, but as this screening use Ecoinvent 3.1, that has a completely different structure, we did not find that we could identify and correct any errors regarding input of Indium.

The issue paper also point at potentially high characterization factors for indium in the ILCD method. One option to address this is to perform sensitivity analysis using other IA methods, but this issue was not considered so important that this was prioritized for this screening.

4.2 Fishing results

4.2.1 Fishing: Life cycle stages

Table 4-5 Identification of most important life cycle stage for each impact category. All values % of total impact for each impact category.



	Climate change	Ozone depletion	Human toxicity, non-cancer effects	Human toxicity, cancer effects	Particulate matter	Ionizing radiation HH	Acidification	Terrestrial eutrophication	Freshwater eutrophication	Marine eutrophication	Freshwater ecotoxicity	Land use	Water resource depletion	Mineral, fossil & ren resource depletion
Distribution: Refrigeration in transport	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Distribution: Transport	5	0	27	5	14	4	11	11	3	11	51	75	0	14
Distribution: Packaging, transport and consumer	13	0	6	4	6	20	9	4	10	5	4	5	54	2
Preparation: Chilled storing	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Preparation: Ensilage	1	0	2	1	1	4	1	0	2	0	1	10	21	2
Preparation: Filleting	31	0	25	24	16	68	20	12	75	14	22	12	24	60
Fishing: Refrigerant	12	99	0	0	0	0	0	0	0	0	0	0	0	3
Fishing: Vessel construction and anti fouling	1	0	15	42	4	1	1	1	5	1	12	9	1	11
Fishing: Fishing gear and bait	0	0	5	21	1	0	0	0	1	0	6	3	-1	8
Fishing: Fuel	35	0	19	3	56	1	56	71	4	68	5	-14	1	0

Table 4-6 Impact assessment results for each IA divided into life cycle stages

Impact category	Unit	Total	Top	Fishing: Fuel	Fishing: Fishing gear and bait	Fishing: Vessel construction and anti fouling	Fishing: Refrigerant	Preparation: Filleting	Preparation: Ensilage	Preparation: Chilled storing	Distribution: Packaging, transport and consumer	Distribution: Transport	Distribution: Refrigeration in transport
Climate change	kg CO2 eq	4,0E+00	0,0E+00	1,4E+00	1,5E-02	5,3E-02	4,9E-01	1,2E+00	3,5E-02	2,9E-03	5,3E-01	2,1E-01	1,3E-02
Ozone depletion	kg CFC-11 eq	1,5E-05	0,0E+00	-5,4E-09	5,6E-10	3,1E-09	1,5E-05	5,6E-08	7,1E-09	7,3E-10	2,2E-08	8,9E-09	1,5E-08
Human toxicity, non-cancer	CTUh	1,2E-07	0,0E+00	2,2E-08	6,2E-09	1,8E-08	3,7E-10	3,0E-08	2,6E-09	8,7E-11	6,6E-09	3,2E-08	1,6E-10
Human toxicity, cancer effects	CTUh	2,6E-08	0,0E+00	8,1E-10	5,3E-09	1,1E-08	3,4E-11	6,1E-09	2,1E-10	1,9E-12	1,1E-09	1,2E-09	6,2E-12
Particulate matter	kg PM2.5 eq	1,4E-03	0,0E+00	7,8E-04	2,1E-05	6,0E-05	3,2E-06	2,2E-04	1,7E-05	1,5E-06	8,9E-05	1,9E-04	5,7E-06
Ionizing radiation HH	kBq U235 eq	9,4E-02	0,0E+00	5,1E-04	3,1E-04	1,3E-03	7,5E-05	6,4E-02	3,8E-03	8,8E-04	1,9E-02	4,0E-03	4,2E-06
Photochemical ozone	kg NMVOC eq	2,1E-02	0,0E+00	1,5E-02	5,0E-05	2,1E-04	9,5E-06	2,5E-03	8,6E-05	6,9E-06	1,3E-03	2,4E-03	1,1E-04
Acidification	molc H+ eq	2,1E-02	0,0E+00	1,2E-02	9,3E-05	3,0E-04	2,4E-05	4,3E-03	2,0E-04	2,5E-05	1,8E-03	2,4E-03	8,7E-05
Terrestrial eutrophication	molc N eq	8,1E-02	0,0E+00	5,7E-02	1,6E-04	5,5E-04	3,0E-05	9,8E-03	2,7E-04	2,3E-05	3,6E-03	8,9E-03	4,2E-04
Freshwater eutrophication	kg P eq	9,5E-05	0,0E+00	4,0E-06	6,2E-07	4,9E-06	1,3E-07	7,1E-05	2,0E-06	2,9E-09	9,8E-06	2,8E-06	3,0E-08
Marine eutrophication	kg N eq	7,6E-03	0,0E+00	5,2E-03	1,5E-05	4,8E-05	2,7E-06	1,1E-03	2,4E-05	2,1E-06	3,6E-04	8,1E-04	3,8E-05
Freshwater ecotoxicity	CTUe	1,2E+00	0,0E+00	5,3E-02	6,4E-02	1,3E-01	1,4E-03	2,5E-01	1,0E-02	1,7E-04	5,0E-02	5,9E-01	4,0E-04
Land use	kg C deficit	8,0E-01	0,0E+00	-1,1E-01	2,1E-02	7,5E-02	2,1E-03	9,8E-02	8,2E-02	0,0E+00	3,6E-02	6,0E-01	-8,2E-04
Water resource depletion	m3 water eq	3,3E-03	0,0E+00	3,3E-05	-2,9E-05	3,9E-05	-2,1E-06	7,9E-04	6,8E-04	1,3E-06	1,8E-03	-1,0E-05	2,2E-07
Mineral, fossil & ren resource	kg Sb eq	6,9E-05	0,0E+00	-1,7E-07	5,8E-06	7,8E-06	2,0E-06	4,1E-05	1,1E-06	9,5E-09	1,5E-06	9,6E-06	1,3E-08

4.2.2 Fishing: Processes and flows

The results are presented in the **excel file " Marine Fish PEFCR Screening results - Fishing - 09 09 2016.xlsx"**:

- ➢ The sheet "PIVOT HOTSPOTS" presents the most important processes and flows for each impact category per life cycle stage
- ➢ The sheet "Most important processes" and "Most important flows" presents what processes and flows contributed to each impact category.

4.2.3 Fishing: Hotspot analysis

Climate change

Life cycle stages: All stages are important. Fishing, preparation and distribution are the most important.
Processes: Use of fuel, waste water treatment, refrigerant emissions from fishing vessel, waste incineration and electricity production.
Elementary flows: Carbon dioxide and HCFC-22
Hotspots:

- Use of fuel and emission of refrigerants from fishing vessel
- Waste water treatment, other waste treatment and electricity used in preparation of fish
- Production and waste handling of packaging materials used in transport packaging and consumer packaging
- Fuel used in transport from preparation to retailer

Biogenic climate impacts

See results for aquaculture

<u>Ozone depletion</u>

Life cycle stages: Emission of refrigerant (R22) from fishing vessel dominates this impact category totally.

<u>Freshwater eutrophication</u>

Life cycle stages: All life cycle stages are important, preparation is most important.
Processes: Production of electric component, production of polystyrene, production of diesel fuel
Elementary flows: Phosphate
Hotspots: Emission of phosphate from production of electric devices used in the preparation factory, from the production of EPS granulate used in transport and consumer packaging and from the production of diesel fuel used in fishing and distribution.

<u>Marine eutrophication</u>

Life cycle stages: All stages are important. Fishing dominates.
Processes: Emissions from combustion of fuel and waste water treatment.
Elementary flows: Nitrogen oxide.
Hotspots: Emission of nitrogen oxides from the use of fuel in fishing vessel and transport vehicles, from waste water treatment in the preparation of the fish and from the production of packaging materials.

<u>Photochemical ozone formation</u>

Life cycle stages: All stages are relevant. Dominated by fishing and distribution.
Processes: Emissions from combustion of fuel and waste water treatment
Elementary flows:
Hotspots: Emission of nitrogen oxides from the use of fuel in fishing vessel and transport vehicles, from waste water treatment in the preparation of the fish and from the production of packaging materials.

<u>Human toxicity, cancer effects</u>

Life cycle stages: All stages are relevant. Fishing dominates.
Processes: Production of steel and aluminium materials, waste water treatment and construction of roads
Elementary flows: Chromium to air and water.

Hotspots: Chromium emissions from production of steel materials used in fishing vessel and fishing equipment, aluminium used in consumer packaging and from waste water treatment in the preparation stage.

<u>Human toxicity, non-cancer effects</u>

Life cycle stages: All stages are relevant.
Processes: Tyre and brake wear, combustion of fuels, production of chromium and reinforcing steel, production of electronic components, production of aluminium and electricity production.
Elementary flows: Zinc, mercury, and lead to air.
Hotspots:

- Emissions from tyre and brake wear during truck transport from preparation to retailer.

- Emissions from production of steel used in fishing vessel and fishing gear
- Combustion of fuels in fishing and distribution
- Production of electronic components in preparation facility and use of electricity in preparation.
- Production of aluminium used in consumer packaging

Particulate matter

Life cycle stages: All stages are relevant

Processes: Combustion and production of fuels, electricity production, construction of road, production of EPS and waste water treatment

Elementary flows: Particulates, < 2.5 um, Sulphur dioxide and Nitrogen oxides to air

Hotspots:

- Combustion and production of fuel used in fishing and distribution (truck and ship)
- Construction of road used in distribution.
- Electricity use and waste water treatment in preparation
- Production of EPS used in transport and consumer packaging

Ionizing radiation HH

Life cycle stages: Fishing is not relevant

Processes: Electricity, aluminium and card board production

Elementary flows: Carbon-14 to air and Cesium-137 to water

Hotspots: This category is strongly linked to the production of electricity used in preparation of the fish and the production of transport and consumer packaging

Acidification

Life cycle stages: All stages are relevant. Fishing dominates.

Processes: Combustion of fuel, waste water treatment and electricity production

Elementary flows: Nitrogen oxides and sulphur dioxide to air

Hotspots:

- Use of fuel in fishing and distribution
- Use of electricity in preparation
- Production of consumer packaging

Terrestrial eutrophication

Life cycle stages: all stages are relevant, dominated by fishing

Processes: Combustion of fuel and waste water treatment

Elementary flows: Nitrogen oxides to air

Hotspots: Use of fuel in fishing and distribution and waste water treatment in preparation

Freshwater ecotoxicity

Life cycle stages: All stages are relevant

Processes: Brake and tyre wear, production of steel and electric components and waste water treatment

Elementary flows: Antimony, Zinc, Chromium, Copper and Zinc

Hotspots:

- Steel used in fishing vessel and equipment
- Production of electric components and waste water treatment in preparation

-

Land use

Life cycle stages: Distribution dominates this through the use of roads
Processes: Construction of roads
Elementary flows: See table for details
Hotspots: Except occupation of land to construct roads also the input of formic acid contributes to this category

Water resource depletion

Life cycle stages: Preparation and distribution
Processes: Production of packaging materials (EPS and corrugated board box)
Elementary flows: See table for details
Hotspots:

- Water used in production of transport and consumer packaging materials
- Water used in preparation facility and in ensilage production

Mineral, fossil & resource depletion

Life cycle stages: All stages are relevant
Processes: Production of metals and electronic components and maintenance of transport vehicle
Elementary flows: Indium, Nickel, Cadmium, silver and gold
Hotspots:

- Production of metals used in fishing vessel and fishing gear
- Construction of preparation facilities and input of electronic devices
- maintenance of truck used in distribution

4.3 Most relevant impact categories

The guideline for the PEFCR development [25] suggest that identification of the most relevant impact categories shall be based on the normalised and weighted results of the screening study. The normalized results are presented in Figure 4-1. At the same time the EC provide the following statement on the current normalization methods *"Within the Environmental Footprint (EF) pilot phase normalisation and equal weighting were foreseen to be used in the EF screenings to identify the most relevant impact categories. The use of normalisation and weighting for this purpose remains the objective for the EF pilots and beyond. However, currently PEF screening results after the normalisation and equal weighing present some inconsistencies stemming from errors at various levels of the assessment. Therefore, screening results after normalisation and equal weighting are not sufficiently robust to apply for product comparisons in an automatic and mandatory way in the Environmental Footprint (EF) pilots, e.g. to identify the most relevant impact categories. ..."*

Even though it is an option to keep the normalized results in a confidential annex the TS of this pilot has chosen to present them.

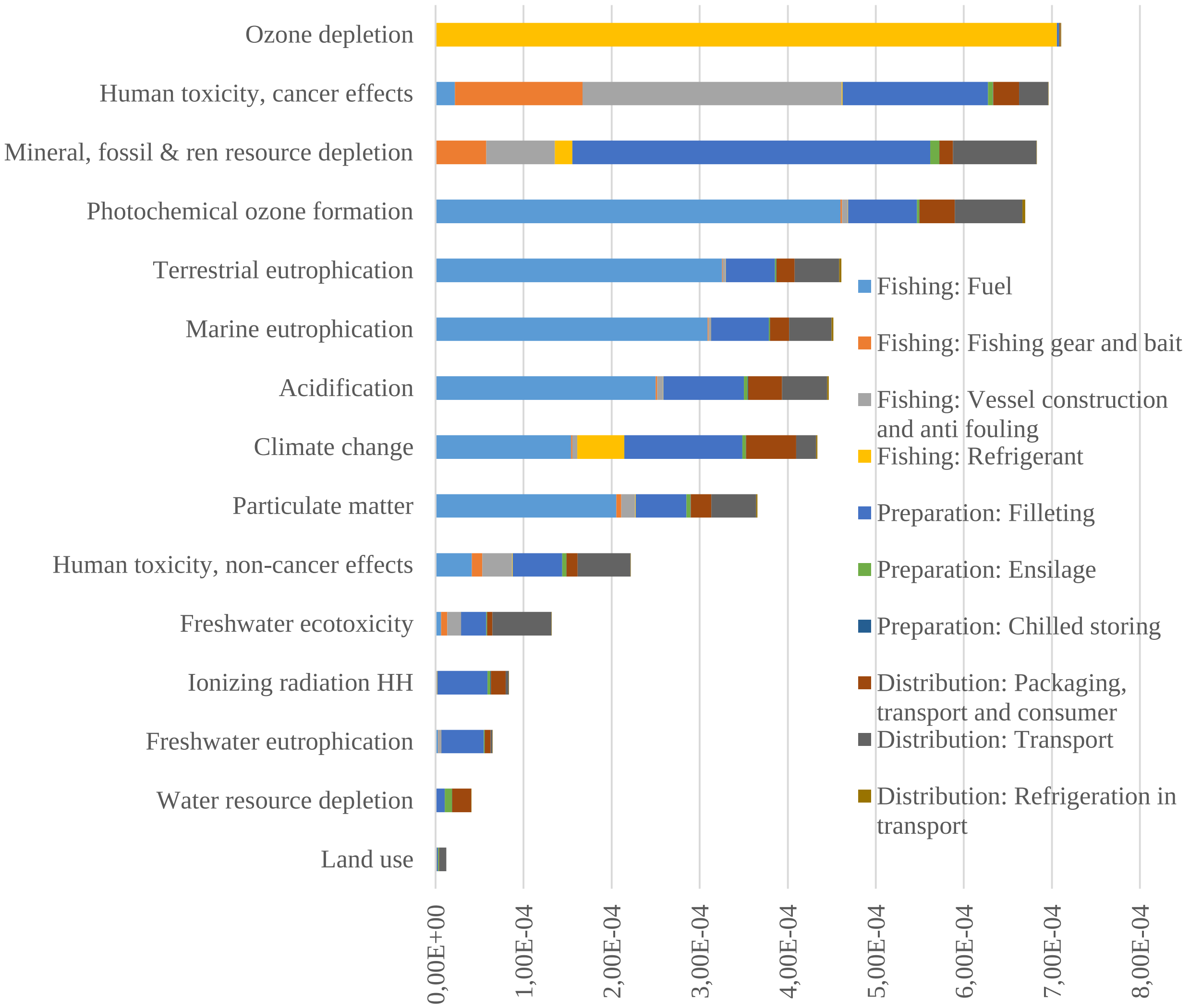


Figure 4-1 Normalized results for 1 kg wild caught product at retailer.

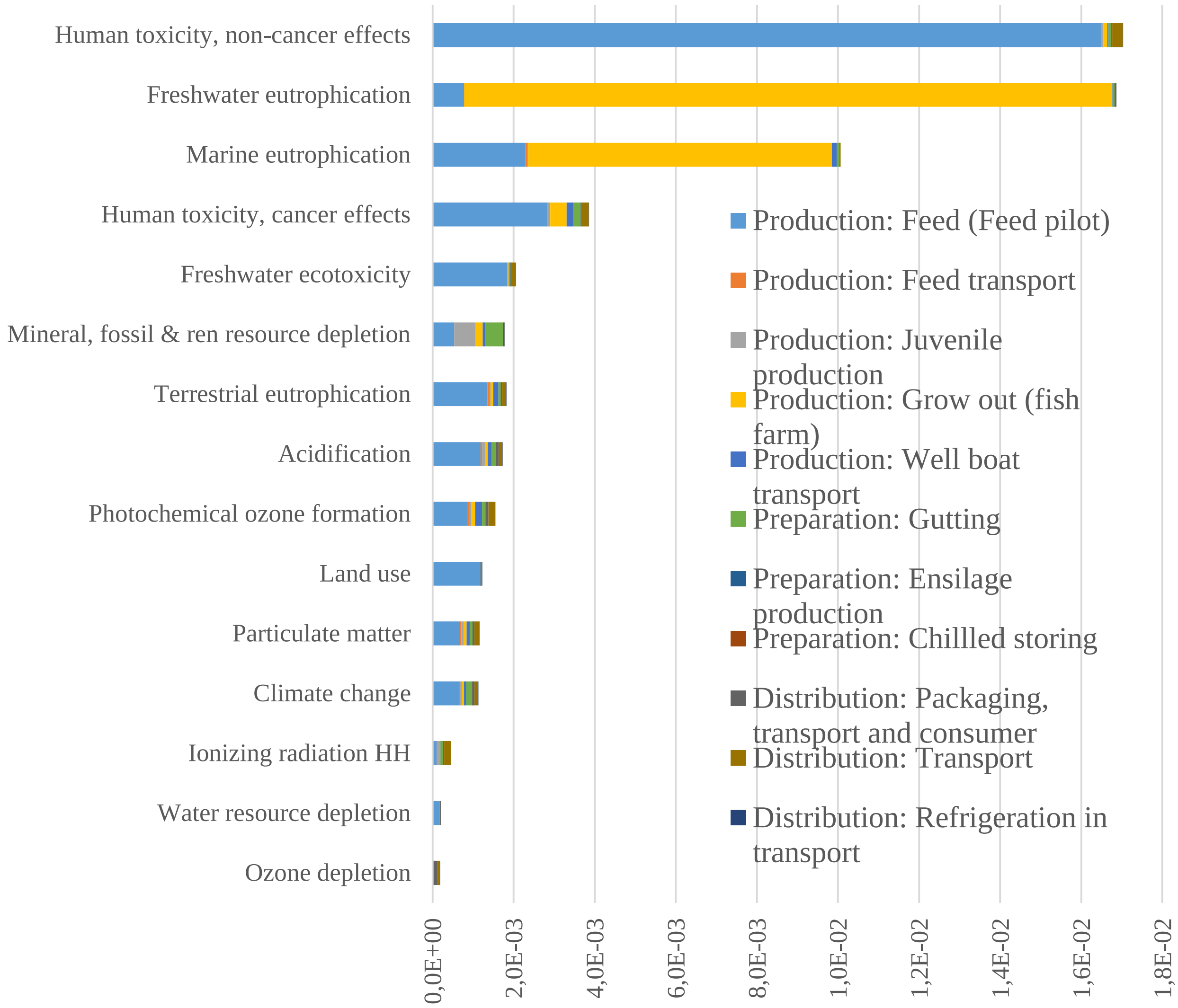


Figure 4-2 Normalized results for 1 kg aquaculture product at retailer.

