NEPTUNUS

PROJECT

Deliverable Title:	**Methodology of Water, Energy, Carbon and Nutritional Footprint for seafood products**
Deliverable Lead:	University of Santiago de Compostela (USC)
Related Work Package:	WP nr. 5 Lifecycle Water-Energy-Food Nexus
Related Actions:	Action nr. 1. Water Footprint Action nr. 2. Energy Footprint Action nr. 3. Carbon Footprint Action nr. 4. Nutritional Footprint
Deliverable number:	D5.1.1; D5.2.1; D5.3.1; D5.4.1
Author(s):	University of Santiago de Compostela (USC) team; University of Aveiro (UA) team, EnergyLab team, University of Cantabria (UC) team, University of Liverpool (UoL) team and IPMA team.
Dissemination level:	Confidential
Due Submission Date:	31/03/2021
Actual Submission Date:	09/04/2021
Project Number:	EAPA_576/2018
Instrument:	Technical and scientific publication
Start date of the project:	30/06/2019
Duration:	42 months
Abstract	The aim of this deliverable is to develop a guide to unify the calculation of the Water, Carbon, Energy and Nutritional Footprint of seafood products. This guide aims to serve as a tool in the development of the Product Environmental Footprint Category Rules of seafood products.

Interreg Atlantic Area

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS).

INDEX

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

TABLES INDEX

FIGURES INDEX

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

GLOSSARY AND ABBREVIATION

AESAN	Spanish Agency for Food Safety and nutrition
BEDCA	Spanish Food Composition Database
BE	Background Emissions
CED	Cumulative Energy Demand
ChF	Characterisation Factor
CF	Carbon Footprint
CFF	Circular Footprint Formula
CPA	Classification of Products by Activity
CSIC	Spanish National Research Council
DV	Daily recommended Value
EAM	European Attribute Mix
EC	European Commission
EF	Energy Footprint
EoL	End-of-Life
EPD	Environmental Product Declaration
FAO	Food and Agriculture Organization of the United Nations
FIAB	Spanish Federation of Food and Beverage Industries
GO	Guarantee of Origin
FU	Functional Unit
HEI	Healthy Eating Index
HFCR	Hortifootprint Category Rules
INA-PG	French national Institute of Agronomy
INRA	French National Institute for Agronomic Research
IRD	French Research Institute for Development
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
MRV	Maximum Recommended Value
NF	Nutritional Footprint
NRF	Nutrient-rich food
OE	On-site Emissions
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rule
RACC	Reference Amounts Customarily Consumed
SS	Subsystem
WE	Waste treatment Emissions
WF	Water Footprint

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

SUMMARY

This report has been developed in the framework of the NEPTUNUS project (EAPA_576/2018) with the collaboration of all WP5 involved partners. This report represents the methodological guide, which includes the basic guidelines to be followed for the calculation of the environmental footprints (Water, Energy, Carbon and Nutritional) of seafood products. This guide is applicable to evaluate the different footprints of seafood products assessed in the NEPTUNUS project. The main objective of this methodological guide is to provide valuable information for the estimation of the different footprints of seafood products within the framework of the NEPTUNUS project. In this context, the unification and homogenization of the different footprints calculation process will be useful to address the evaluation of the most important stages from the seafood production system, as well as their nutritional quality in a single value. To that end, this guide follows the next steps:

i. Selection of the most suitable functional unit for the system under study.

ii. Definition of the system boundaries for the most accurate assessment, establishing the mandatory and optional elements, in addition to the elements that are excluded from the system boundaries (cut-off criteria).

iii. Establish the inventory data required for each stage as well as the most appropriate allocations methods.

iv. Selection of the most suitable nutritional index according to the objectives of the NEPTUNUS project.

v. Calculation of the different environmental footprints according to the methodology established.

vi. Obtention of the NEXUS eco-label that integrates the environmental and nutritional results of seafood products.

This methodological guide is aligned with the Product Environmental Footprint methodology of the European Union, so it is expected that it will serve as a basis to develop the Product Environmental Footprint Category Rules of seafood products in the short term.