5 Conclusions from screening

The results of the screening confirm the environmental hot spots identified in previous LCAs of seafood production systems [8-10, 12, 19, 20, 26-58], even though these LCAs have most often only focused on energy use and climate impact.

The investigation of biotic carbon emissions showed that biogenic carbon emissions can be of importance for the climate impact of fish products. With the assumptions and data used in this screening, it was no net climate impact from biogenic carbon (no noticeable emission of biogenic methane). This was due to the assumption that all fish and card board waste go to incineration at the retailer and the consumer stages. Also for the use of paper and card board it is concluded that the EoL formula needs better data to be able to make sure how the carbon cycle of this material is included. Potentially biotic carbon emissions from degradation of packaging materials can be of significance for the climate impact of marine fish products

5.1 Quality of screening data and results

The conclusions and recommendations presented in this report is resting on the existing knowledge from published LCAs of seafood production systems and the screening performed, and thus the quality of the screening.

- The inventory stage confirmed that it does not exist any data sources that makes it possible to perform a screening that cover all production systems that provide the EU market with marine fish products. Neither with respect to exact technologies/methods nor geography. Based on the expertise in the TS it was concluded that using Norwegian data as a proxy is a robust approach to achieve the goals of the screening analysis (chapter 2) and with respect to what types of resource use and environmental impacts that can actually be captured by the default impact assessment method for the screening (the ILCD method).

- Global fisheries and aquaculture systems include a large variation in the quantities of in- and outputs they involve – and thus the environmental impacts they cause. Because of the hugh variation and the lack of data, this screening does not represent any kind of benchmark for this product group. This screening highlights the need for more PEF and LCA analysis of the most important global seafood production systems and the establishment of wide and currently updated databases with the data that these analysis can collect. It is however the opinion of the Marine Fish Pilot TS that a relevant PEFCR will be a requirement to increase the number of PEF studies of fish products. Thus that benchmarking will need a proper PEFCR rather than the other way around.

- Electricity and water input is not regionalized in this screening. This means that the water depletion impact assessment is not precise on where the water is used. And the impacts associated with the electricity production is not as precise as it could be. Despite these weaknesses the conclusion and recommendations for where electricity and water use should be included in the PEF of marine fish products are considered robust.

- Refrigerants emissions was important for several impact categories, e.g. climate and ozone depletion. In the model it is assumed that the refrigerant R134a is used, and that must be considered to be a worst case scenario in terms of these two impacts. It is known for a fact that modern refrigeration systems run on both ammonia and CO2.

- For the preparation of fish it was not possible to get comprehensive data that was both complete and specific to the different product groups (demersal, pelagic and salmon) so a generic process was constructed by combining data for all of these products.

- Brood stock and production of roe is not included. These stages of the aquaculture life cycle is probably not very important for the overall results. Example: From a brood stock of 50 – 60 000 fish it was in Norway produced around 350 million fish. Also note that one roe ends up as ~5 kg salmon.

- Model does not separate between fresh and frozen in terms of energy used during transport and storage, loss at retailer and consumer.

- Waste lost at sea from fish farms and fishing vessels are not included.

- Screening did not include the following potential sources for a net climate impact from the generation of biotic carbon (biotic methane) from: Fish waste (screening assumes that all go to incineration); feed spill; anaerobe degradation of sludge from the juvenile production and anaerobe degradation of paper and card box materials used in packaging.

- EoL formula is not applied

- Sludge treatment only includes drying and no potential substitutions effects from the different nutrients and energy in that sludge.

5.2 Methodical challenges identified in screening

5.2.1 Impact Assessment methodical challenges

Investigation of the ILCD method and other LCA and PEF impact assessment methods shows that several known potential environmental impacts from marine fish production systems are not covered. It is well known that impacts from emission to marine and fresh water is poorly or weakly covered by the established IA methods. Chapter 6.5.1 presents examples of issues associated with marine fish production systems that are not covered by existing/established IA methods. These are mainly different forms of biotic impacts. Novel methods to include abiotic depletion of marine resources was investigated and one alternative is presented in Annex I and Annex II).

In addition to all of the different issues not covered by the ILCD method it was also surprisingly to discover how many of the elementary flow included in important life cycle inventory databases such as Ecoinvent and the ELCD database that the method does not cover (used in Simapro with methods and data provided by Pre consultants). It was also discovered several obvious errors in the ILCD method, e.g. characterization, e.g. emission of phosphorus to marine water showed up in fresh water eutrophication.

It was also pointed out by the marine fish TS that for important impact categories for marine fish such as eutrophication the PEF methodology has an important weakness as long as it can not take into account the exact local conditions and emission rate (speed) thus the Eutrophication potentials can only be understood as vague indicators.

5.3 Feed

This screening confirmed what is well known from existing LCAs of aquaculture products: Feed production is an especially important environmental aspect for fed aquaculture products. Feed showed up as especially important for process/stage for all impact categories except freshwater eutrophication, but this impact category is also connected to feed as the nutrient emitted come from the feed. More detail information of what determines the PEF of aquaculture feeds can be found in the compound feed pilots, but aquaculture feeds have also been studied other places, e.g. Norwegian aquaculture [14, 21, 27, 33, 43] and numerous journal articles [6, 12, 31]

5.4 Aquaculture grow out

The grow out of the fish is contributing to all impact categories except the land use. Especially important is eutrophication and freshwater ecotoxicity. These impacts are mostly caused by emissions of nutrient from feed spill and faeces. Toxicity is caused by emissions anti fouling agents.

- **Aquaculture, marine net pen grow out.** The most important environmental aspect with this stage is the use of feed and emission of nutrients, phosphorus and nitrogen from feed loss from the pens and faeces. Here it is pointed out that the ILCD method contains errors for its freshwater eutrophication impact assessment. It is also pointed out that as long as the impact assessment do not include the exact locality and local conditions for the emission of nutrients, the calculation of marine eutrophication potential is highly uncertain. The most important input to these processes (since feed is considered its own life cycle stage) is the use of fuel and electricity. It is known that a lot of the fuel that is used at marine net pen farms is used by subcontractors and it will be important to include this consumption.

5.5 Juvenile production

The juvenile production is especially relevant for ozone depletion, ionizing radiation and resource depletion. This through the use of electricity.

For this screening it was assumed that the juvenile RAS plant produce fish up to 100 gr and that this fish is slaughtered 18 months later with a weight around 4-5 kg. Thus it was easy to foresee that impacts from juvenile production would not make a major contribution to the overall impacts once this is measured per unit of edible fish. It is, however, possible that other production than salmon, and also future salmon production systems, will bring the juveniles up to bigger sizes before they are transferred to net pen systems. Based on this knowledge it is concluded that the energy used in the juvenile production and the feed should be included with specific data. We assume that the recommendations presented here would also be valid for systems where also the grow out is performed in recycling aquaculture systems (RAS).

5.6 Fishing

Fishing is an important life cycle stage several impact categories and should be included with precise data on consumption of fuel and emissions of refrigerants per unit of fish landed. To make sure that these consumptions and emissions cover all activities needed to perform the fishery and seasonal variations these data should be based on average values for at least one year.

The screening model uses data from Norwegian fisheries as a proxy for the fuel use in fisheries, but it is well known that fuel intensity in fisheries can vary a lot. It will be the results of parameters such as:

- the fishing gear that is used, active fishing gears like trawl often use more fuel per unit landed than passive fishing gears like gillnets
- Natural variations. The behaviour and abundance of the targeted species vary with time and place.
- Weather. Especially for fisheries that are only open at certain times or with species that is best to fish at certain times of the year, the weather at that time can play a role for the energy used/efficiency of the fishery.
- Condition of the targeted stock, les abundant fish normally means more effort to find and catch what is left

- Regulations, all fisheries operate within a frameset defined by regulators. These will influence on the fuel use of the fishery, e.g .by regulating what gears can be used, how they can be used and where and when they can be used. Quota allocation.
- Energy prices and fuel subsidies
- The "skipper" effect. It has been studied how the competence and the behaviour of thos operating the vessel will influence the fuel use. E.g. the speed used during transport to and from fishing fields will be important.

5.6.1 Analysis: Fuel intensity of fisheries

To study he potential effect of other fuel input a sensitivity analysis was set up with the following cases:

1. Using the same fuel factor for demersal and pelagic fishing as is used in this screening: 0,095 and 0,245 litre fuel per kg landed.
2. A low case, here we consider the average value for Norwegian pelagic fisheries already as low. For the low value of demersal fishing the fuel factor for Norwegian coastal demersal fisheries was used, 0,15 litre per kg landed.
3. A high case. Here the fuel factor for tuna fishing, data was collected from the journal article " Life cycle environmental impacts of Spanish tuna fisheries" by Hospido and Tyedmers (2005) [59], this gave pelagic fisheries a fuel factor of 0,527 litre/kg landed. As a high value for demersal fishers the fuel factors found in some Norwegian trawlers was used that also fish shrimp, these vessels can use up to 1,3 litre of fuel per kg landed. This is of course not representative for that fishery, but used here to include what we consider an extreme value. It is obvious that having fuel factors higher than that would be challenging economically unless a very high value species is targeted.

Figure 5-1 presents the result of this sensitivity analysis. The result is as expected: For all impact categories where the fuel used in fishery is important, the results shift with the change in fuel input. For particulate matter, acidification and terrestrial eutrophication the result can be doubled if the fisheries have what we consider as high fuel inputs.

Conclusions:
This sensitivity analysis does not change the conclusion that fuel use in fisheries is an especially important parameter for the environmental footprint of fish products and that these data should be as specific as possible for each product. However, the analysis do show that the use of Norwegian data as a proxy for all pelagic species, is probably underestimating the importance of fuel use since tuna is a very important species in terms of volume consumed in the EU and Tuna fisheries show a considerably higher fuel input than the average Norwegian pelagic fishery. This point at an important improvement point for this screening.

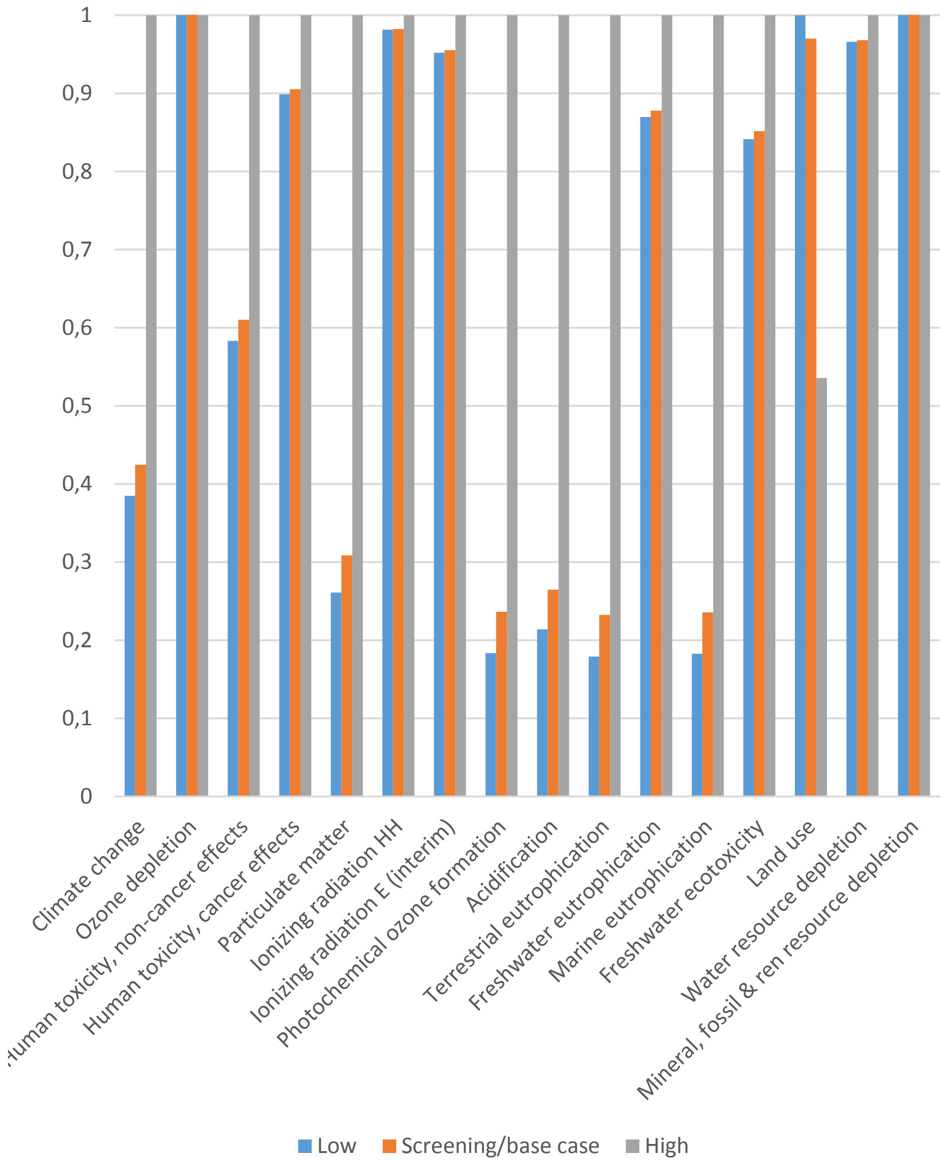


Figure 5-1 Sensitivity analysis fuel factor in fisheries, per kg representative product consumed.

5.7 Preparation

This process refer to the steps transforming or conserving the fish between being fished or fed in the fish farm and being sold to the consumer. Preparation can include transformation of the fish, e.g. bleeding, gutting and filleting, and freezing and chilling of the fish.
The main part of the environmental impacts from this stage is connected to the use of electricity and the waste water treatment. A closer look at the data that was used for the waste water treatment, shows that there can be significant differences and that probably more specific data should be used.

5.7.1 Analysis: Waste water treatment

Waste water treatment showed up as an important contributor to global warming, particulate matter and human toxicity (cancer effects). This process modelled the treatment of waste water from the fish preparation with the ELCD process "Waste water - untreated, organic contaminated EU-27 S LCI result

S". This data set covers all relevant inputs and outputs from the treatment of incoming waste water from industrial processes.

The ELCD data used for this screening was compared with other data set on waste water treatment from the ELCD database. Figure 5-2 show a comparison of three ELCD data sets on waste water treatment (treatment of 1 kg waste water), the one that is used in this screening (Waste water - untreated, organic contaminated EU-27 S LCI result S") has more than twice the environmental footprint than the others.

From this is concluded that it must be considered if the data that is used in this screening, actually is representative for the type of water treatment that water from fish preparation factories go through. Likely a lot of this water goes directly to the sea without treatment, then the contaminants (e.g. organic components) on this emission need to be included in the PEF.

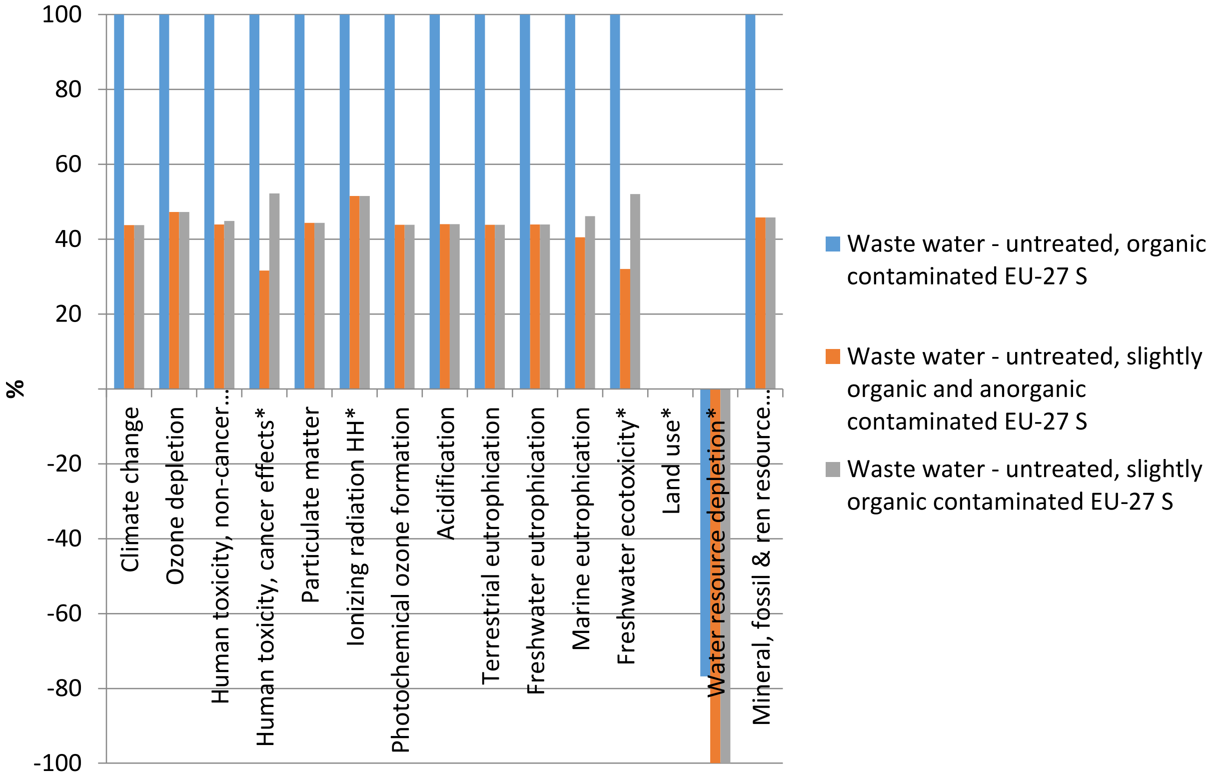


Figure 5-2 Comparison of ELCD data on waste water treatment

5.8 Transports

Distribution (or transports) was an important life cycle stage for several impact categories. These impacts arise from emissions from combustion of fuels; fuel/energy production and production of refrigerants, production of refrigerants and energy used in the refrigerating systems. For toxic impacts the use of road transport vehicles, brake and tyre wear, was also relevant.
This screening only included transport on road and sea. Seafood products are also often transported with airplanes, such transport typically have an even higher environmental impact per tonne*kilometre. Other transport means that are used and have a lower footprint than road transport I railway. Even with a high

share of railway transport it is still assumed that transport will play a significant role in the PEF of a marine fish product.

5.8.1 Analysis: Transport distances

The fish consumed in EU comes from all over the world and thus transport distances will vary from close to zero to the other side of the world. Sometimes even more as some products have a very inefficient transport route, e.g. Norwegian products consumed in Europe can be prepared in China. In the screening transports from preparation to retailer was included using the distance from Norway to big cities in Europe as a proxy (chapter 3.5). Many transport will be longer than those used in the screening, e.g. for products coming outside of Europe and also for fish from the very north of Norway to the very south of Europe. To study the effect of changing transport distances three cases was modelled:

- Half scenario: Distances half of what is used in the screening
- Screening: Distance as is used in the screening
- Double: Distances double of what they are in the screening.

Figure 5-3 presents the result of this sensitivity analysis.

Conclusions:
Transport distances is obviously an important parameter for several of the impact categories, still it had to be a doubling of the distances to shift the results with more than 10% for several impact categories. For the four impact categories suggested as most relevant (chapter 4.2): climate change, ozone depletion photochemical ozone formation and marine eutrophication, the changes was highest for ozone formation where a doubling of distance lead to more than 10% increase in the result.

In a PEFCR the transport distances should be included with precise data. Not only distance but also duration of transport sine resources use and emissions from refrigeration systems is determined by duration rather than distance (even though they are connected). Also the transport vehicle capacity utilization will be an important parameter. Ideally transport should be covered with a specific fuel consumption rather than being calculate based on assumptions on fuel use per ton*km.

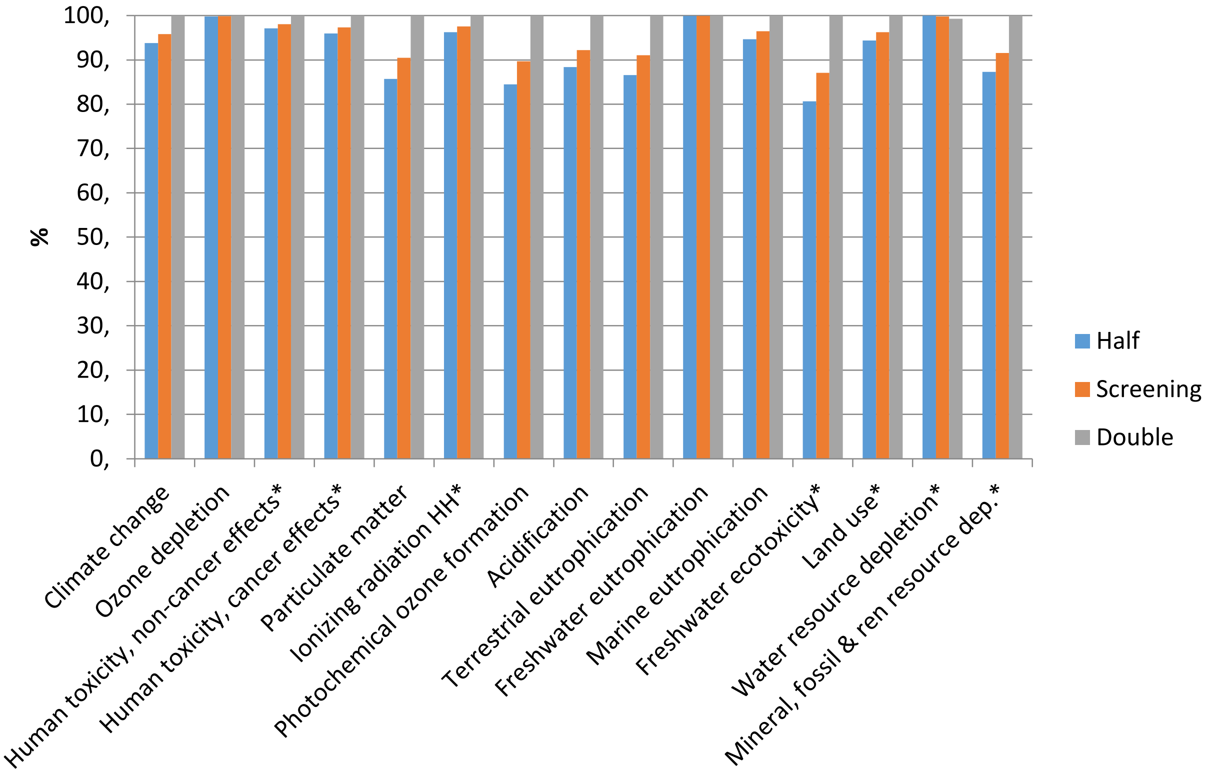


Figure 5-3 Analysis of the sensitivity of transport distances

5.9 Packaging materials

The screening model did not include a complete EOL formula, this was limited by the availability of data for the different parameters in this formula. Thus there are several weaknesses in how packaging materials are included in this screening, but it is the opinion that it is safe to conclude that for marine fish products, the packaging plays such an important role that it should be included with data that are specific on the composition of the input material and on what end of life treatment it goes through, e.g. if biogenic methane will be generated.

5.10 Analysis: Electricity production data

To investigate the importance of the impact profile associated with the electricity input and potential weaknesses of not having regionalized the electricity inputs to the foreground system the representative product was modelled with three different electricity consumption mixes (with ELCD v3.1 data):

I. Average for EU27, same as what is used for the screening results (see chapter 3.17)
II. Icelandic consumption mix
III. Estonian consumption mix

Icelandic and Estonian consumption mixes was chosen as two extremes based on the following approach: All data on consumption mixes (27 countries) in the ELCD v3.1 database was analysed with the ILCD method. The normalized results was summarized (the value/results for impact category) and this number was used to sort the data from low to high. With this approach the Icelandic consumption mix got the lowest score and was chosen to present a low impact electricity mix. On the other side the Estonian consumption mix had the highest score and was chosen to represent a high impact electricity consumption mix.

This sensitivity only address changing electricity input to the foreground systems and not the entire model (including background data from the ELCD, Ecoinvent and Agrifootprint database). More precisely to the following processes:

- Ice production
- Retailer and consumer activities
- Aquaculture grow out and juvenile production
- Preparation
- Juvenile production 0,3 Mj/kg
- Preparation of fish 1 MJ/kg

In total the electricity input to the foreground system of the screening model was around 2,3 MJ/kg fish consumed. The biggest drivers for this electricity use was preparation 1 MJ, smolt production 0,29 MJ; retailer 0,12 MJ; chilled storage, heating and dishwasher at consumer 0,77 MJ.

The results with these different electricity inputs are presented in Figure 5-4. The impact categories that changed more than 10% was:

- Climate change, Particulate matter and Acidification: Showed an expected pattern with a reduction with an electricity mix with more renewables
- Ionizing radiation: The EU27 mix has a higher score than the Estonia mix,
- Water depletion: The only case where the Icelandic mix gives the highest impact, shows how much electricity dominates this impact category.

Conclusion:

For the impact categories climate change, particulate matter, ionizing radiation and water depletion it important to use country/region specific data. This is especially important for the life cycle stages production, preparation, retail and consumer.

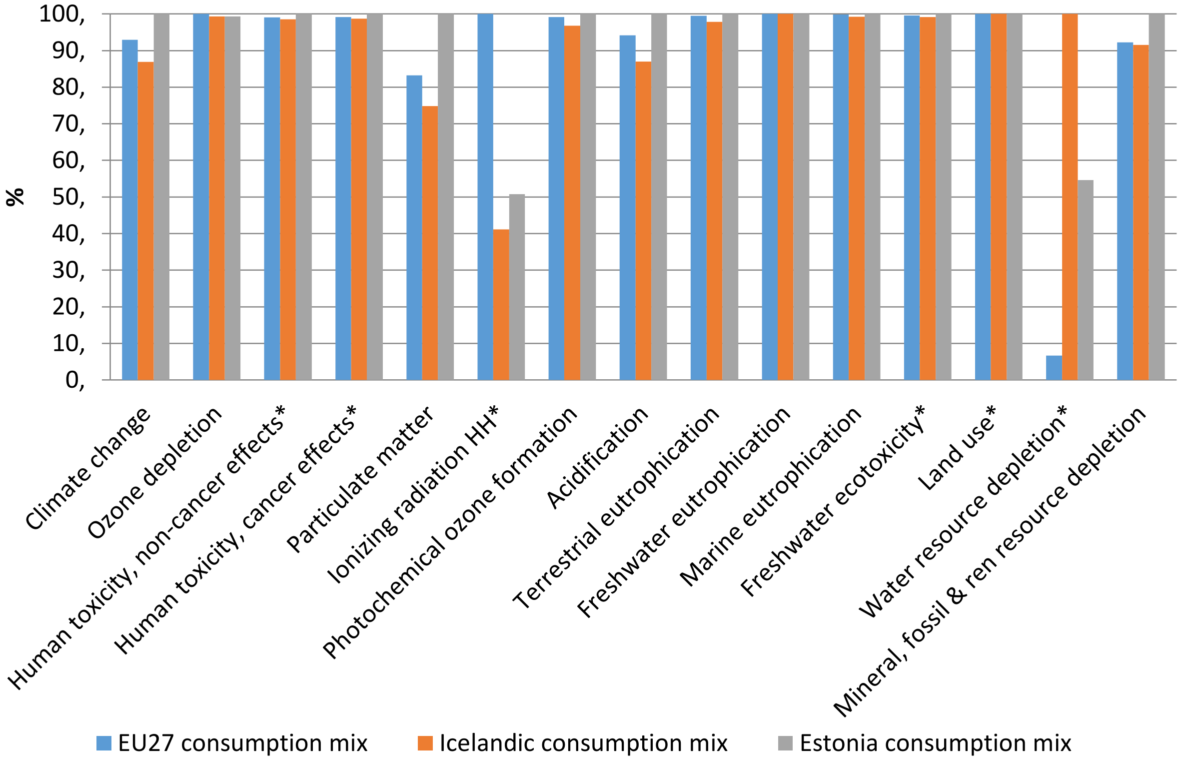


Figure 5-4 Electricity input sensitivity analysis

5.11 Analysis: Refrigeration systems

As was expected from the study of carbon footprints of fished seafood, emission of refrigerants was identified as an important environmental hotspot for climate impacts and ozone depletion [21, 33]. The results that are related to refrigerants emissions, will be sensitive to a number of assumptions and/or data uncertainty:

- What type of refrigerant is actually being used? The baseline for this screening was that refrigeration systems in fishing vessels, preparation factories, transport, retailer and consumer use the refrigerant CFC-113, also known as R22. It is known that most new fishing vessels use ammonia and/or CO_2 and this is also probably the case for most onshore use of refrigeration systems. Thus the baseline results must be considered a worst case scenario with respect to refrigerants related impacts.
- Emission rate. The emission rate per unit of fish handled is a function of several factors each with their own uncertainty:
    - In the baseline, it is a general assumption that 10% of the volume of refrigerants in each system leaks out per year. In a perfect system this would be zero and for other systems it can be much more, especially when considering wrong handling of old systems and accidents during use and maintenance.

- Volume of refrigerants in each system is depending of a more precise definition. Especially for fishing vessels the size of the refrigeration systems together with the size of the vessel, thus with several orders of magnitude
- Allocation of refrigeration capacity to units of fish handled.

These results have a considerable weakness in that it does not take into account that the change of refrigerants also changes the efficiency of the refrigeration systems and possibly the average emission rate. On reason for the popularity of the R22, despite its heavy climate and ozone impacts, is that it is an energy efficient refrigerant. In this screening, we did not have the data to evaluate where the trade-off between decreased impacts from emissions would be traded off with an increase in energy used to provide the same level of refrigeration. For ozone depletion, the change from replacing R22 is so big that it is probably safe to conclude that it is a net reducing effect, but for climate impact, the change is smaller and thus more difficult to conclude.

6 Recommendations for Marine fish PEFCR

The following chapters presents recommendations for a future PEFCR for marine fish products.

6.1 Terminology: shall, should and may

This recommendation uses the following terminology to indicate the requirements, the recommendations and options that could be chosen when a PEF study is conducted.

- The term “shall” indicated an absolute requirement
- The term “should” is used to indicate a recommendation rather than a requirement.
- The term “may” is used to indicate an option that is permissible.

6.2 Scope: Functional unit and reference flow

The following functional unit is recommended:

What: Marine fish products for human consumption and the packaging needed to deliver 1 kg of edible product to the final consumer.

How much: 1 kg edible marine fish

How good: The product should be appropriate for human consumption

How long: For products where durability or shelf-life is established

This definition includes that the suggested reference flow will be 1 kg edible fish. Edible is here defined as skin and boneless fillet.

The conversion factors that are used to calculate from live to edible fish, and all intermediate stages, shall be clearly documented. The mass flow of fish from live state to edible part shall be documented including indication of all by-product and waste flows generated from the fish.

It exists established conversion factors for most species as this conversion is an important part of both trade and fisheries regulation[13,14].

[13] Example of official conversion factors used in the Norwegian economic zone: http://ec.europa.eu/fisheries/cfp/control/conversion_factors/norway_regulation_en.pdf

6.3 Scope: System boundaries – life-cycle stages and processes

The screening covered the life cycle from cradle-to-gate – feed production and fishing up to retailer gate, and showed that for both fished marine products and marine aquaculture products all life cycle stages are relevant for one or several impact categories. How detailed each stage should be modelled in is suggested in chapter 6.7.

The following life cycle stages shall be included in a marine fish PEF:

- Feed production including feed transports. The complete feed production system, from growing of crops and extraction of marine feed ingredients and up to farm gate (where feed is used). This can be covered by the Feed for food-producing animals PEFCR that is being developed [15]
- Juvenile production. Including energy used to operate the production and feed used.
- Fish grow out. Including energy used in operation and maintenance of the fish farm and all other activities needed to run the fish grow out.
- Fishing of wild caught fish. Including energy used by the fishing vessels (for all operations that is needed to perform fishing over time). Input and emissions of refrigerants.
- Transport of living fish: Juveniles to fish farm and fish ready for slaughter.
- Preparation of the fish. Including energy used in the handling, refrigeration and storing of the fish. Preservation of by-products should also be included.
- Packaging materials. Including production of the packaging materials and waste handling of these materials.
- Transport of fish from landing/preparation to retailer. Including energy used to move the products and refrigerants and energy used to keep them refrigerated.

6.3.1 Use and retail phase impact potential

The screening presented here did not include the retail and use phase. In earlier stages of the screening these stages were included[15] based on the recommended data from the EC commission[16]. As was foreseen the relative low footprint of seafood products showed that also the retailer and consumer activities can cause a significant contribution to several impact categories. Examples that seems to be especially important are; how the consumer got “transported” to the retailer, how much and what energy was used to prepare and store the product and how much of the fish was actually eaten. To ensure that durability of the product is included it is recommended that if the PEF includes the retail and use phase the functional unit should be per unit of fish eaten – not just edible. A very important measure to reduce environmental impacts from retail and consumer activities is to reduce loss/waste and to improve overall resource utilization.

---

[14] Conversion factors used by the FAO: www.fao.org/fishery/cwp/handbook/I/en
[15] Screening for public consultation available from Marine Fish PEFCR pilot webpage: https://webgate.ec.europa.eu/fpfis/wikis/display/EUENVFP/PEFCR+Pilot%3A+Marine+fish+for+human+consumption
[16] TAB Issue paper: Guidance and requirements for handling the use stage in PEFCRs Version 5.1 – January 2016

6.4 Allocation

For processes with multiple outputs allocation shall be done based on the hierarchy defined by ISO 14044:20065, the PEF guidelines and ENVIFOOD protocol:

- Step 1. Allocation should be avoided by 1) dividing the unit processes to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or by 2) expanding the product system to include the additional functions related to the co-products.

- Step 2. The inputs and outputs should be partitioned between each of its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products of functions delivered by the system. **For the marine fish products, the preferred physical relationship is mass.**

- Step 3. Other relationships, including economic allocation.

If allocation cannot be avoided, mass allocation shall be used in at least the following processes:
- Fishing
- Aquaculture (juvenile production and grow out)
- Preparation, all steps of preparation between live fish and consumption.

For transport and storing of the fish it is often more relevant to use volume rather than mass as allocation key.

It shall not be allocated to outputs considered waste, only to outputs that are a commercial commodity for other production systems – this includes by-products. Input to energy recovery through incineration should not be considered as a commercial product.

Allocation is always debated. Mass allocation is recommended because it is a simple and straight forward method that can easily be understood and controlled. The most commonly suggested alternative is economic allocation. Both these allocation methods have numerous strengths and weaknesses and potential effects on the behaviour of decision makers in the value chain. One effect of mass allocation in seafood production systems is that the share of environmental burdens attributed to the by-products can be higher that what it would be using economic allocation. However it is advised that when considering the net effects of different allocation methods it must be considered that most aquaculture systems both yield and use by products so the net effect is not always straight forward to identify if the allocation is consistent all the way from feed production through preparation and processing.