ACKNOWLEDGEMENTS

The methodology of Water, Energy, Carbon and Nutritional Footprint for seafood products was prepared under the coordination of the University of Santiago de Compostela (USC) team, coordinator of the Work Package 5. Lifecycle Water-Energy-Food nexus and with the direct participation of the rest of partners involved in the WP5: University of Aveiro (UA), EnergyLab, University of Cantabria (UC), University of Liverpool (UoL) and Instituto Português do Mar e da Atmosfera (IPMA). The USC staff involved in this report were: Antonio Cortés, Xavier Esteve-Llorens, Eduardo Entrena-Barbero, Amaya Franco-Uría, Sara González-García, Maria Teresa Moreira and Gumersindo Feijoo. UA staff involved in this report were: Tamiris Pacheco da Costa, Paula Quinteiro and Ana Cláudia Dias. EnergyLab staff involved in this report were: Eduardo Rodríguez, Dolores Mariño, Lucía Poceiro, Diego Quiño and Pedro Villanueva-Rey. UC staff involved in this report were: Jara Laso, Israel Ruiz, María Margallo and Rubén Aldaco. UoL staff involved in this report were: Andy Morse. IPMA staff involved in this report were: Cheila Almeida, Maria Leonor Nunes and António Marques. The USC, UA, EnergyLab, UC, UoL and IPMA teams would like to acknowledge to all the researchers involved in the NEPTUNUS project (EAPA_576/2018), whose contributions and comments allowed improving the quality of the document.

1. Introduction

1.1. Background

During the last decade, companies throughout the supply chain, processing units and consumers are aware of the environmental impacts related to fishing, aquaculture, processing, transportation, packaging and to all steps from farm to fork, increasing the demand for sustainable produced seafood products. Therefore, there is a growing interest for calculating the environmental footprints of these products. In this context, as consumers, producers, authorities, and retailers are willing to evaluate and communicate products' sustainability; there is not yet any standard methodology for calculating it. In 2012, it was published a specification for the assessment of the carbon footprint of seafood and other aquatic products (PAS 2050-2:2012), but it does not include other environmental issues apart from greenhouse gas (GHG) emissions. Additionally, its methodology is out-of-date for some aspects.

In the framework of the Interreg Atlantic Area NEPTUNUS project, it is developed a standardized and uniform methodology to perform environmental footprints of seafood products from a life cycle perspective. Hence, the main aim of this methodological guide is to provide, in a concise and short way, detailed and comprehensive technical guidance on how to perform environmental footprints studies of the seafood products in a harmonised and consistent manner. Using this guide, European —focusing on the Atlantic Area— seafood sector will be able to perform environmental footprint studies in a harmonised and consistent way.

The development of the guide and its structure follows the main international Life Cycle Assessment (LCA) guidelines and has been developed in alignment to the European Commission (EC) Product Environmental Footprint (PEF) method (Zampori and Pant, 2019) and Product Environmental Footprint Category Rules Guidance (European Commission, 2018).

1.2. Environmental foot-printing

Since the development of "ecological footprint" concept —which aims at quantifying the mark left by human activities on natural environment—, several footprints have raised in the environmental field (Hauschild et al., 2018). In addition, most of the footprints are based on the life cycle perspective, having as well-known examples: ecological footprint, water footprint (WF), carbon footprint (CF), cumulative energy demand (CED) or chemical footprint.

The life cycle perspective footprints are mainly focused on one environmental issue of area of interest/concern. Additionally, given the fact that they can be applied to products, services, organizations, populations, countries, etc., they have been very successful in the last decades. According to Hauschild et al. (2018), their main strengths rely on:

- Easy to communicate to non-environmental experts.
- Accessible and intuitive.
- Relatively easy to perform when data available.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

However, footprints have also some important limitations:

- Focused only on one environmental issue/impact.
- Some only assess the quantity or consumption of one resource.
- They are not suitable to support decisions regarding environmental sustainability.
- Some footprints cannot be combined because it can lead to double counting of impacts when they are not aligned.

The focus on single environmental problems is the main drawback of footprints due to its limitations regarding their use in decision-making processes and policies development. For instance, CF does not account emissions related to toxic substances. Thus, in those situations CF does not represent the environmental burden of a product, being environmental management outcomes focused only on GHG emissions. Therefore, the use of environmental footprints as stand-alone indicator may be often limited.

Furthermore, the environmental footprints can be combined to enlarge their narrow scope in terms of environmental indicators - impact categories - covered. Hence, given their ability to raise environmental awareness, the life cycle perspective footprints can be a good entry-door into the life cycle thinking concept for public and policy makers. The appropriate combination of environmental footprints would imply a comprehensive analysis, increasing the environmental issues covered and providing complete life cycle environmental performance profile.

1.3. Product Environmental Footprint method

In recent years, the growing demand for LCA-based product declarations, such as Environmental Product Declarations (EPD) have supported the need for standards to make claims on products within the same category. The rules are defined according to the standard used, such as ISO 14025, GHG Protocol Product Life Cycle Accounting and Reporting Standard, PAS 2050, BP-X30, SMRS or TS 0100 among many others. It is therefore necessary to establish a single criterion for each product category. The PEF initiative represents the contribution of the EU to this field.