We recommend that further discussions of allocation methods include a wide range of LCA experts (from the seafood sector and outside of it) that are currently not directly involved in the PEFCR pilots and that this discussions start out from the already existing body of peer reviewed articles where allocation is a theme, e.g. the discussion of allocation methods between Tyedmers, Pelletier and Weinzettel [60-63] and other articles and reports [63, 64]

6.4.1 Analysis: Economic vs mass allocation

This chapter presents the results when allocation in the preparation of the fish is 1) changed from mass to economic allocation and 2) if it is assumed that none of the by-products are utilized. That they are all waste.

Figure 6-1 presents how the results change when allocation is changed for the fished product. As expected they increase with economic allocation. The increase is biggest for the impact categories where the lifecycle stages before preparation are especially important, see the detailed study of how the carbon footprint changes in Figure 6-2. The salmon aquaculture product was also studied with the different allocation methods and showed the same trend, but the differences was less since that case already included lower utilization of by products (that case assumed that the fish is exported gutted).

The economic allocation is done based on input from TS members on the value of their products, these values and the yields are presented in Table 6-1. The economic allocation factor for each product is calculated as their share of the total value of the output. For product *a* from a process with *n* outputs, the allocation factor is calculated like this (the yield is the mass of each product):

$$allocation\ to\ product\ a = \frac{value_a * yield_a}{\sum_{i=0}^{n} value_i * yield_i}$$

Table 6-1 Yield data for mass allocation and relative product values for economic allocation in preparation

Process	Mass yield	Economic value used for screening
Salmon from live to fillet	Live to head on and gutted: 0,83 kg/kg Skin and boneless fillet from head on and gutted: 0,54 kg/kg **Live to skin and boneless fillet: 0,45 kg fillet/kg live**	**Fillet: 78 NOK/kg** **By-products: 3 NOK/kg**
Demersal from live to fillet	0,75 kg head off and gutted /kg live fish *0,6 kg skin and boneless fillet/kg head off and gutted = **0,45 kg skin and bone less fillet/kg live**	**Fillet: 78 NOK/kg** **By-products: 3 NOK/kg** **The TS representatives did not provide data so salmon values are used as a proxy until better data is made available**
Pelagic from live to fillet	**0,5 kg skin and boneless fillet/kg live fish**	**Fillet: 1,6 NOK/kg** **By-products: 0,22 NOK/kg**

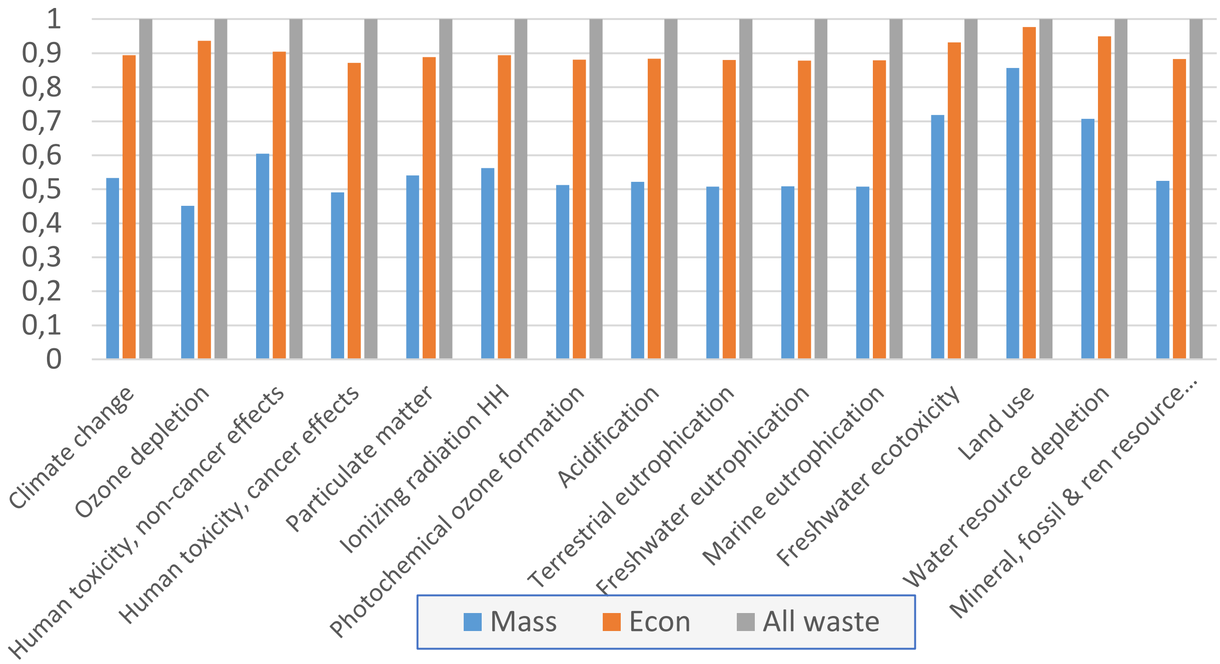


Figure 6-1 Comparison of the results for 1 kg fished edible product at retailer gate, with mass or economic allocation or assuming that all by-products are waste in the preparation of the fish from live to fillet.

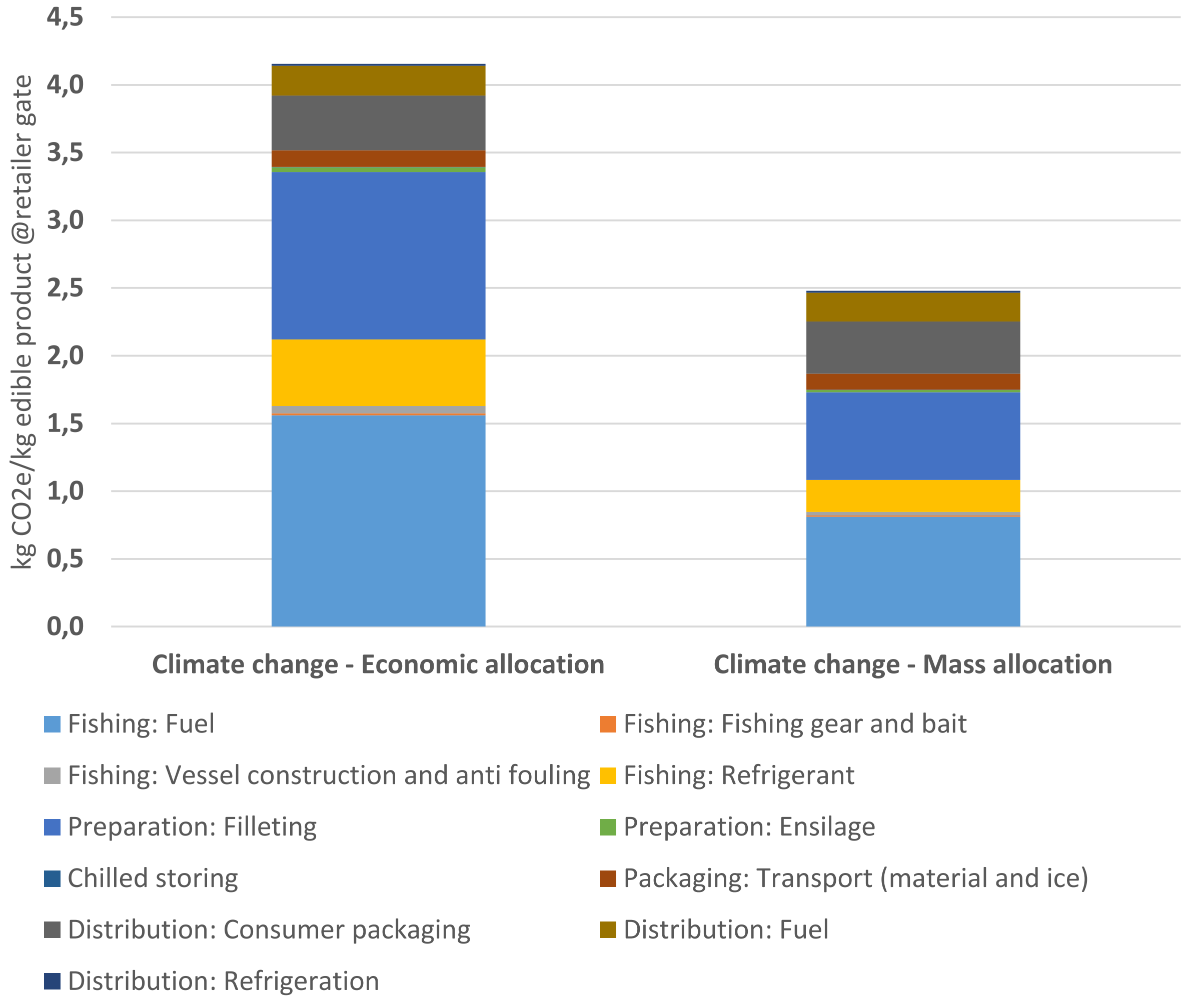


Figure 6-2 Detailed study of how the carbon footprint of the fished product changes when using economic allocation instead of mass allocation

6.5 Scope: Impact assessment methods

The following impact categories shall be covered in a marine fish PEF, this is only a minimum and other impact categories should also be included if possible.

The PEFCR guide suggest to that the impact categories that are included in a PEF is selected based on the normalized results in the screening, but considering the results of this and the known weaknesses in both impact assessment methods and normalization this approach is not considered any better than a more qualitative selection. Marin Fish Pilot TS suggests the following impact categories for the PEFCR and communication purposes:

Climate change. GHG emission and global warming potential is a concern and focus area for all products, global food production is also a significant source of GHG emissions and thus an impact category it is important to address for food products. The low normalized score for the fish product is actually an argument that climate should be one of the impact categories used for fish products.

Ozone depletion Ozone depletion can often be linked to the use of refrigerants, electricity and EPS packaging and refrigeration is a part of all seafood life cycles, thus an environmental aspect that is important for the producers to have an eye on.

Photochemical ozone formation as the dominating life cycle stages are fishing, feed production, aquaculture, distribution, preparation with the use of fuel in various processes as the hotspots. This indicates that potential improvements can be achieved by the relevant operators concerning this impact.

Marine eutrophication as the dominating life cycle stages are aquaculture, feeding, fishing and distribution with direct emissions and use of fuel are the hotspots which also indicate potential for improvements. Eutrophication is, however, dependent on the capacity of the recipient and this might vary considerably between areas and geography (closed / open waters, currents).

Other impact category that was also suggested for communication was:

Water resource depletion and land use: Together with climate changes, water resource depletion and land use is an environmental challenge for food production systems and food production is a major user of fresh water resources and land. For marine fish systems fresh water and land is mainly used in the growing of crops for aquaculture feed. In addition water is also used in the rearing phase of juveniles, however, this is more and more done in recycling systems where the net input of fresh water is relatively low. Fresh water might also be used in cleaning and disinfection processes, e.g. in preparation of fish. Sea water might be used as substitute for fresh water during the preparation of marine fish. One major challenge to include water resource depletion in the current state is the impact assessment method that is used by the ILCD method of today, is not considered reliable. The same goes for land use. However, better and more consistent impact assessment methods for these two categories are currently under significant development and including them in a Marin Fish PEFCR should be reconsidered once these have been evaluated and maybe implemented in the ILCD method.

6.5.1 Additional environmental information

The following chapters presents environmental issues that can be associated with fisheries and aquaculture – by sound scientific evident and/or because important stakeholder groups perceive them as environmental concerns. These are issues that if relevant for the product should be addressed under additional information for marine fish PEFs.

It is known that several environmental impacts from fish production systems are not covered by existing and established LCA/PEF impacts assessment methods. Especially important is that it does not exist methods that can quantify biotic impacts. This is not saying that it does not exist methods to assess biotic impacts, but as of today these are still under development, and we do not consider them as established or robust enough for the purpose of including them in a marine fish PEF of today. Even for the most promising methods it is still a challenge that the data necessary to use them is lacking. An exception from this paragraph is the novel method for inclusion of biotic impacts that we suggest (Annex I). Some comments to that method is presented in Annex II.

The inclusion of biotic impacts is a challenge for several PEFs pilots. One suggestion to address such impacts is to require that it is informed (under additional environmental information) if the product is certified by a recognized third part (eco-certification and eco-label scheme). This suggestion have been discussed by the Steering Committee (SC) and the Technical Advisory Board (TAB) of the PEFCR pilots. The exact details of these discussions can be found in the documentation from these meeting, but the overall conclusion seem to be that this is not recommended as a "shall" requirement. Some of the arguments for this is that it is that commercial actors should not be an obligatory part of a PEF and that the methods the known certification schemes use for biotic impacts is not quantitative, thus decision makers would still not be able to directly compare biotic impacts with the quantitative impact assessment methods.

Table 6-2 potential environmental impacts and additional environmental information

Fishing. Reducing stock and its bearing capacity through fishing of targeted and none targeted species.	By killing fish the fishing will influence the bearing capacity of the stock. If the sum of fish killed exceed the bearing capacity of the stocks/ecosystem this can lead to unwanted negative biotic impacts. In worst case stocks can become extinct. By-catch is a concern when these catches are not included in the regimes that regulates the fishery to make sure that the bearing capacity is maintained. When by-catch or unwanted sizes ore qualities are discarded these losses in the ecosystem are not accounted for and may lead to the sum of outtake/killing becoming too high. This type of impacts is not covered by any of the existing and established impact assessment methods, but a new method is explored and an explanation of this method together with examples of its use is provided in Annex I. Discard is included as an inefficiency as none of the resource use or emissions from the fishing should be allocated to the discard. Discard rates/volumes for the fishery should be given as additional information. The impact assessment method suggested in appendix I also includes discard as one of the input parameters.
Fishing. Benthic impacts from the use of fishing gears such as trawl	Potential for biotic impacts if benthic environment is disturbed and/or destroyed by fishing gears. There are numerous different suggestions for how to address benthic impacts in a quantitative way. One of them is to inform about the distance that is trawled per unit of mass landed. This does however not inform in any way about the actual environmental impact as that would depend on things such as specific conditions of the area that is trawled, the fishing gear, speed and if the area has been swept with bottom trawls for a long time and regularly.
Fishing. Impacts on fish and mammals from lost or left fishing gear (ghost fishing).	These impacts are specific to the use of certain gears and/or of occasional kind, but are of concerns due to possible effect on biodiversity but also a matter of animal welfare if birds or mammals are trapped in lost fishing gear. Methods to assess these impacts are however, up to the knowledge of the TS, not developed. Loss of fishing gear can also be a waste problem as it adds plastic, e.g. micro particles) to the marine environment. A method to address this is providing information of the mass of gear that are lost. Problematic that decision makers probably will not be able to distinguish between the mass of e.g. A gillnet (relative low mass, but high ability to catch fish) vs a trawl (high mass, but also a potential to sink to the bottom and stop catching fish).

Fishing/aquaculture. Impacts from paints, fuel and other chemicals used in the marine environment.	Both fishing and aquaculture involves using chemical close to or in the marine environment. These can be emitted through leaks or accidents. The use of anti-growing agents on fishing vessels and fish nets are one example. Such chemicals have been known to contain toxins. As of today the ILCD method does not seem to capture the elementary flows that can be associated with the chemicals identified in this screening, but for sure there are a lot of different chemicals that can be used and probably some of them does not follow the relevant regulations on what chemicals they can contain. A method to address this, is that it should be informed about what chemicals that are used for anti-growing purposes (on nets and vessels), lice treatment and the volumes/mass that are used. Information about what mass and volumes that are used can be difficult to understand as that does not say anything about potential environmental impacts unless identical chemicals are compared.
Aquaculture. Potential to increase the occurrence in open cages of parasites for example sea lice and other agents causing transmissible infections or infestations that might have an effect on wild populations.	There are several different infections and infestations in fish caused by quite different microorganisms and parasites, and the susceptibility of the various fish species of a given disease differs considerably. Thus the impact of a given aquaculture production is dependent on: - the species of the farmed fish, - the variety of wild species in the surrounding area, - the geographical location of the fish farm itself since the occurrence of various infectious microorganisms, the occurrence of wild species that might have and/or attract the various diseases and the geographical and physical characteristics around the site itself, might differ considerably even between relatively short distances. (e.g. currents and tidal water flows). It is also so, that the likelihood and the risk of impacts on wild stocks from infectious agents in fish farms, is in general, considered as very low[17]. However, in certain regions or situations there may be concerns when a specific infection or parasite occurs in large amounts and if there are wild stocks of susceptible species in the same area. The occurrence of sea lice on salmonids is an example of this. The current scientific knowledge indicates that sea lice represent a relative risk of non-return of salmon to the rivers for reproduction due to sea lice is in the interval 1.1 - 1.2 compared to non-existence of sea lice. However, the contribution from sea lice from fish farms compared to sea lice from wild salmon stocks, is not known, but several studies indicate a limited contribution from sea lice from fish farms[18]. A consequence, is that there are no validated method to assess the impact of sea lice from fish farms on wild stocks in addition to the fact that the impact can not be of significance for the regional nor global occurrence of wild salmonides.

[17] www.imr.no/publikasjoner/andre_publikasjoner/risikovurdering_miljovirkninger_av_norsk_fiskeoppdrett/nb-no
[18] www.fhf.no/prosjektdetaljer/?projectNumber=900932

Aquaculture. The potential to have negative effect on wild stocks through escaped farmed fish that breed with wild fish and/or compete on breeding grounds.	The likelihood of impact of escapee from fish farms on the genetics of the corresponding wild stocks, might vary. A relevant example is escapees from salmon farming on wild salmon. No impact will of course occur if escapes does not occur, but even if escapees get away, methods do not exist for the estimation of impact on the genetics nor the genotype of the wild stocks from a given production site or area. Therefore, it is suggested not to give information on number of fish that have escaped during a production period since this will be misleading concerning estimation of potential impact to wild stocks.
Aquaculture. Local benthic impacts from the fish farm and organic matter being emitted from the farm such as faeces and feed residues.	The local impact of emission of organic material such as feed and faeces on the benthic biotope under the open cages, will vary considerably pending on the geography and water movements around the sites, the species of fish, the climate, the kind and level of feeding and more. With reference to national regulations in Norway, all aquaculture sites have to carry out monitoring of the environmental impact on the bottom at the site covering a combination of biological and chemical parameters. The results from this monitoring show that the environmental benthic condition are good or very good in approx. 95 % of the sites[19]. The percentage of farms in an unacceptable ecological state has been stable and <3%, results based on 2761 MOM B investigations between 2009 and 2013 in Norway[65]. These results indicate that the magnitude of the benthic impacts from aquaculture in sea is low.
Aquaculture. Effects of the use of medicines, e.g. antibiotics, on surrounding organisms.	Use of veterinary medicines to treat farmed fish that have attracted one or more infections or infestations might vary considerably between regions. Methods to assess the potential environmental impact have not been developed. However, the major concern related to the use of some of these medicines (antibiotics etc.), is the risk of developing resistance by the agents causing the disease to the medicines used, thus leading to reduced opportunities to control the diseases. The major impact of this is economic character for the aquaculture industry and not a significant environmental issue. Occurrence of populations of microorganisms or parasites having resistance against drugs, have no impact on these populations in the environment since neither resistant nor non-resistant subpopulations will be exposed to any drugs outside the aquaculture site and therefore none of them will be exposed to any evolutionary "pressure" due to the use of such drugs in the fish farms. Thus, giving information on the use of antibiotics or anti parasitic drugs is not suggested to be part of the additional information. However, drugs that might have a direct negative effect on populations on wild species in the environment, shall be recorded and reported.

[19] Ref: www.imr.no/publikasjoner/andre_publikasjoner/risikovurdering_miljovirkninger_av_norsk_fiskeoppdrett/nb-no

In the attached ***Annex I Fish PEFCR screening report Examples Biotic impact assessment PEF_150916*** examples of assessment according to this method are presented.

6.6 Data quality requirements

The data quality of a marine fish PEF shall be assessed with the semi-quantitative data quality assessment method as it is presented in the PEF guide chapter 5.6 [16] and chapter 3.5 in the PEFCR guide.

For communication of PEF results to consumers at least 90% of the data contributing to the selected impact categories shall have a score of "fair" or better.

For use of PEFs internal environmental management the necessary data quality shall be considered with respect to the goal and scope of the assessments and by trained LCA professionals together with experts from the industries/sectors under study.

6.6.1 Secondary data sources / databases

As of today it does not exist any database that cover all Marine fish production systems that provide the EU market with marine fish products. Not with respect to the different technologies/methods that are used or geographical differences. Two consequences of this is that:

1) Any PEF of marine fish products (or any other marine resource) will be heavily dependent on the collection of primary data from all life cycle stages. Even if generic data would be sufficient for the purpose of the study these data does not exist.

2) It does not exist any data basis to define quantitative data quality requirements, e.g. based on statistical mathematics. The well known variation in the parameters forming the PEF of marine fish products have not yet been quantified across the complete marine resources sector.

With this in mind it is not possible as of today to recommend detailed data quality requirements. The following chapters point at what data need to be included and which one of them are especially important and should be included with a high degree of precision. What is needed is to start the development of wide and deep data collection from the whole marine resources sector. Once this is in place requirements can be precisely defined for different purposes of Marine fish PEFs.

6.7 Requirements for each life cycle stage and processes

The data requirements suggested here does not define a default reference flow for each unit process, but what in- and outputs that shall or should be included for each process. For all unit process and associated data sets it shall be clearly stated what the reference flow is, not only quantities, but also qualitatively.

Example: For unit processes involving the production and/or handling of the fish it shall be clearly defined exactly for what all the inn- and outputs are quantified against.

The mass balance for the fish product through the life cycle shall be presented for all Marine fish PEFs.

6.7.1 Feed

The feed input shall be included using data based on PEF conducted according to the compound feed PEFCR [15].

6.7.2 Marine net pen aquaculture grow out

To cover seasonal differences and the different activities performed between grow out cycles and maintenance the data shall as a general rule cover longer time periods, a minimum of 5 years. Exceptions from this rule are given.

- The feed efficiency is the most important parameter in the PEF of fed aquaculture products and shall represent the mass of feed bought per unit of mass fish delivered to human consumption or other commercial products. The mass balance for the grow out shall be documented: How much fish is produced, how much is sold for human consumption and how much is lost (dead and escapes) per unit of feed delivered to the production. The feed efficiency can be given for the specific production cycle providing the product.
- Loss rate in the production shall be documented and it shall be clear how the feed efficiency used takes losses into account.
- Emissions of Phosphorus and Nitrogen from the fish farm from faeces and feed spillage shall be included. These emissions shall be calculated specifically for the feed efficiency in the production of the fish; content of N, P and C in the feed; spillage and retention in the fish. For Atlantic salmon this mass balance is demonstrated by Wang et al [17, 24]. The emissions shall be included with elementary flows covered by the ILCD method.
- Emissions of chemicals (e.g. paints, antifouling agents and treatment of the fish) shall be included. This shall include documentation of what the chemical contain, in what form they are emitted to the water and in what concentrations. If these emissions are not covered by elementary flows covered by the default impact assessment method (e.g. ILCD method) they shall still be documented and quantified.
- Activities and energy used by sub-contractors shall be included. This include companies performing maintenance operations, cleaning and inspections on the grow-out facilities and on shore maintenance of the equipment.
- Transport of personnel and equipment to and from the grow-out site shall be included.

6.7.3 Aquaculture Juvenile Production

Juvenile production shall be included with data that capture seasonal variations and the different phases of the production cycle average data for 3 production cycles or 3 years.

- All electricity and fuel use that is needed to keep the juvenile production plant operating shall be included. Energy used for processes such as: Water treatment, temperature control, maintenance, cleaning and handling of the fish.
- The feed efficiency shall follow the same requirements as that for the fish grow out.
- The feed input shall be included according to the requirements in chapter 6.7.1.
- Emission and production of refrigerants should be included.
- Handling and treatment of sludge from the juvenile production shall be included with energy use and emissions to water and air. If the sludge treatment includes material and/or energy recovery this shall be included according to the Resource Use and Emissions Profile (RUaEP) as presented Annex V in the PEF guide [16].
- Emissions to water of N and P shall be included.
- Input of fresh water shall be included and categorized according to the water impact assessment methods that is used. Also for recycling systems the water that I refilled shall be included.

6.7.4 Fishing

All energy used to maintain the activity of the fishing vessels shall be included: Transport to and from fishing area, fishing operations, transport of fish, on-board processing, maintenance, harbour activities etc. To make sure everything is included the energy use shall be the sum of fuels supplied to the ship over a time period that include all these activities.

Input and emissions of refrigerants from the fishing vessel shall be included. Also that emitted during service and what is emitted because of failures. It shall be clearly documented what refrigerant that is used, volume of refrigerant in the system and what emission rate that is used for the assessment.

Production of the refrigerants and the fuel should be included, but this input can be covered with generic data.

Material inputs (metals) to the fishing vessel and fishing gear can be of relevance for toxic impact assessment categories, but considering the uncertainties in these IAs these inputs can be optional.

6.7.5 Preparation

This process refer to the steps transforming or conserving the fish between being fished or fed in the fish farm and being sold to the consumer. Preparation can include transformation of the fish, e.g. bleeding, gutting and filleting, and freezing and chilling of the fish.

- The yield (the mass balance) of the preparation shall be clearly stated.
- It shall be defined exactly what preparation that is done, in what state the fish enters preparation and what types of mass flows in is converted to.

- All in- and outputs must be clearly defined against units of fish going through this transformation. It must also be clear if the in- and outputs are per unit into preparation or units out of preparation.
- All electricity and fuel that is needed to operate the preparation facility and supporting activities shall be included. Including: Heating, ventilation, refrigeration systems (including ice production) and cleaning. If these activities are performed by subcontractors their energy use shall also be included.
- Refrigerants shall be included, including emission of refrigerants and production of refrigerants.
- Input of fresh water shall be included. This input shall be categorized according to the water impact assessment method that is used.
- Emissions to water shall be included and also wastewater treatment/cleaning processes. Emissions that are not covered by the ILCD method shall be documented under additional environmental information.

6.7.6 Fuel: Use of and production

Fuel use is a very important environmental aspect that shall be included for several unit processes. Wherever the use of fuel is a required part of the PEF, this shall include the emissions from combustion of the fuel and production of the fuel (the fuel life cycle from extraction of raw materials and up to fuel on the market). For the latter generic data can be used. For the use/combustion of the fuel the emission factors should be representative for the fuel and engine technology that is applied. **Table 6-3** presents an example of what emissions that should be included for fuel combustion. NOx emissions and SO2 emissions should be adjusted according to the properties of the fuel that is used, the engine technology that is used and measurements that is taken to reduce NOx emissions.

Table 6-3 Emission factor for the use/combustion of 1 tonne of fuel in engines

Ammonia	0,02	kg
Arsenic	0,04	g
Benzene	0,0073	kg
Benzene, hexachloro-	0,08	mg
Cadmium	0,01	g
Carbon dioxide, fossil	3190	kg
Carbon monoxide, fossil	7,4	kg
Chromium	0,05	g
Copper	0,88	g
Dinitrogen monoxide	1,22	kg
Dioxins (TEQ)	0,13	µg
Lead	0,13	g
Mercury	0,03	g
Methane, fossil	0,3	kg
Nickel	1	g
Nitrogen oxides	78,5	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	2,8	kg
PAH, polycyclic aromatic hydrocarbons	0,00336	kg

Particulates, < 2.5 um	1,4	kg
Particulates, > 10 um	1,5	kg
Polychlorinated biphenyls	0,038	mg
Selenium	0,1	g
Sulphur dioxide	2	kg
Toluene	0	kg
TSP	1,5	kg
Xylene	0	kg
Zinc	1,2	g

6.7.7 Refrigeration systems

Emission of refrigerants are especially important for ozone depletion, but can also be for global warming potential [21]. The production and emission of refrigerants shall be included for several stages/processes in marine fish PEFs: Fishing, preparation, transport and storing.

Refrigeration shall be included with the following details:

- Emissions of refrigerants to air
- The energy used to run the refrigeration system.
- production of the refrigerant, this can be included with generic data

Regarding the energy used to operate the refrigeration systems, it shall be explicitly documented if the energy to run the refrigeration systems are already included in the energy included for the life cycle stages where the refrigeration is used. E.g. the reported fuel use of fishing vessel can shall include all on board systems, including refrigeration systems. Equally for preparation the energy used associated with the preparation factory shall include all refrigeration systems. A common example of situations where energy used by refrigeration systems are not included, is the transports where refrigeration aggregates can have their own fuel tanks.

Energy use and emissions from refrigeration systems shall be specific for the time they handle the fish product, this is especially relevant for refrigeration on transport vehicles where the time that the fish is stored in the transport vehicle is often considerably longer than the time the vehicle moves.

6.7.8 Electricity inputs

Until cross sectorial guidelines/rules for inclusion of electricity in products PEFs have been adopted, the use of electricity shall be included with the following requirements:

- The use of electricity shall be included with data specific for the consumption mix in the region where the electricity is used, if electricity use cannot be regionalized, the European average shall be used.
- If secondary data is used for the consumption mix, then it shall be with ELCD data.
- Where a country specific consumption mix cannot be defined the average European consumption mix shall be used
- Until any other cross sectorial decision is made, the consumption mix shall be based on the actual physical production mix consumed not taking into account any type of certificates, contractual instrument or other similar paper mechanisms. Inclusion of such paper mechanisms can only be included in a marine fish PEF when, and only when, a

safe, transparent, robust and sector wide system for the calculation of residual mixes is in place together with a system that secures that only those with certificates can use them in the assessment, and everybody else uses the residual mix. These systems must work across all sectors, not only the marine fish sector.

6.7.9 Distribution, transport

Transports in the distribution of the fish from landing or fish farm and all the way to the retailer, shall be included with the following hierarchy:

1) With the actual fuel used to transport the product
2) Calculated based on specific fuel consumption of the transport vehicle (units of fuel per kilometre), capacity utilization (units of product transported per transport unit) and distance of the transport.
3) With ELCD data on transport if it can be documented that ELCD data are representative for the actual transport vehicles that are used. Still the transport distance need to be specific for the product.

Refrigeration in the distribution shall also be included according to chapter 6.7.7.

6.7.10 Biogenic carbon

If the life cycle of the fish product includes anaerobe degradation of fish, sludge or packaging materials, the resulting biogenic methane emissions shall be included in the climate impact assessment.

6.7.11 Packaging materials

The use of packaging materials shall be included using the Resource Use and Emissions Profile (RUaEP) as presented Annex V in the PEF guide [16]

Data collection for the RAaEP formula should follow this hierarchy:
1) Use specific data
2) Use generic data

As soon as generic data on the rates and processes that are a part of the RUaEP formula are made available from the EC and adapted across sectors, these data shall be used for option 2.

If the life cycle of the packaging materials include generation of biogenic methane this climate impact shall be included.

6.7.12 End-of-life stage / waste handling

Waste handling shall be included for all waste flows generated, especially important are waste flows of fish, this including waste from production of the fish and all other stages, and waste flows of packaging materials.

Waste handling shall be included using the end-of-life formula taking into account processes and transport in the waste handling and if generated "credits" from materials and energy generated from the waste.

If the waste handling includes anaerobe degradation the emissions of biotic methane to air this shall be included for the climate impact. [Default factors for biogenic methane from degradation of fish will be suggested, not calculated at the current state.]

Chapter 2.7 presents some of the current challenges for using the complete end-of-life formula for packaging materials. This problem is the same for most waste flows. Thus it is today very difficult to fully apply the EoL formula, but we expect that the availability of data on waste flows and processing to be greatly improved in the near future.

References

1. BSI, *PAS 2050-2:2012 Assessment of life cycle greenhouse gas emissions - Supplementary requirements for the application of PAS 2050:2011 to seafood and other aquatic food products*. 2012: http://shop.bsigroup.com/en/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2050/PAS-2050-2/.
2. Standard Norway, *Carbon footprint for seafood - Product category rules (CFP-PCR) / Klimaspor for sjømat - Produktkategoriregler (CFP-PCR)*. 2013, Standards Norway.
3. Eyjolfsdottir, H., et al., *Environmental Assessment of Seafood Products through LCA*, in *TemaNord 2004:546* B. Mattsson, Ziegler, F. , Editor. 2004, Nordisk Ministerråd.
4. Papatryphon, E., et al., *Environmental Impact Assessment of Salmonid Feeds Using Life Cycle Assessment (LCA).* AMBIO: A Journal of the Human Environment, 2004. **33**(6): p. 316-323.
5. Ellingsen, H. and S.A. Aanondsen, *Environmental Impacts of Wild Caught Cod and Farmed Salmon - A Comparison with Chicken (7 pp).* The International Journal of Life Cycle Assessment, 2006. **11**(1): p. 60-65.
6. Pelletier, N. and P. Tyedmers, *Feeding farmed salmon: Is organic better?* Aquaculture, 2007. **272**(1-4): p. 399-416.
7. Ayer, N.W. and P.H. Tyedmers, *Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada.* Journal of Cleaner Production, 2009. **17**(3): p. 362-373.
8. Cederberg, C., et al., *Greenhouse gas emissions from Swedish production of meat, milk and eggs 1990 and 2005*. 2009, SIK – The Swedish Institute for food and Biotechnology, Göteborg, Sweden.
9. Ellingsen, H., et al., *Prosjektrapport: Energibruk og klimautslipp i eksport av norsk sjømat* *http://skala.sintef.no/Content/publikasjonsbase/publikasjon.aspx?pubid=SINTEF+A19097*. 2009.
10. Ellingsen, H., J.O. Olaussen, and I.B. Utne, *Environmental analysis of the Norwegian fishery and aquaculture industry--A preliminary study focusing on farmed salmon.* Marine Policy, 2009. **33**(3): p. 479-488.
11. Hasan, M.R. and M. Halwart, *Fish as feed inputs for aquaculture: practices, sustainability and implications. FAO Fisheries and Aquaculture Technical Paper. No. 518. www.fao.org/docrep/012/i1140e/i1140e.pdf*. 2009, FAO. p. 407p
12. Pelletier, N., et al., *Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems.* Environmental Science & Technology, 2009. **43**(23): p. 8730-8736.

13. Hognes, E.S., et al. *Carbon footprint and energy use of Norwegian fisheries and seafood products*. in *14th international congress of the international maritime association of the mediterranean (IMAM)*. 2011. Genova, Italy.
14. Ytrestøyl, T., et al., *Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010* 2011, NOFIMA.
15. FEFAC. *Product EF pilots: Feed for food-producing animals: http://ec.europa.eu/environment/eussd/smgp/pdf/Fiche_feed.pdf* 2016 [cited 2016 23.08]; Available from: http://ec.europa.eu/environment/eussd/smgp/pdf/Fiche_feed.pdf.
16. EC, *PRODUCT ENVIRONMENTAL FOOTPRINT (PEF) GUIDE. Official journal L124 of the European Union Legislation. Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations*, E. Union, Editor. 2013.
17. Wang, X., et al., *Discharge of nutrient wastes from salmon farms: environmental effects, and potential for integrated multi-trophic aquaculture.* Aquaculture Environment Interactions, 2012. **2**(3): p. 267-283.
18. Liu, Y., et al., *Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (Salmo salar): Land-based closed containment system in freshwater and open net pen in seawater.* Aquacultural Engineering, 2016. **71**: p. 1-12.
19. Hospido, A. and P. Tyedmers, *Life cycle environmental impacts of Spanish tuna fisheries.* Fisheries Research, 2005. **76**(2): p. 174-186.
20. Parker, R.W.R., I. Vázquez-Rowe, and P.H. Tyedmers, *Fuel performance and carbon footprint of the global purse seine tuna fleet.* Journal of Cleaner Production, 2014(0).
21. Winther, U., et al., *Project report: Carbon footprint and energy use of Norwegian seafood products http://www.sintef.no/Publikasjonssok/Publikasjon/?pubid=SINTEF+A21457* 2009, SINTEF Fisheries and aquaculture: Trondheim, Norway.
22. Schryver, A.D., et al., *Issue paper: Guidance and requirements for handling the use stage in PEFCRs Version 4.0 – 11 November 2015*. 2015, European Comission - DG ENV and PEFCR pilot helpdesk.
23. JRC-IES, *Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods. Database and Supporting Information. First edition. EUR 25167. http://eplca.jrc.ec.europa.eu/uploads/LCIA-characterization-factors-of-the-ILCD.pdf* 2012, European Commission, Joint Research Centre, Institute for Environment and Sustainability.: Luxembourg. Publications Office of the European Union.
24. X, W., et al., *Chemical composition and release rate of waste discharge from an Atlantic salmon farm with an evaluation of IMTA feasibility.* Aquaculture Environment Interactions, 2013. **4**(2): p. 147-162.