The PEF is an LCA-based method to quantify the relevant environmental impacts of products (good or services). It builds on existing approaches and international standards. The PEF initiative began in 2013 when the European Commission adopted Recommendation 2013/179/EU on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. The PEF method was part of a wider policy defined by the Single Market for Green Products Initiative. Thus, the PEF project was initiated with the aim of developing a harmonised EU methodology for environmental footprint studies that can accommodate a wider suite of relevant environmental performance criteria using a life-cycle approach to provide the basis for better reproducibility and comparison of the results. However, comparability is only possible if the results are based on the same Product Environmental Footprint Category Rules (PEFCR).

PEFCR are specific standards applied to a certain product or range of similar products, which set the basis for any life cycle assessment study from the time of its publication. The primary objective of a PEFCR is to establish a set of coherent and specific standards for calculating the relevant environmental information of products belonging to the product category. The PEFCR should be developed in accordance with the PEF method and provide the necessary specifications to achieve comparability, reproducibility, and consistency.

In 2013, the first wave of PEFCR was proposed with 3 main objectives: (i) to address the process of developing product- and sector- specific rules or standards; (ii) to test different verification approaches and (iii) to examine communication vehicles for communicating life cycle environmental performance to business partners, consumers, and other stakeholders. A list of PEF Pilots was proposed, consisting of very different products such as batteries and accumulators, paints, detergents, footwear, T-shirts, photovoltaic electricity generation, dairy products. In 2014, the development of a PEFCR for marine fish was started as part of the second wave of PEFCR pilots, which continued until May 2016, when it was decided to stop the process due to time-constraints. Therefore, since there is currently no PEFCR for marine products, the development of a roadmap for the assessment of the carbon footprint of marine products in line with the requirements of the PEF project was considered. It is expected that this document will serve in the future as a basis for the development of a specific PEFCR for marine products.

1.4. Conformance to other documents

This methodological guide aims to provide technical guidance to evaluate the environmental impacts of seafood products, applying a harmonised approach, to have comparable results. The present guide has been developed in conformance with the following documents:

- Suggestions for updating the Product Environmental Footprint (PEF) method (Zampori and Pant, 2019).
- Product Environmental Footprint Category Rules Guidance version 6.3-May 2018.
- 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 (BSI, 2012).
- ISO 22948: 2020 Carbon footprint for seafood — Product category rules (CFP-PCR) for finfish.

2. Objectives

The main objective of this methodological guide is to provide valuable information for the estimation of the environmental footprints of seafood products within the framework of the NEPTUNUS project. In this context, the unification and homogenisation of the different environmental footprints calculation processes will be useful to address the evaluation of the most important stages from the seafood production system. The specific objectives to achieve the proposed goal are the following:

i. Selection of the most suitable functional unit for the system under study.

ii. Definition of the system boundaries, establishing the mandatory and optional elements, in addition to the elements that are excluded from the system boundaries (cut-off criteria).

iii. Establishment of the minimum inventory data required for each stage as well as the most appropriate allocation factors.

iv. Identification of the life cycle impact assessment methods to calculate the water, energy, and carbon footprint, as well as to set the correct nutritional characterisation for the most accurate assessment in terms of the nutritional footprint.

v. Development of a proposal for integrating these environmental and nutritional indicators to design a Water-Energy-Food NEXUS eco-label that allows better communication with the general public.

3. Scope of the environmental footprint

This methodological guide includes the guidelines for the calculation of the environmental footprints of seafood products within the European Atlantic Area framework and their integration in the NEXUS Energy-Food-Environment. In this sense, the scope of this guide includes seafood for human consumption from fisheries or aquaculture, which comprises fresh and preserved products with techniques such as refrigeration, freezing, brining, drying, salting, and smoking. The processing of seafood products to produce into canned and similar products is also included within the scope of this guide, provided that the final objective of the processing processes is to obtain products for human consumption. Therefore, this guide excludes the production of fish oil and/or fishmeal for feed production.

3.1. Product classification

The guide is valid for the following product categories (categorisation based on the Classification of Products by Activity (CPA) codes (European Commission, 2008):

Fish and other fishing products; aquaculture products; support services to fishing:

- 03.00.1 Fish, live: including the following subcategories.
  - 03.00.12 Live fish, marine, not farmed.
  - 03.00.13 Live fish, freshwater, not farmed.
  - 03.00.14 Live fish, marine, farmed.
  - 03.00.15 Live fish, freshwater, farmed.

Processed and preserved fish, crustaceans, and molluscs:

- 10.2 Processed and preserved fish, crustaceans, and molluscs: including the following subcategories:
  - 10.20.1 Fish, fresh, chilled, or frozen. Including all subcategories, except for:

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

        - 10.20.12 Fish livers and roes, fresh or chilled.
        - 10.20.16 Fish livers and roes, frozen.
    - 10.20.2 Fish, otherwise prepared or preserved: caviar and caviar substitutes. Including all subcategories, except for:
        - 10.20.26 Caviar and caviar substitutes.
    - 10.20.3 Crustaceans, molluscs, and other aquatic invertebrates, frozen, prepared or preserved.
    - 10.20.9. Smoking and other preservation and preparation services for manufacture of fish products; sub-contracted operations as part of manufacturing of processed and preserved fish, crustaceans, and molluscs.

3.2. Functional unit and reference flow definition

The Functional Unit (FU) is the quantified performance of a product, to be used as a reference unit. Meaningful comparisons shall only be made when products can fulfil the same function (ISO, 2006a). Therefore, the FU of the system should describe qualitatively and quantitatively the function of the system. To calculate the WF, EF, CF and NF of seafood products, two different scenarios can be defined: (1) the case of environmental footprints (WF, EF and CF), in which case the objective is to assess the impact of food production for human consumption and (2) the case of nutritional footprint (NF), in which the objective is to characterise the seafood to determine the nutritional properties. Thus, for the proposed scenarios, the use of the following FU is recommended (1) 1 kg of seafood, either landed at port, at the aquaculture facilities gate or 1 unit product at factory gate with their corresponding packaging (for processed products); and (2) 100 g of seafood to characterize their nutritional content. In the case of processed products, when estimating the weight of the product, it should include liquids or preservatives considered as edible since their weight is intended to contribute to the declared unit (e.g., oil, tomato sauce, etc.). Otherwise, in other specific cases, only the seafood drained weight of the seafood shall be considered (e.g., in case of tuna in brine). In summary, FU must answer the questions listed in **Table 1**.

Table 1. *Questions to be answered by the FU for the calculation of the WF, CF and NF of seafood products.*

Questions	Fishing	Aquaculture	Processing
What?*	1 kg of seafood landed at port	1 kg of seafood at facilities gate	1 unit product at factory gate
How much?	1 kg	1 kg	1 unit product
How good?	The products should be appropriate for human consumption		
How long?	Only for products where durability or shelf-life is established		

* In all cases it is necessary to consider the specific characteristics associated with the established unit.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Other functional units could have been relevant and included for study (e.g., amount of protein); however, seafood contains a range of different nutritious substances, such as proteins with all essential amino acids, minerals, vitamins, and fatty acids. The content of these elements among the different species varies considerably, so it is complex to choose an element as FU without conditioning the environmental footprint of the products. Since the function of the system was determined as "to land/produce seafood for direct human consumption" in the cases of fishing and aquaculture and "to manufacture canned or other processed seafood products for direct human consumption" in the case of processing, the choice of an amount of protein as FU would not quantify the function of the system. For example, the selection of 100 g of protein as FU would be consistent if the function of the system were defined as "the intake of food to obtain the amount of protein needed in a healthy diet" or similar.

3.3. System boundaries – life-cycle stages and processes

The system boundaries follow an approach where all attributional processes from "cradle-to-grave" should be included using the principle of limited loss of information at the final product. This is especially important in the case of business-to-consumer communication. The "cradle-to-grave" system boundaries are indicated in **Figure 1**, including the following life cycle stages:

- **Fishing and landing**: Include all activities and inputs that are needed to extract seafood and land it at fishing port. These activities are mandatory when analysing the environmental footprint of the fishing stage. These stages must include all the necessary inputs for the use and maintenance of the vessel. Waste treatment should be also included in this system and priority should be given to the valorisation of discards and by-products.
- **Feed production and aquaculture:** It includes all the raw material and energy flows necessary for the manufacture of feed required for feeding larvae, juveniles, and adults for aquaculture production. The operations carried out in the aquaculture facilities and feed manufacturing are mandatory, while infrastructure and construction processes are optional. In this system, as fishing stage, the treatment of the waste generated during the operation must be included, as well as the treatment of rejected seafood.
- **Transport:** Transportation from fishing port or aquaculture facilities to processing facilities in specialized refrigerated or freezing trucks.
- **Processing:** It includes all the technologies used, including processes from live fish to processed fish. All the materials and energy consumption necessary to carry out the processing activities must be included. It is important to include all packaging materials used including primary and other packaging levels. This stage, along with the fish production stage (fishing or aquaculture) are the mandatory stages for any environmental study for seafood products processing. It is also necessary to include within the system boundaries the treatment carried out on both packaging end-of-life (plastic, cardboard, wood, metal, etc.) and by-products application (viscera, fish

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

heads, fish bones, etc.), adding actions or inputs from these operations whenever it is possible.

- **Distribution:** Transport from processing plant to the distribution and retail centres.
- **Storage:** Display of and storing of product.
- **Use:** Storing and heating/preparation of seafood in households.
- **End-of-life:** Waste treatment of seafood that is not consumed and not considered a by-product. End-of-life (EoL) treatments of packaging associated with the products are also included in this stage.