25. EC, *Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) pilot phase Version 5.1 - September 2015*. 2015, European Commission.
26. Henriksson, P.J.G., et al., *Product Carbon Footprints and Their Uncertainties in Comparative Decision Contexts.* PLoS ONE, 2015. **10**(3): p. e0121221.
27. Hognes, E.S., et al., *LCA of Norwegian salmon production 2012 (A26401 ISBN 978-82-14-05770-6)*. 2014, SINETF Fisheries and aquaculture: http://www.sintef.no/Publikasjoner-SINTEF/AnsattesPublikasjoner/?empId=3001. p. 41.
28. Avadí, Á., I. Vázquez-Rowe, and P. Fréon, *Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework.* Journal of Cleaner Production, 2014. **70**(0): p. 118-131.
29. Wilfart, A., et al., *LCA and emergy accounting of aquaculture systems: Towards ecological intensification.* Journal of Environmental Management, 2013. **121**(0): p. 96-109.
30. Samuel-Fitwi, B., et al., *Comparative life cycle assessment (LCA) of raising rainbow trout (Oncorhynchus mykiss) in different production systems.* Aquacultural Engineering, 2013. **54**(0): p. 85-92.
31. Samuel-Fitwi, B., et al., *Aspiring for environmentally conscious aquafeed: comparative LCA of aquafeed manufacturing using different protein sources.* Journal of Cleaner Production, 2013. **52**(0): p. 225-233.
32. Avadí, A. and P. Fréon, *Life cycle assessment of fisheries: A review for fisheries scientists and managers.* Fisheries Research, 2013. **143**(0): p. 21-38.
33. Ziegler, F., et al., *The Carbon Footprint of Norwegian Seafood Products on the Global Seafood Market.* Journal of Industrial Ecology, 2012: p. no-no.
34. Vázquez-Rowe, I., M.T. Moreira, and G. Feijoo, *Environmental assessment of frozen common octopus (Octopus vulgaris) captured by Spanish fishing vessels in the Mauritanian EEZ.* Marine Policy, 2012. **36**(1): p. 180-188.
35. Parker, R., *Review of life cycle assessment research on products derived fromfisheries and aquaculture: a report for Seafish as part of the collective action to address greenhouse gas emissions in seafood. Online on Seafish website: www.seafish.org/media/583639/seafish_lca_review_report_final.pdf* 2012, Seafish.
36. Jerbi, M.A., et al., *Life cycle assessment (LCA) of two rearing techniques of sea bass (Dicentrarchus labrax).* Aquacultural Engineering, 2012. **46**: p. 1-9.
37. Hornborg, S., et al., *Integrated environmental assessment of fisheries management: Swedish Nephrops trawl fisheries evaluated using a life cycle approach.* Marine Policy, 2012. **36**(6): p. 1193-1201.
38. Vázquez-Rowe, I., M.T. Moreira, and G. Feijoo, *Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock.* Fisheries Research, 2011. **110**(1): p. 128-135.

39. Torrissen, O., et al., *Atlantic Salmon (Salmo salar): The "Super-Chicken" of the Sea?* Reviews in Fisheries Science, 2011. **19**(3): p. 257-278.
40. Svanes, E., M. Vold, and O. Hanssen, *Environmental assessment of cod from autoline fisheries.* The International Journal of Life Cycle Assessment, 2011. **16**(7): p. 611-624.
41. Ramos, S., et al., *Environmental assessment of the Atlantic mackerel (<i>Scomber scombrus</i>) season in the Basque Country. Increasing the timeline delimitation in fishery LCA studies.* The International Journal of Life Cycle Assessment, 2011. **16**(7): p. 599-610.
42. Iribarren, D., et al., *Updating the carbon footprint of the Galician fishing activity (NW Spain).* Science of The Total Environment, 2011. **409**(8): p. 1609-1611.
43. Hognes, E.S., F. Ziegler, and V. Sund, *Carbon footprint and area use of farmed Norwegian salmon* www.sintef.no/Publikasjoner-SINTEF/Publikasjon/?pubid=SINTEF+A22673. 2011, SINTEF Fisheries and aquaculture.
44. Vázquez-Rowe, I., M.T. Moreira, and G. Feijoo, *Life cycle assessment of horse mackerel fisheries in Galicia (NW Spain): Comparative analysis of two major fishing methods.* Fisheries Research, 2010. **106**(3): p. 517-527.
45. Iribarren, D., M.T. Moreira, and G. Feijoo, *Implementing by-product management into the Life Cycle Assessment of the mussel sector.* Resources, Conservation and Recycling, 2010. **54**(12): p. 1219-1230.
46. Iribarren, D., M.T. Moreira, and G. Feijoo, *Life Cycle Assessment of fresh and canned mussel processing and consumption in Galicia (NW Spain).* Resources, Conservation and Recycling, 2010. **55**(2): p. 106-117.
47. Iribarren, D., et al., *Carbon footprint of canned mussels from a business-to-consumer approach. A starting point for mussel processors and policy makers.* Environmental Science & Policy, 2010. **13**(6): p. 509-521.
48. Driscoll, J. and P. Tyedmers, *Fuel use and greenhouse gas emission implications of fisheries management: the case of the new england atlantic herring fishery.* Marine Policy, 2010. **34**(3): p. 353-359.
49. Ziegler, F., et al., *Life Cycle Assessment of southern pink shrimp products from Senegal. An environmental comparison between artisanal fisheries in the Casamance region and a trawl fishery based in Dakar*. 2009.
50. Thrane, M., E.H. Nielsen, and P. Christensen, *Cleaner production in Danish fish processing - experiences, status and possible future strategies.* Journal of Cleaner Production, 2009. **17**(3): p. 380-390.
51. Schau, E.M., et al., *Energy consumption in the Norwegian fisheries.* Journal of Cleaner Production, 2009. **17**(3): p. 325-334.
52. Ziegler, F., *New LCA Theses. Environmental Life cycle assessment of seafood products from capture fisheries.* 2007: International Journal of LCA, 12 (1), p. 61.
53. Thrane, M., *LCA of Danish Fish Products. New methods and insights (9 pp).* The International Journal of Life Cycle Assessment, 2006. **11**(1): p. 66-74.

54. Grönroos, J., et al., *Life cycle assessment of Finnish cultured rainbow trout. Boreal Environmental Research*, 2006. **11**: p. 401-414.
55. Tyedmers, P., R. Watson, and D. Pauly, *Fueling global fishing fleets.* AMBIO: A Journal of the Human Environment, 2004. **2004:34:635**.
56. Tyedmers, P., *Fisheries and Energy Use*, in *Encyclopedia of Energy*, J.C. Editor-in-Chief: Cutler, Editor. 2004, Elsevier: New York. p. 683-693.
57. Ziegler, F., et al., *Life Cycle assessment of frozen cod fillets including fishery-specific environmental impacts.* The International Journal of Life Cycle Assessment, 2003. **8**(1): p. 39-47.
58. Ziegler, F. and P.-A. Hansson, *Emissions from fuel combustion in Swedish cod fishery.* Journal of Cleaner Production, 2003. **11**(3): p. 303-314.
59. Hospido, A. and P. Tyedmers, *Life cycle environmental impacts of Spanish tuna fisheries.* Fisheries Research 2005;76:174, 2005.
60. Pelletier, N. and P. Tyedmers, *Response to Weinzettel.* Journal of Industrial Ecology, 2012. **16**(3): p. 456-458.
61. Pelletier, N. and P. Tyedmers, *An Ecological Economic Critique of the Use of Market Information in Life Cycle Assessment Research.* Journal of Industrial Ecology, 2011. **15**(3): p. 342-354.
62. Weinzettel, J., *Understanding Who is Responsible for Pollution: What Only the Market can Tell Us—Comment on "An Ecological Economic Critique of the Use of Market Information in Life Cycle Assessment Research".* Journal of Industrial Ecology, 2012. **16**(3): p. 455-456.
63. Ayer, N.W., et al., *Co-product allocation in life cycle assessments of seafood production systems: Review of problems and strategies.* International Journal of Life Cycle Assessment, 2007. **12**(7): p. 480-487.
64. Svanes, E., M. Vold, and O. Hanssen, *Effect of different allocation methods on LCA results of products from wild-caught fish and on the use of such results.* The International Journal of Life Cycle Assessment, 2011. **16**(6): p. 512-521.
65. Taranger, G.L., et al., *Risk assessment of the environmental impact of Norwegian Atlantic salmon farming.* ICES Journal of Marine Science: Journal du Conseil, 2014.

ANNEX I

Suggested approach to integrate assessment of biotic impacts in seafood from capture fisheries PEF pilots

Sara Hornborg & Friederike Ziegler
SP Food and Bioscience, Sustainable Food Production, P. O. Box 5401, 402 29 Göteborg

Summary of suggestions:
Including ecological impacts of seafood production is vital for a comprehensive assessment in the sense of covering all relevant environmental issues. However, the development and use of these methods in LCA is a work in progress, with constraints related to both available methods and data. Based on findings so far and which ecological aspects that are important to consider, different approaches are suggested for on impact on target species, by-catches, habitats and ecological communities.

1. ***For target species, overfishing through fishing mortality (OF) and overfishedness of biomass (OB) is suggested.***
2. ***For by-catch, a hierarchical approach consisting of excluding catches with biological reference points and assessing the remaining part of the catch as impact on threatened species according to the IUCN Red List (VEC) and the rest as amount of data-limited catch (D-L) is suggested.***
3. ***For habitats, a model for quantifying seafloor area swept (m^2) is recommended as a rough metric, not yet assessing actual impacts on habitats.***
4. ***For ecological communities, quantifying the primary production required (PPR) of catches (landings and discards) is suggested. This is an approach of high relevance to seafood from aquaculture.***

In appendix I, examples on how to perform the impact assessment are given. Appendix II comprise of response to the comments given by the EU commission on the methods provided.

Life cycle assessment of seafood: coverage of methods for ecological assessment

For many types of industrial food production, ecological impacts are important (Foley *et al.* 2011); this is especially true for food production which interferes with biodiversity while depending on productive and functioning ecosystems, and in particular seafood from capture fisheries, representing the only large-scale food production based on a wild resource. As for seafood LCAs, the need to assess the potential impacts from removal of marine ecosystem components has repeatedly been pointed out (Pelletier *et al.* 2007, Vázquez-Rowe *et al.* 2012a, Avadí & Fréon 2013).

The PEF requirements mandate that (article 4.4):

> *"The selection of EF impact categories should therefore be comprehensive in the sense that they cover all relevant environmental issues related to the product supply chain of interest."*

As the most renowned environmental impact and resource use of fisheries are those of depletion of natural fish production and ecological effects in the marine ecosystem, reflected in for example the focus by environmental NGOs, consumer awareness and public debate, the inclusion of ecological assessment of the seafood from capture fisheries should be imperative.

However, one of many methodological challenges with ecological assessment methods in LCA is that the impact assessment methods in LCAs normally are independent of time and space; yet ecological impacts of fisheries could be characterized as being a proximate ecological concern. This area is in general not adequately covered in traditional LCAs (Reap *et al.* 2008), but similar discussions are had in e.g. impact assessment of land use (i Canals *et al.* 2007). The ISO standard also mandates that impact categories, category indicators and characterization models should for example be internationally accepted, scientifically and technically valid and environmentally relevant (4.4.2.2.3 ISO 14044:2006). Therefore, in the case of seafood from capture fisheries, new impact assessment approaches, choice of indicators and characterization methods with a higher level of resolution in terms of time and space.

Seafood from capture fisheries

One approach to make sure that important elements of ecosystem interference are covered is to make use of the framework ecological risk assessment (ERA) of fisheries, which scope has been to cover fishing pressure on ecological components of an ecosystem in such was that all elements of an ecosystem are covered (Hobday *et al.* 2011). These have been split into the following categories:

1) Target species
2) By-product and by-catch species
3) Threatened, endangered and protected species (TEP)
4) Habitats
5) Ecological communities

This categorization of impacts will hence be used as a basis for presenting and categorising currently available LCA impact assessment methods and proposing which methods to use in seafood PEFs for ecological assessment of capture fisheries. On note, categories two and three are merged as one by-catch category.

1. **Target species**

The most evident ecological impact of fishing is removal of biomass from a natural ecosystem, which may have various effects on ecosystem structure and function depending on catch amount, frequency of disturbance, species impacted and more (see e.g. Jennings & Kaiser 1998).

LCA methods available

Emanuelsson *et al.* (2014) developed a quantitative methodology (three midpoint impact categories) to include overfishing in seafood LCAs based on the Maximum Sustainable Yield (MSY) framework. MSY represents the theoretical maximum annual landing (or yield) that can be harvested from a wild fish stock over time and has been a concept in fisheries science since it was initially developed in the 1930s (Punt & Smith 2001). The use of MSY in seafood LCA to account for single-stock overfishing is in Emanuelsson *et al.* (2014) done in three midpoint impact categories: lost potential yield (LPY),a future projection of fishing under more optimal conditions, overfishing through fishing mortality (OF) and overfishedness of biomass (OB). The two latter categories relate current fishing mortality and spawning stock biomass to the target levels for those parameters, respectively. OF and OB are complementary categories which may be used either to interpret LPY results, or separately when all input parameters are not available.

Langlois *et al.* (2014a,b) also suggested a framework for assessing biotic resource depletion in LCAs of fisheries at endpoint level, using the MSY framework and the primary production needed with impact pathways to two Areas of Protection (AoP), natural resources and ecosystem quality. However, the theory behind this approach is questionable in terms of being scientifically valid; to mention some points of critique, a) the unit referred to for both AoPs is time for regeneration of biomass (which could not be quantified as part of this framework as it depends on more factors than suggested (see e.g. Hutchings & Reynolds 2004) and b) referring to impact on ecosystem quality while studying separate fish species trophic level is an inadequate as it depends on the total amount of biomass that is taken out of an ecosystem; a low catch of higher trophic level species from an ecosystem may be less severe that a high catch of lower trophic level species in terms of ecosystem quality depending on how the ecosystem production is controlled (Hunt & McKinnel 2006) or the strength of the connectivity of the species in the food chain (Smith *et al.* 2011). Similar critique, i.e. the scientific robustness of estimating time perspectives for resource depletion and replenishment, applies to the LPY-framework proposed by Emanuelsson *et al.* (2014), as well as data availability for estimating LPY. These frameworks are therefore seen as not applicable for seafood in their current format.

<u>Proposed method for assessing overfishing of target stock:</u>

The OF and OB midpoint impact categories suggested by Emanuelsson *et al.* (2014). The information needed is catch in mass of a certain stock and year to be inserted in Simapro where characterization factors are available based on:

$$\mathbf{OF = F/F_{MSY} - 1;}$$

$$\mathbf{OB = B_{MSY}/B - 1}$$

OF, referring to fishing pressure, describes how close to the target fishing mortality the fishery is at present (with the OF value to be understood as how many kilos that are currently fished too much for every kilo that is landed), while OB, referring to fish biomass, describes how close the stock is to its target biomass (the resulting OB value to be understood as how much too low the spawning stock biomass is in kilos per kilo landed). Note that when $F=F_{MSY}$ and $B=B_{MSY}$ both OF and OB are 0, indicating no ongoing overfishing or overfishedness. The characterization model is therefore expressed for OF so that the optimum case ($F=F_{MSY}$) to result in no impact per FU, and for OB to correspond to zero impact when $B = B_{MSY}$ and is also inverted in order to make larger value equal to higher impact).

SimaPro applicability

For all stocks that have defined MSY-values, these could be inserted into SimaPro in a format that would only require the practitioner to inventory catch in mass per species/stock and year.

Data availability and plan for update

The RAM Legacy Stock Assessment Database (Ricard *et al*. 2012) has MSY values for 138 stocks that are fished globally. Additional MSY values may be found in the publicly available database administered by ICES (ices.dk). In 2012, F_{MSY} values were found for 31 major European stocks (Emanuelsson *et al.* 2014), and more values will become available as all European stocks shall be managed with an MSY objective in the reformed Common Fisheries Policy (CFP; EU 2013).

The values for MSY would have to be updated at least once per year, based on new stock assessment and scientific advice.

2. **By-product and by-catch species including threatened, endangered and protected species (TEP)**

By-catch, i.e. the unintentional catch of non- targeted species or sizes which are either discarded at sea or landed, can be vast is some fisheries and is as a waste of resources and unsustainable pressure on vulnerable species (Kelleher 2005). Fishing activities undeniably also affect vulnerable species whether these are targeted or not and contribute to loss and/or depletion of species (e.g. Dulvy *et al.* 2014; Hoffman *et al.* 2010); to which extent depends on e.g. gear type and target species.

LCA methods available

Different approaches have been suggested and evaluated to include by-catch of fish species in seafood LCAs. Predominantly, by-catch and discard have at best been assessed in terms of live weight (in kilo discard per landing, possible separated by species composition); in recent years, new approaches has been suggested and evaluated such as discard rate in a fishery relative to a global discard rate (GDI), primary production required (PPR) of discards, mass or count of fish classified as threatened by the IUCN Red List of Threatened species (VEC) or quantified in mass as data-limited (D-L) by-catch per unit of landing (Hornborg *et al.* 2012,Vázquez-Rowe *et al.* 2012a,b, Ziegler *et al.* in press).

Discard mass in weight:

The first method proposed to assess by-catch was that of simply inventory the mass discarded per functional unit, possibly also stating the dominant species or a qualitative discussion on the potential impact (e.g. Ziegler *et al.* 2003, Ziegler & Valentinsson 2008). Even if this could be seen as being only an inventory result, this indicator shall be included in any seafood LCA based on capture fisheries, given the discard rate contribution to sustainable use of resources and marine ecosystem impacts (Kelleher 2005; Coll *et al.* 2008).