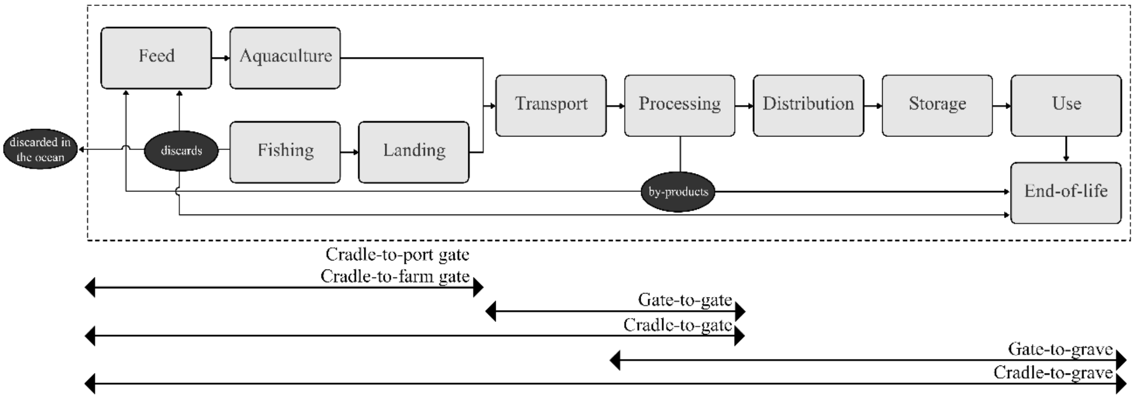

Figure 1. *System boundaries of the complete life cycle of the production and consumption of seafood products.*

This guide is focused on "cradle-to-gate" studies, dealing specifically with the fishing, aquaculture and processing stages, excluding the distribution, use and end-of-life stages. The guide also provides flexibility to LCA practitioners to define the system boundaries of the environmental footprint to be performed, allowing users to select the life cycle stages that will be in scope of their own study. Consequently, the chosen system boundary shall be reflected in the functional unit and reference flow of the study. Some rules shall apply to the flexible approach:

- Cradle-to-gate shall be the minimum scope. It includes those studies from fishing or aquaculture activities to either port/farm or processing facilities gate.
- It shall be stated the life cycle stages included and excluded.
- A system diagram shall be provided.
- The functional unit and reference flow shall be consistent to the chosen system boundaries.

The flexible approach has been followed by other initiatives to develop a standardized environmental footprint methodology in the absence of specific PEFCR. The Hortifootprint Category Rules (HFCR) provides technical guidance to the horticultural sector on how to perform LCA studies of horticultural products as required by the PEFCR methodology but

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

giving flexibility to: i) define system boundaries and ii) select secondary data for background modelling (Helmes et al., 2020).

3.3.1. System boundaries – Fishing

The system boundaries for fisheries shall include the elements related to the use and maintenance of the vessel. Optionally, the construction and EoL operations of the vessel should be included (if data available). Fishing activities must include a series of relevant elements. As detailed in previous scientific articles related to the environmental impacts of fisheries, some key parameters are diesel, antifouling, paint, lubricant oil, nets (or different gears). Thus, these elements can be divided between vessel maintenance and vessel use. The system boundaries for any study related to environmental impacts of fishing activities must include at least the elements listed in **Figure 2**.

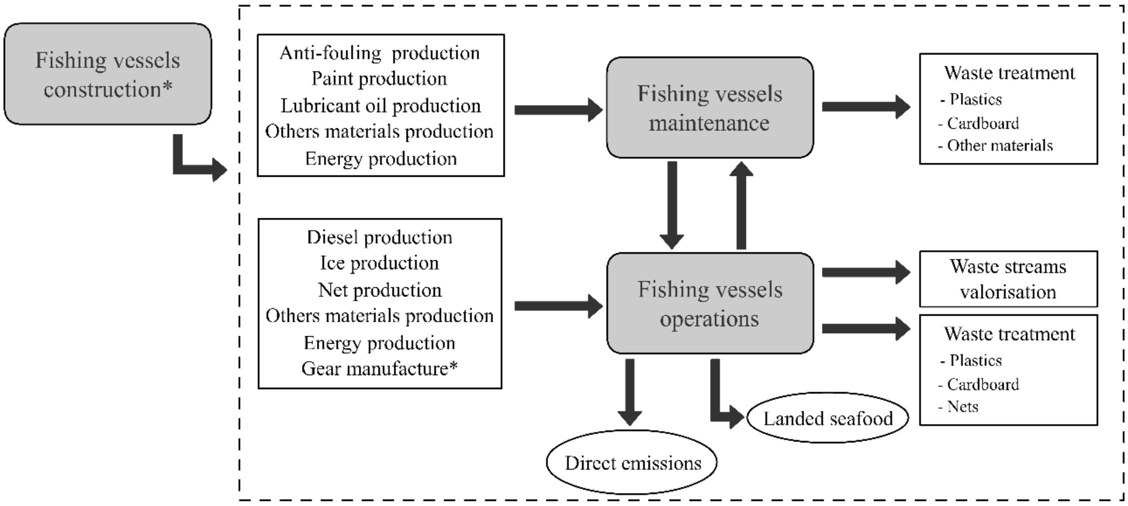

Figure 2. *System boundaries for fishing-related case studies. * Optative elements.*

It is also necessary to determine the direct emissions derived from the consumption of materials. Direct gaseous emissions derived from diesel or natural gas combustion are relevant, which have been estimated in previous scientific literature according to the updated EMEP/EEA air pollutant emissions inventory guidebook. Likewise, it shall be considered the emissions derived from lubricant oils consumption since a small fraction is oxidised during use (EMEP/EEA, 2019).

Direct emissions to the water derived from the use of paint and antifouling should be quantified as, following the recommendations of fisheries LCA literature, two thirds of the original paint and antifouling applied to vessels (Hospido and Tyedmers, 2005). Regarding nets and trawls, these are usually made of nylon and lead and steel, respectively, so it is necessary to estimate the amount of nylon and lead that is “lost” in the ocean during the fishing stage (Vázquez-Rowe et al., 2012).

In the case of the WF profile, it is necessary to consider direct water consumption during fishing vessel operations required for preservation (e.g., ice consumption) and during fishing vessel maintenance (e.g., vessel cleaning). The indirect water consumption related to the production

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

of all materials and fuels required (e.g., water consumed in oil refineries for diesel production) should also be considered. The degradative component of the WF profile is mainly related to the direct emissions derived from the combustion of fuels, such as nitrogen oxides (NOx) emissions that contribute to marine eutrophication and to emission of chemicals to water derived from the use of paint and antifouling that can contribute to freshwater eutrophication. Indirect emissions contributing to water degradation are mainly related to the production of materials and fuels and waste treatment.

3.3.2. System boundaries – Aquaculture

As demonstrated in a wide range of scientific articles, several processes constitute the life-cycle stages of an aquaculture production systems. As illustrated in **Figure 3**, the mandatory elements to define a complete analysis must include all the component necessary for the manufacture of aquafeeds, as well as the production of energy and fossil fuels and the production of other materials, which including chemicals, fertilizers, antibiotics, medical agents, etc. All these elements must be included in an LCA study to ensure a complete LCI. However, it seems reasonable to think that, given the difficulty to obtain high-quality data related to infrastructure construction, capital goods should be optional data. Finally, undesirable outputs from the process, such as waste and/or wastewater treatment should be included within the system boundaries, as well as direct emissions produced by the direct use of fossil fuels (if they are directly burned in boilers or similar) (EMEP/EEA, 2019; IPPC, 2006)

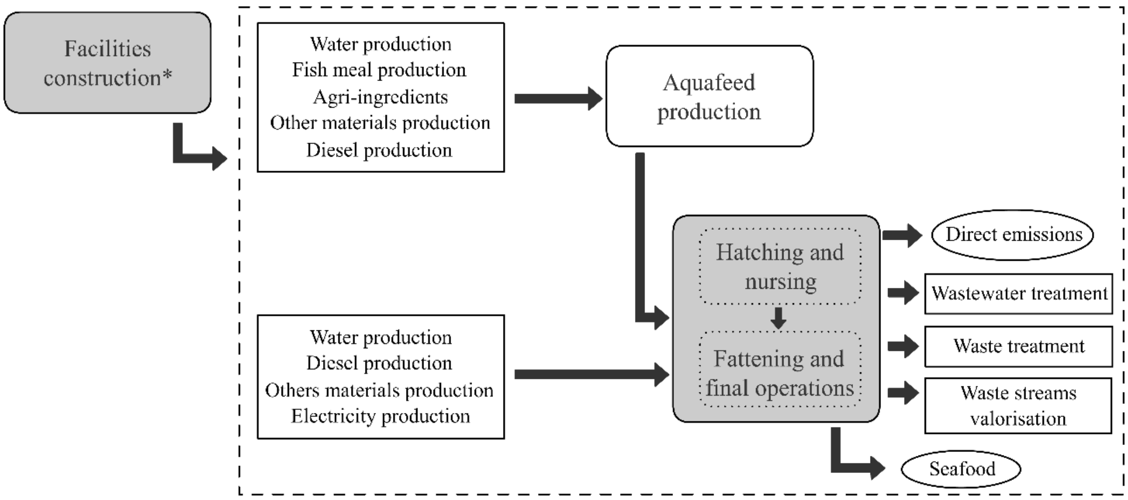

Figure 3. *System boundaries for aquaculture-related case studies. *Optative elements.*