Primary Production Required (PPR):

Primary Production Required (PPR) is metric intending to reflect the disturbance of ecosystem flows as it takes into account the trophic level of the species affected by estimating how much carbon that has to be assimilated through photosynthesis to produce a certain species (Hornborg *et al.* 2013a). Global fisheries catches have been identified to be constrained by the available primary production (Chassot *et al.* 2010, Watson *et al.* 2014), and depending on discard amount may jeopardize sustainable use of fish resources (Coll *et al.* 2008). Estimating the primary production required is therefore an important advancement; however, as the discarded part represent a resource that is thrown back to the ecosystem it might be argued that this impact assessment is more related to ecological communities. Following this reasoning, PPR may be used to assess marine ecosystem appropriation when fish is used as feed for aquaculture (see section on seafood from aquaculture).

Hierarchical framework including Data-Limited (D-L) stocks:

This approach offers a hierarchical framework for assessing by-catch impacts, proposed and tested in Ziegler (in press). The method basically inventory which information is available for the assessment; if biological reference points such as those related to MSY are available for the species, the target stock method proposed by Emanuelsson et al. (2014) is used. If those are not available, the rest of the catch is screened for presence of threatened species according to the IUCN Red List is used, following the framework of Hornborg et al. (2013b). The rest of the catch is then reported as being Data-Limited, i.e. the amount of the catch (in weight) that have neither biological reference points, nor been assessed by the IUCN Red List. It has e. g. been estimated that 80 % of global landings lack proper stock assessment (Costello *et al.* 2012) and about one-quarter (4,337 of some 17,000 species of marine fish) were on the IUCN Red List in 2013 (Colette *et al*. 2013). Of the marine fish species assessed by the IUCN, 416 species are considered as threatened (i.e. Critically Endangered, Endangered or Vulnerable) and 1,180 species are Data Deficient. All in all, by this approach, the whole fish catch in a fishery would be categorised in any of the three compartments (target, VEC or data-limited).

Constraints of the method comprise of the limited coverage of the IUCN Red List assessment and its geographical resolution and time for assessment (risk of being outdated), and the fact that the Data-Limited part does not convey any information on the situation of these fish.

Global Discard Rate (GDI):

The Global Discard Rate (GDI) index was proposed by Vázquez-Rowe *et al.* (2012b) as a dynamic midpoint indicator. The discard rate in the assessed fishery is related to a global discard rate according the Kelleher (2005). Two options are presented: either by computing PPR of the discard (GDI_{BRU}) and relate this to a global average of PPR of discards, which is assumed to be 3.1 based on the estimate of mean trophic level (MTL) of landings from Pauly et al. (1998), or merely use the mass reference without computing PPR (GDI_{mass}).

Based on the difficulty of interpreting the MTL metric (Hornborg et al. 2013a) and in the next step, the rough assumption that has to be made for computing global average of PPR of discards for computing GDI_{BRU}, this approach is not seen as coherent with the ISO requirements as discussed earlier (4.4.2.2.3 ISO 14044:2006). As for the mass approach (GDI_{mass}), this is not much of an advancement compared to merely presenting discard in mass and then discuss results in relation to what is a high and low discard rate in a fishery based on literature (such as Kelleher 2005). Thus, none of these methods of high relevance to include in SimaPro.

Vulnerable, Endangered or Critically endangered (VEC) fish species

It was initially proposed by Lindeijer *et al.* (2002) to make use of the International Union for Conservation of Nature (IUCN) Red List Categories and Criteria to assess risks of extinction in impact assessment methods for biotic resource extraction. The IUCN Red List was initiated with the aim to "identify and document those species most in need of conservation attention if global extinction rates are to be reduced", and has over time expanded its remit to also monitor trends in global levels of biodiversity loss (IUCN 2012). Inclusion of the IUCN framework in seafood LCA has been initiated in terms of assessment of catch of threatened fish by Hornborg *et al*. (2013b) and applied in case studies (Hornborg *et al*. 2012; Ziegler *et al.* accepted). In Hornborg *et al.* (2013b), it is proposed that the amount of threatened fish (i.e. VEC; stands for Vulnerable, Endangered or Critically Endangered, the three threat categories) is quantified as volume of VEC discarded per kilo landed, in mass (kilo) and individuals (number). Hornborg *et al.* (2013b) also opened up for assessing landed by-catch as VEC in case no biological reference points were available, an approach that was further tested in Ziegler *et al.* (in press). Another metric, the Red List Index, was also tested in Hornborg *et al.* (2013b) but dismissed.

When evaluated in case studies (Hornborg *et al.* 2012; 2013a), this method showed coherence with other estimates on vulnerability and what is known of the studied fisheries impacts on sensitive fish species, further supported by a prior study (Dulvy *et al.* 2005). It was thus concluded that the study of the amount of VEC fish discarded per landed kilo of seafood is a new and promising quantitative approach for assessing differences in un-wanted catches of sensitive species on a product level. However, constraints comprise of species resolution (the IUCN assess species while there may be major differences between separate stocks), choosing geographical resolution (species may have different level of threat locally compared to globally), and update frequency of assessment (insufficient globally, every five years in regional initiatives) why the target species approach is preferable.

The method only covers fish species, at it is proposed now, but may be used to assess by-catch of other threatened species such as marine mammals and birds (Online Resource 3 in Hornborg *et al*. 2013b). There have also been doubts on whether the assessment by the IUCN is appropriate for actively regulated stocks, where it could falsely lead to false alarms as well as missing signals that indicate risk (ICES 2009a,b), partly due to the low update frequency (Rondinini *et al*. 2014).

<u>Proposed method for assessing landed by-catch and discard:</u>

The hierarchical framework including Data-Limited (D-L) stocks developed by Ziegler *et al.* (in press).

1. **Exclude fish landings that have OF and/or OB values in SimaPro (these belong to target)**
2. **Quantify quantities of the remaining part of the catch (landed by-catch and, if available discarded, as separate entities) comprising of species listed as VEC or is at all assessed by the IUCN Red List**
3. **Quantify the rest of the fish catch as being Data-Limited catches (by-catch and discard respectively, in mass)**

LCA software applicability

Catch (landings and discards in mass and species composition) is an important part of inventory and should thus be collected by the LCA practitioner and inserted into in e.g. SimaPro as input from nature.

To calculate the VEC indicator, threatened species will be available as inputs from nature and the LCA practitioner would have to multiply by mass. Species listed as VEC will count as 1, those that are not as 0.

Data availability and plan for update

Data on landings are found in national statistics, or could be collected by the practitioner from the industry if absent or higher resolution that the total landing by a country is needed for a specific study.

Data on discard mass in weight may be collected and available for use from management authorities, or if absent possibly be inventoried by the LCA practitioner from the industry or as the last option, found in literature on the specific fishery (such as Kelleher 2005) and merely be discussed qualitatively.

Increased coverage of species by the IUCN Red List is essential. Species groups known to be extra sensitive to fishing pressure have been given priority in terms of assessment, and the global IUCN Red List currently covers e.g. all cartilaginous fishes (Hoffman *et al.* 2010). The assessment of marine species by the IUCN Red List is highly prioritized, with currently one-quarter of marine fish assessed, and recent initiatives intend to complete assessments within five years (Collette *et al.* 2013). These efforts will be most useful for future product comparisons. All European fish species have now been assessed by the IUCN Red List Categories and Criteria; the complete list will be released beginning of June 2015.

3. Habitats

Fishing gears in contact with the seafloor, predominantly demersal trawls, alter the physiological structure, species composition and ecosystem function of the benthic habitat (Puig *et al.* 2012; Watling 2005) even if potential effects are far from fully understood (Sheppard 2006).

LCA methods available

Nilsson & Ziegler (2007) developed a function for estimating seafloor area swept by various demersal trawls and related that to the spatial distribution of fishing activities, frequency of disturbance and what was known of habitat distribution. Since then, the function for estimating area swept has been applied in several case studies (e.g. Hornborg *et al.* 2012, Ziegler *et al.* in press). Recent development includes a theoretical best-practise framework to stepwise guide an LCA practitioner in how to assess seafloor impacts (Emanuelsson & Ziegler unpublished).

Given that the area metric is sufficient as a basic habitat impact, there are new models that can be used for assessing seafloor area swept. Outcomes of the BENTHIS-project (Eigaard *et al.* in press) offer a characterization model for assessing doorspread D (width of trawl):

D=a(kW)b

Were *a* and *b* are fishing-type specific parameters and kW is the kW of the boat. Seafloor area swept can then be estimated from:

Seafloor area= D*speed of the boat*hours trawled

<u>Proposed method for assessing impact on habitats:</u>

The general BENTHIS-model:

Door spread (m)=(a*kWb)

with *a* and *b* fishing-type specific parameters (found in Eigaard *et al*. in press) indicating the width between otter boards in seafloor contact during trawling, in meters. To calculate seafloor area swept per kilo landing, this estimate needs to be multiplied with the speed of the trawl (in meters/hour) adjusted for the landing per hour trawled (CPUE, in kg/hour).

Data availability and plan for update

The LCA practitioner will have to inventory the kW of the boats involved in the fishery, trawling speed and hours trawled in order to perform the seafloor assessment. These data should be available by the national fisheries authority.

4. Ecological communities

Ecological communities are affected by fishing activities and may alter the ecosystem in terms of trophic structure, size composition, diversity, primary production and more (Fulton *et al.* 2005, Rochet & Trenkel 2003).

LCA methods available

This is an area of method development that has been the least advanced in LCA of seafood, in part due to the complexity. The impact on ecological communities is the sum of all fishing activities and more, making the impact contribution from a certain fishing activity hard to decouple from the total impact. Of note, Avadi *et al.* (2014) coupled LCA with ecosystem modelling in the form of Ecopath with Ecosim (EwE; Christensen & Walters 2004). This is a promising area, but given the novelty, Simapro and LCA practitioner applicability is yet to resolve. The sea use approach suggested by Langlois *et al.* (2014b) could also be seen as an attempt to take a wider approach to ecosystem effects but was earlier dismissed as not being scientifically valid.

In one sense, the PPR metric (or biotic resource use, BRU) offers a measure of this aspect and may be used until more complete approaches are defined (Hornborg *et al. 2013a*). This metric has been widely applied for assessing feed composition in aquaculture (e.g. Pelletier *et al.* 2009). PPR is calculated according to an equation from Pauly and Christensen (1995).

<u>Proposed method for assessing impact on ecological communities:</u>

Quantifying PPR for both landings and discard. This is done based on a conservative 9:1 conversion ratio of wet weight to carbon:

$$\textbf{PPR}= \sum_i (Y_i/9) \times \left(\frac{1}{TE}\right)^{(TL_i-1)}$$

where Y_i is landing yield for species i with trophic level TL_i, and transfer efficiency TE (global average 10%).

Based on the fact that different regions have different TE (Coll *et al.* 2008), regional values may be used (Hornborg *et al.* 2013a).

SimaPro applicability

The LCA practitioner would have to inventory catch volume per species. Regionalized characterization factors for estimating PPR would be available in Simapro.

Data availability and plan for update

Trophic level estimates are found on FishBase (fishbase.org). Regionalized TE values are found in e.g. Coll *et al.* (2008).

Directions on how to calculate biotic impacts

Examples are here provided on how biotic impact assessment may be done for a seafood product (cod, haddock and shrimp) from capture fisheries, here landings from a Norwegian freeze-trawler during 2013 in the Barents- and Norwegian Sea (Ziegler *et al.* 2015). Mass allocation is used.

1. Target species

The OF and OB midpoint impact categories are as suggested by Emanuelsson et al. (2014):

$$OF = F/F_{MSY} - 1;$$
$$OB = B_{MSY}/B - 1$$

OF, referring to fishing pressure, describes how close to the target fishing mortality the fishery is at present (with the OF value to be understood as how many kilos that are currently fished too much for every kilo that is landed), while OB, referring to fish biomass, describes how close the stock is to its target biomass (the resulting OB value to be understood as how much too low the spawning stock biomass is in kilos per kilo landed). Note that when $F=F_{MSY}$ ***and*** $B=B_{MSY}$ ***both OF and OB are 0, indicating no ongoing overfishing or overfishedness. The characterization model is therefore expressed for OF so that the optimum case (***$F=F_{MSY}$***) to result in no impact per FU, and for OB to correspond to zero impact when*** $B = B_{MSY}$ ***and is also inverted in order to make larger value equal to higher impact).***

Alternatively, if there are no reference points relating to MSY while it is sustainably fished according to scientific advice, the OF is set to 0.

To calculate overfishing through fishing mortality (OF), the fishing mortality F for the assessed species during the year it was caught is compared with the target fishing mortality for maximum sustainable yield F_{MSY} for the stock during the same year, as defined by the International Council for the Exploration of the Seas (ICES). For the example below, landings from a fishery that took place during 2013, the reference points for F (i.e. the fishing mortality during 2013) and F_{MSY} (i.e. the target value for 2013) is taken from the ICES advice released in 2014. Values for F and F_{MSY} for the specific stock, is found under stock advices at the ICES webpage (ICES 2015).

Four species/stocks had biological reference points allowing them to be evaluated in terms of impact on target species; OF was 0 kg/kg for cod and hake, whereas 0.6 kg/kg for haddock in 2013 (Table 1). Shrimp did not have explicit reference points related to *MSY* identified, but was categorised as green in the advice (harvested sustainably).

Table 0-1 Calculation of overfishing through fishing mortality (OF) in 2013 for a Norwegian seafood product (cod or haddock) delivered to port.

Fishery	Stock	Scientific name	F	F_{MSY}	Landings (kg)	OF x kg	OF (kg/kg)
Cod-haddock	Northeast Arctic cod	*Gadus morhua*	0.23	0.4	4 557 259	0	0
Cod-haddock	Northeast Arctic haddock	*Melanogrammus aeglefinus*	0.56	0.35	489 078	293 447	0.06
Cod-haddock	Hake (northern stock)	*Merluccius merluccius*	0.24	0.24	144	0	0
Shrimp	Northern shrimp[20]	*Pandalus borealis*	-	-	185 768	0	0

As the fishing boat had different target species during different trips during the year, the trips for cod and haddock were separated from those targeting shrimp. For the cod-haddock fishery, there was a total landing of all species of 5 225 305 kg during 2013 (trips 5, 6, 9-11, 13, 16-23). The only species caught with an impact value for OF was haddock; this implies a total OF for the fishery at 293 447/5 225 305 = 0.056 kg/kg landing in the cod/haddock fishery (see By-catch assessment). Pure shrimp fishing was only done in one trip (trip 7), with no by-catch of fish, resulting in an OF of 0 kg/kg shrimp.

Overfishedness of biomass (OB) was not possible to calculate due to lack of reference points in the advice.

2. By-catches

The hierarchical framework developed by Ziegler et al. (2015) is as follows:

4. ***Exclude fish landings that have OF and/or OB values (these belong to target)***
5. ***Quantify the composition of the remaining landings comprising of species listed as VEC or is assessed by the IUCN Red List***
6. ***Quantify the rest of the landings as being Data-Limited catches***
7. ***If there is data on discards, repeat the procedure for the discarded part of the catch; if discard data is lacking, provide for alternative references for estimates of discard rate (e.g. Kelleher 2005)***

From the same data set as for the target species impact assessment, landings belonging to the OF category was excluded and landings were screened for presence of species listed as threatened, i.e. belonging to either the Vulnerable (VU), Endangered (EN) or Critically endangered (EN) category, on the latest Norwegian Red list of Threatened Species (Kålås *et al.* 2010). Two

[20] The stock are given no quantitative reference points in the advice, merely “green”= harvested sustainably.

species were assessed to have a threat status, both red fishes: *Sebastes marinus* and *Sebastes mentella*. Landings of these two species combined comprised of 33 720 kg in the cod/haddock fishery during 2013, none in the shrimp fishery, resulting in a VEC-value of:

33 720/5 225 305 = **0.006 kg VEC/kg landing in the cod and haddock fishery**; and
0/185 768 = **0 kg VEC/kg landing in the shrimp fishery**

Of note, Norway and Sweden provide unique examples of having national IUCN Red Lists updated every five years. There is however a recent European initiative that has categorised all European marine fish according to the IUCN framework. When available, national lists are preferred, as is the case with Norway. If the European IUCN Red List would have been used, the two red fish species would have been categorised as VEC, plus a few additional species, namely halibut *Hippoglossus hippoglossus* (VU), roundnose grenadier *Coryphaenoides rupestris* (EN) and possibly wolffish (but it was not identified to a species level and only one is considered to be threatened). There is also a global IUCN Red list.

The rest of the catch, i.e. the total catch minus OF- and VEC-species, was categorised as Data-Limited catches (D-L), estimated as follows for the cod-haddock fishery:

5 225 305 – 4 557 259 – 144 – 489 078 – 33 720 = 144 960 D-L landings

Per landing, this is equivalent to **0.03 kg D-L/kg cod/haddock.**

The shrimp fishery had no reported by-catch of fish, thus **0 kg D-L/kg shrimp.**

Discard data was not available. According to a Norwegian report from 2004 (Kommisjonen for tiltak mot utkast av fisk 2004), the discard ratios are relatively small in these two fisheries. The shrimp fishery uses a species-selective grid, but may discard juvenile fish, mainly gadoids (approximately 0.05- 0.1 kg/kg landed shrimp; table 3). In the cod-haddock fishery, discards are also in the range of 0.05-0.1 kg/kg landing.

3. Habitats

The general BENTHIS-model is as follows:

$$\textit{Door spread (m)} = (a * kW^{b})$$

Where a and b are fishing-type specific parameters indicating the width between otter boards in seafloor contact during trawling, in meters. To calculate seafloor area swept per kilo landing, this estimate needs to be multiplied with the speed of the trawl (in meters/hour) adjusted for the landing per hour trawled (CPUE, in kg/hour).

For crustacean trawling (OT_CRU, table 4 in Eigaard et al. 2015), this equals to:

$$\textit{Seafloor area per landing } m^2/kg = ((5.1 * kW^{0.47}) * speed)/CPUE; \textit{ and}$$

for demersal fish trawling (OT_DMF):

Seafloor area per landing m²/kg=((9.6*kW$^{0.43}$)*speed)/CPUE

According to the online resource 1 in Ziegler et al. (2015), the Norwegian freeze-trawler reported different speed depending on target species, higher for fish than for shrimp. A typical shrimp haul has a speed up to 2.5 knots, whereas a typical cod and haddock haul has a speed up to 3.8 knots; 1 knot equals to 1 852 m/h. The engine effect of the boat was approximately 3840 kW.