Semi-intensive and extensive aquacultures are two special cases that should be addressed separately. As the semi-intensive aquaculture concerns, is necessary to expand the system boundaries, adding another system that includes the activity of the vessels that manage maintenance activities and transport of materials. In this way, it would be necessary to add another system such as fishing, mentioned in **Section 3.3.1** to include the activity of these vessels. Extensive aquaculture is similar to fishing due to its characteristics, as external feeding and medical care are avoided. Only the consumption of the vessel in charge to maintenance and collecting activities is relevant, therefore, this case study should be similar to the fishing system addressed in **Section 3.3.1**.

In the case of the WF, it should consider direct and indirect water consumption and quality degradation. In the specific case of closed farming systems, direct water consumption takes place during eggs, larvae or fingerlings production and on-growing phase and includes water evaporated from the system, water incorporated in the seafood and the water used to wash ponds and facilities (if wash waters are discharged into a different watershed or to the ocean, or at the same watershed in a different time period). Indirect water consumption is required to produce aquafeed, other materials and energy vectors consumed in the aquaculture system. Direct water quality degradation may occur on-site at the aquaculture facilities by producing wastewaters (Bouwman et al., 2013; Gephart et al., 2017), as well as by the release of eutrophication emissions from the combustion of fuels. Indirect emissions that contribute for water quality degradation are mainly related to the production of materials, energy vectors and waste treatment.

3.3.3. System boundaries – Processing

As in the previous cases, system boundaries shall include all the elements necessary to produce the evaluated elements. As can be seen in **Figure 4**, seafood processing facilities can be divided into two main sections: on the one hand the seafood processing activities (reception, washing, gutting, filleting, cooking, boiling, freezing, etc.) and on the other, the product packaging operations.

The mandatory elements are electricity, fuel (i.e., diesel, natural gas, propane, etc.) and derived emissions —following the approaches abovementioned for fishing and aquaculture stages—, water, plastics, chemicals and other materials consumption and additives (understood as any element that is included in the package together with seafood, e.g., sauces, brine, agricultural ingredients, etc.). As the packaging stage is concerned, all the elements that make up the primary packaging are relevant (whether seafood is canned in tin, aluminium or glass jar, or whether it is simply filleted or frozen). The secondary packaging shall include the necessary cardboard, packaging film and other materials such as labels or any other relevant element. The elements used to transport the seafood through the facilities, as polystyrene trays or wooden pallets must be considered, considering the time of use and the rate of reuse and useful life.

The treatment of all the waste that is produced during seafood processing must be included within the system boundaries. The most common elements include organic remains (viscera, fish-heads, fishbones, bivalves' shells, etc.) that cannot be transformed into products or co-products, as well as the waste derived from the packaging stage such as plastics, cardboard, aluminium, or tin waste, etc.

In the processing of seafood products, direct water consumption occurs due to water withdrawal for seafood processing activities (washing, freezing, etc.), water evaporation during the process (cooking, boiling, etc.) and integration of water into the product. Indirect water

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

consumption is required to produce materials (e.g., olive oil, sauces, brine, etc.) and energy consumed, as well as in waste treatment. Direct water quality degradation is mainly related to the discharge of wastewater from the processing activities, as well as by the release of eutrophication emissions from the combustion of fuels. Indirect water degradation is mainly related to the production of materials and energy, as well as and waste treatment.