As there was no information on trawl hours for 2013, this assessment was based on the background data on catch per unit effort (CPUE, in kg/h) from 2011. The seafloor impact for the shrimp fishery, with an average CPUE of 680 kg/h and speed of 2.5 knots thus equals to:

((5.1*3840*0.47)*(2.5*1 852))/680= **1 680 m²/kg shrimp**

For cod and haddock, trawling with a speed of 3.8 knots and a CPUE of 6200 kg/h, this equals to:

((9.6*3840*0.43)*(3.8*1 852))/6200= **380 m²/kg cod/haddock**

5. Ecological communities

The quantifying of primary production required (PPR) for catches is done based on a conservative 9:1 conversion ratio of wet weight to carbon:

$$PPR = \sum_i (Y_i/9) \times \left(\frac{1}{TE}\right)^{(TL_i - 1)}$$

where Y_i is landing yield for species i with trophic level TL_i, and transfer efficiency TE (global average 10%).
Based on the fact that different regions have different TE (Coll et al. 2008), regional values may be used (Hornborg et al. 2013a).

To estimate PPR, trophic levels are found at Froese and Pauly (2015). If ecosystem-specific transfer efficiencies *TE* are not found, the global average 10% may be used. Ecosystem-specific values can be found at webpages (Pauly and Zeller 2015; NOAA 2015) http://www.seaaroundus.org/or scientific publications such as Coll et al. (2008).

Using the 10% global average for *TE* and the data from 2013, PPR for the cod and haddock fishery was 139 gC/kg cod and haddock (table 2) whereas shrimp had the equivalent of 56 gC/kg (table 3).

Table 2 PPR estimates for cod and haddock fishing.

Species	TL	Landing (kg)	PPR (g C)	PPR/kg
Cod	4.1	4 557 259	637 472 129	
Haddock	4.0	489 078	54 342 000	

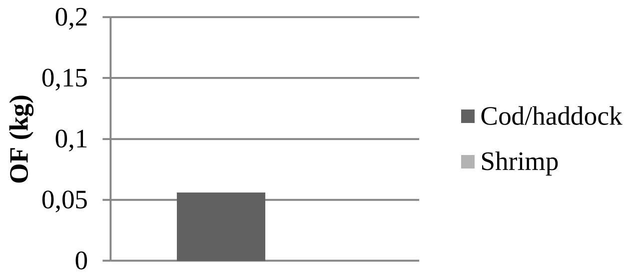
Others	3.6-4.4	178 968	32 997 155	
Total		5 225 305	724 811 284	**139**

Table 3 PPR estimates for shrimp fishing.

Species	TL	Landing (kg)	PPR	PPR/kg
Shrimp	3.7	185 768	10 344 950	
Total				**56**

Discard data was not available.

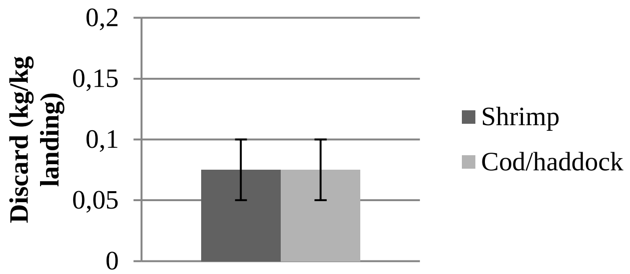
Overall results



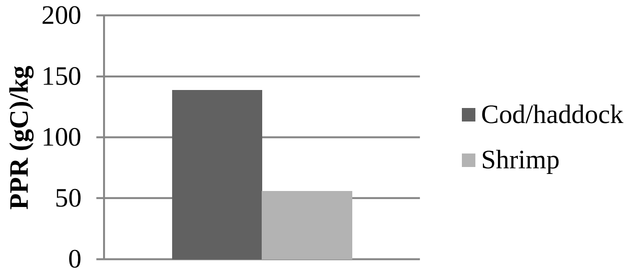
Overfishing is low in the cod and haddock fishery and there is no overfishing in the shrimp fishery.

Landing of Data-Limited species is low in the cod and haddock fishery and none in the shrimp fishery.

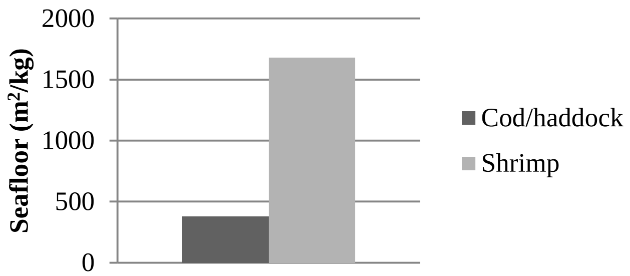
Landing of threatened species is low in the cod and haddock fishery and none in the shrimp fishery.



No inventory data was available on discards; figures are based on a report describing discards in the two different fisheries. The shrimp fishery is estimated to have lower discards per kilo landing, or they could the same.



The primary production required is more than double for the cod and haddock fishery compared to the shrimp fishery.



The seafloor area swept per kilo is more than three times as high for the shrimp fishery compared to the cod and haddock fishery.

Some considerations on the methods proposed by SP Food and Bioscience and presented inn Annex I

As regards overfishedness of biomass (OB) the application of the method is complex, also given the quality of data, and that part might be questioned due to that. However, biomass is an indicator evaluated by ICES, the scientific body delivering data to the EC and also internationally (e.g. US/Canada) so data is available.
As regards by-catch, some might consider that the IUCN list should not be the reference. However, since the IUCN categories and criteria, is a globally applied assessment method which is e.g. supporting one of the indicators to the Convention of Biological Diversity. The recent initiative on assessing the status of all marine fish further strengthens its applicability in European waters and this is not to say that it cannot be used outside of EU waters.
With regard to the last two impacts, namely on habitats and ecological communities, one might consider as first option is what is already available in EU regulations. In particular, Appendix XIII of Commission Decision of 18 December 2009 (2010/93/EU) adopting a multiannual Community programme for the collection, management and use of data in the fisheries sector for the period 2011-2013 defines a series of environmental indicators to measure the effects of fisheries on the marine ecosystem, that are linked to the Marine Strategy Framework Directive. The Commission will soon start working on the preparation of a new proposal replacing

decision 93/2010, the Multiannual Programme for data collection, but for the moment this may constitute a reference for the definition of environmental indicators.

Similarly, Annex III of Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) provides an indicative lists of impacts on the environment caused by human activity. This is a piece of ENV legislation. Below is the link to one of the last reports released by ICES on descriptors and indicators related with the MSFD:
http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2015/Special_Requests/EU_Revisions_to_MSFD_manuals_for_Descriptors_346.pdf

Another option, envisaged under point 4.5 of the recommendations on the use of methods for PEF (2013/179/EU) PEF, might be that the impacts on habitats and ecological communities should be explained by means of qualitative descriptions as provided in the abovementioned legal acts.

References for Annex I

Avadí, A. & Fréon, P. (2013) Life cycle assessment of fisheries: a review for fisheries scientists and managers. *Fisheries Research* 143: 21-38

Avadí, A., Fréon, P. & Tam, J. (2014) Coupled ecosystem/supply chain modelling of fish products from sea to shelf: the Peruvian anchoveta case. *PloS one* 9(7): e102057

Chassot, E., Bonhommeau, S., Dulvy, N. K., Mélin, F., Watson, R., Gascuel, D. & Le Pape, O. (2010) Global marine primary production constrains fisheries catches. *Ecology letters* 13(4): 495-505

Christensen, V. & Walters, C. J. (2004) Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172: 109-139

Coll, M., Libralato, S., Tudela, S., Palomera, I. & Pranovi, F. (2008) Ecosystem overfishing in the ocean. *PLoS one*, 3(12): e3881

Collette, B. B., Polidoro, B. & Carpenter, K. (2013) Fisheries: Corrected numbers for fish on Red List. *Nature* 495(7439): 47-47

Costello, C., Ovando, D., Hilborn, R., Gaines, S. D., Deschenes, O., *et al.* (2012) Status and solutions for the world's unassessed fisheries. *Science* 338(6106): 517-520

Dulvy, N. K., Jennings, S., Goodwin, N. B., Grant, A. & Reynolds, J. D. (2005) Comparison of threat and exploitation status in North-East Atlantic marine populations. *Journal of Applied Ecology* 42(5): 883-891

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., *et al.* (2014). Extinction risk and conservation of the world's sharks and rays. *Elife* 3: e00590

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., *et al.* (in press) Estimating seafloor pressure from demersal trawls, seines and dredges based on gear design and dimensions. *ICES Journal of Marine Science*

Emanuelsson, A., Ziegler, F., Pihl, L, Sköld, M. & Sonesson, U. (2014) Accounting for overfishing in Life Cycle Assessment: new impact categories for biotic resource use. *International Journal of Life Cycle Assessment* 19:1156-1168

Emanuelsson, A. & Ziegler, F. (unpublished) Desk study on alternative approaches to include fishing impacts on seafloor areas in seafood LCAs. LC IMPACT deliverable.

EU (2013) Regulation No 1380/2013 of the European Parliament and the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., *et al.* (2011) Solutions for a cultivated planet. *Nature* 478(7369): 337-342

Fulton, E. A., Smith, A. D. & Punt, A. E. (2005) Which ecological indicators can robustly detect effects of fishing? *ICES Journal of Marine Science,* 62(3): 540-551

Hobday, A. J., Smith, A. D. M., Stobutzki, I. C., Bulman, C., Daley, R., *et al.* (2011) Ecological risk assessment for the effects of fishing. *Fisheries Research* 108(2): 372-384

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., *et al.* (2010). The impact of conservation on the status of the world's vertebrates. *Science* 330(6010): 1503-1509

Hornborg, S., Belgrano, A., Bartolino, V., Valentinsson, D. & Ziegler, F. (2013a) Trophic indicators in fisheries: a call for re-evaluation. *Biology Letters* 9(1):20121050

Hornborg, S., Svensson, M., Nilsson, P. & Ziegler F. (2013b) By-Catch impacts in fisheries: Utilizing the IUCN Red List categories for enhanced product level assessment in seafood LCAs. *Environmental Management* 52(5):1239-1248

Hornborg, S. Nilsson, P., Valentinsson, D. & Ziegler, F. (2012) Integrated environmental assessment of fisheries management: Swedish *Nephrops* trawl fisheries evaluated using a life cycle approach. *Marine Policy* 36: 1193-1201

Hunt, G. L., & McKinnell, S. (2006) Interplay between top-down, bottom-up, and wasp-waist control in marine ecosystems. *Progress in Oceanography* 68(2): 115-124

Hutchings, J. A. & Reynolds, J. D. (2004) Marine fish population collapses: consequences for recovery and extinction risk. *Bioscience* 54(4): 297-309

ICES (2009a) Report of the Workshop on analytical methods for evaluation of extinction risk of stocks in poor condition (WKPOOR1), 18-20 May 2009, Copenhagen, Denmark. ICES CM 2009\ACOM:29.

ICES (2009b) Workshop for the Exploration of the Dynamics of Fish Socks in Poor Conditions (WKPOOR2), 24-27 August 2009, Bergen, Norway. ICES CM 2009\ACOM:49.

IUCN (2012) IUCN Red List of Threatened Species. Version 2011.2. <www.iucnredlist.org>. Downloaded on 31 March 2012.

Jennings, S. & Kaiser, M. J. (1998) The effects of fishing on marine ecosystems. *Advances in marine biology* 34: 201-352

Kelleher, K. (2005) Discards in the world's marine fisheries: an update (No. 470). Food & Agriculture Org..

Langlois, J., Fréon, P., Delgenes, J. P., Steyer, J. P. & Hélias, A. (2014a) New methods for impact assessment of biotic-resource depletion in life cycle assessment of fisheries: theory and application. *Journal of Cleaner Production* 73: 63-71

Langlois, J., Fréon, P., Steyer, J. P., Delgenès, J. P. & Hélias, A. (2014b) Sea-use impact category in life cycle assessment: state of the art and perspectives. *The International Journal of Life Cycle Assessment* 19(5): 994-1006

Lindeijer, E., Müller-Wenk, R. & Steen, B. (2002) Impact assessment of resources and land use. In: Udo de Haes *et al.* Life cycle impact assessment: Striving towards best practice. SETAC, Pensacola, Florida.

i Canals, L. M., Bauer, C., Depestele, J., Dubreuil, A., Knuchel, R. F., *et al.* (2007) Key elements in a framework for land use impact assessment within LCA. *The International Journal of Life Cycle Assessment* 12(1): 5-15

Nilsson, P. & Ziegler, F. (2007) Spatial distribution of fishing effort in relation to seafloor habitats of the Kattegat, a GIS analysis. *Aquatic Conservation: Marine and Freshwater Ecosystems* 17:421-440

Pauly, D. & Christensen, V. (1995) Primary production required to sustain global fisheries. *Nature* 374(6519): 255-257

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Torres, F. (1998) Fishing down marine food webs. *Science* 279(5352): 860-863

Pelletier, N. L., Ayer, N. W., Tyedmers, P. H., Kruse, S. A., Flysjo, A., *et al.* (2007). Impact categories for life cycle assessment research of seafood production systems: review and prospectus. *The International Journal of Life Cycle Assessment* 12(6): 414-421

Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., *et al.* (2009). Not all salmon are created equal: life cycle assessment (LCA) of global salmon farming systems. *Environmental Science & Technology* 43(23): 8730-8736

Puig, P., Canals, M., Company, J. B., Martín, J., Amblas, D., *et al.* (2012). Ploughing the deep sea floor. *Nature* 489(7415): 286-289

Punt, A. & Smith, A. D. M. (2001) The gospel of maximum sustainable yield in fisheries management: birth, crucifixion, and reincarnation. In: Reynolds JD, Mace GM, Redford KH, Robinsson HG (eds) Conservation of exploited species. Cambridge University Press, Cambridge UK, pp 41–66

Reap, J., Roman, F., Duncan, S. & Bras, B. (2008) A survey of unresolved problems in life cycle assessment, Part 2: Impact assessment and interpretation. *The International Journal of Life Cycle Assessment* 13: 374-388

Rochet, M. J. & Trenkel, V. M. (2003) Which community indicators can measure the impact of fishing? A review and proposals. *Canadian Journal of Fisheries and Aquatic Sciences* 60(1): 86-99

Rondinini, C., Marco, M., Visconti, P., Butchart, S. H. & Boitani, L. (2014) Update or outdate: Long-term viability of the IUCN Red List. *Conservation Letters* 7(2): 126-130

Sheppard, C. (2006) Trawling the sea bed. *Marine Pollution Bulletin* 52(8): 831-835

Smith, A. D., Brown, C. J., Bulman, C. M., Fulton, E. A., Johnson, P., *et al.* (2011). Impacts of fishing low–trophic level species on marine ecosystems. *Science* 333(6046): 1147-1150

Vázquez-Rowe, I., Hospido, A., Moreira, M. T. & Feijoo, G. (2012a) Best practices in life cycle assessment implementation in fisheries. Improving and broadening environmental assessment for seafood production systems. *Trends in Food Science & Technology* 28(2): 116-131

Vázquez-Rowe, I., Moreira, M. T. & Feijoo, G. (2012b) Inclusion of discard assessment indicators in fisheries life cycle assessment studies. Expanding the use of fishery-specific impact categories. *The International Journal of Life Cycle Assessment* 17(5): 535-549

Watling, L. (2005) The global destruction of bottom habitats by mobile fishing gear. Marine conservation biology: the science of maintaining the sea's biodiversity. Island Press, Washington, DC, 198-210.

Watson, R., Zeller, D. & Pauly, D. (2014) Primary productivity demands of global fishing fleets. *Fish and Fisheries* 15(2): 231-241

Ziegler, F., Nilsson, P., Mattsson, B. & Walther, Y. (2003) Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts. *The International Journal of Life Cycle Assessment* 8(1): 39-47

Ziegler, F. & Valentinsson, D. (2008) Environmental life cycle assessment of Norway lobster (*Nephrops norvegicus*) caught along the Swedish west coast by creels and conventional trawls. *The International Journal of Life Cycle Assessment* 13(6): 487-497

Ziegler, F., Groen, E., Hornborg, S., Bokkers, E., Karlsen, K.M. & de Boer, I. (accepted) Assessing broad life cycle impacts of a northeast Atlantic trawl fishery: The importance of daily onboard decision-making, annual strategic planning and fisheries management. *International Journal of Life Cycle Assessment*

Coll, M., Libralato, S., Tudela, S., Palomera, I. and Pranovi, F. (2008) Ecosystem overfishing in the ocean. PLoS one, 3(12), e3881.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., Nielsen, J. R., Nilsson, H. C., O Neill, F. G., Polet, H., Reid, D. G., Sala, A., Sköld, M., Smith, C., Sørensen, T. K., Tully, O., Zengin, M. and Rijnsdorp, A. D. (2015) Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. *ICES Journal of Marine Science*, doi: 10.1093/icesjms/fsv099.

Froese, R. and Pauly, D. Editors. (2015) FishBase. World Wide Web electronic publication. www.fishbase.org, version (08/2015).

ICES (2015) Latest advice found at: http://www.ices.dk/community/advisory-process/Pages/Latest-advice.aspx

Kelleher, K. (2005) Discards in the world's marine fisheries: an update. Food and Agriculture Organisation. Report No. 470.

Kommisjonen for tiltak mot utkast av fisk (2004) Rapport med anbefalinger. 28 april, 88 pages.
NOAA (2015) Large Marine Ecosystems of the World http://lme.edc.uri.edu/

Pauly, D. and Zeller, D. Editors (2015) Sea Around Us Concepts, Design and Data www.seaaroundus.org

Ziegler, F., Groen, E. A., Hornborg, S., Bokkers, E. A., Karlsen, K. M. and de Boer, I. J. (2015) Assessing broad life cycle impacts of daily onboard decision-making, annual strategic planning, and fisheries management in a northeast Atlantic trawl fishery. *The International Journal of Life Cycle Assessment*, 1-11.

Kålås, J. A., Viken, Å., Henriksen, S. and Skjelseth, S. (2010) The 2010 Norwegian Red List for species. Norwegian Biodiversity Information Centre, Norway

Hornborg, S., Svensson, M., Nilsson, P., & Ziegler, F. (2013). By-catch impacts in fisheries: Utilizing the IUCN Red List categories for enhanced Product Level Assessment in seafood LCAs. Environmental management, 52(5), 1239-1248.