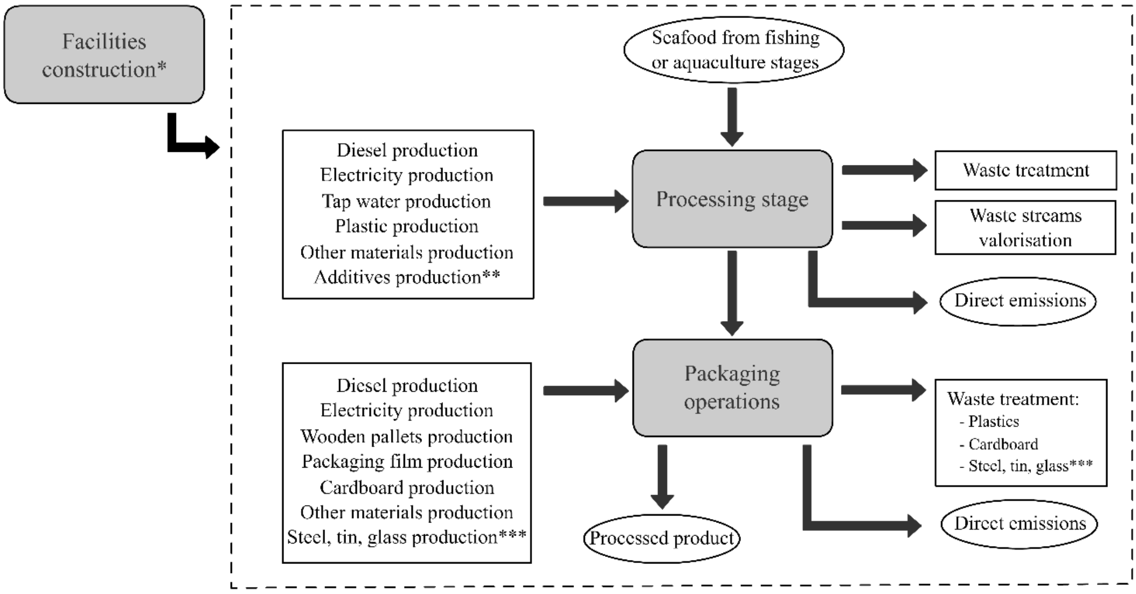

Figure 4. *System boundaries for seafood processing-related case studies. *Optative elements. **This element must include the production and transport of food stuff to produce covering liquids or preservatives (sauces, brines, spices, etc.). ***Depending on the processing characteristics, it will be one material or another, or none.*

3.3.4. System boundaries exclusions – Cut off

This issue has been widely discussed in scientific literature, but no consensus has been reached among LCA practitioners. On the one hand, the sum of impacts of processes with small individual impacts (e.g., <0.5% of the total) can be far from negligible (Fréon et al., 2014). On the other, the exclusion of the same flows of material and energy means that these flows have hardly ever been assessed by LCA practitioners and therefore, their negligibility cannot be guaranteed. Consequently, data for elementary flows to and from the product systems contributing to a minimum of 99% of the declared environmental impacts shall be included. The check for cut-off rules in a satisfactory way is through the combination of expert judgment based on experience of similar product systems and a sensitivity analysis in which it is possible to understand how the un-investigated input or output could affect the results.

In the case of fisheries LCA studies, construction and EoL phases from fishing vessels and industrial facilities are usually excluded due to their negligible contribution. Conversely, it is difficult to obtain reliable data for EoL phases and, for this reason, they are usually left outside the system boundaries (Avadí et al., 2020). Nevertheless, the present methodologic guide does encourage the construction stage to be included if quality data is available.

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Regarding water consumption, some assumptions can be considered to simplify data collection, such as:

- The volume of water evaporated from the aquaculture systems can be excluded, since this information is not easily obtained through questionnaires.
- The volume of water incorporated in the seafood can be excluded, since its contribution is normally not relevant to the total WF.
- The volume of seawater and brackish water withdrawal and released in these receiving bodies can be excluded because it is not addressed in the impact assessment method of water use.

4. Life Cycle Inventory

4.1. Data acquisition

Within the LCA methodology, the construction of a comprehensive life cycle inventory (LCI) is a mandatory stage. Data acquisition is the most relevant step in an LCA study as the quality of the LCI data directly influences the quality and representativeness of the results. Obtaining primary data of sufficient quality should be a priority, although secondary information from scientific studies and databases can be used to fill some gaps and for background processes (e.g., chemicals production or electricity generation).

To obtain good-quality primary data, we recommend carrying out surveys and/or questionnaires to be completed by the agents responsible for the industries to be further analysed. For example, in the case of aquaculture and seafood processing facilities, the questionnaire should be completed by the workers or the plant manager. In the case of fisheries studies, the skipper is the right person to fill in the questionnaires, as they know the details of the vessel, the consumption of materials and the catches. Moreover, associations and producer organizations are also frequently a valuable source of data in these cases.

The minimum number of questionnaires to be completed to obtain representative data varies depending on the case study. In intensive and semi-intensive aquaculture and seafood processing facilities, one questionnaire that includes all the elements consumed and produced is more than enough. However, in the case of fisheries and extensive aquaculture, to analyse a specific fleet, the number of questionnaires must be sufficient to obtain relevant and representative data. Understandably, sometimes, obtaining a decent number of questionnaires is difficult due to reluctance of skippers to sharing information, the inability to contact them and even sometimes the skippers do not know the necessary information to carry out the study. For this reason, on some occasions, obtaining as many surveys as possible, even if they are not representative of the fleet, may be enough.

Within the framework of the NEPTUNUS project, questionnaires were prepared to obtain complete inventory data from fishing, aquaculture, and processing steps. These are a good

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

example of a complete and thorough questionnaire for the collection of inventory data.

NEPTUNUS PROJECT

Questionnaire for fishing step
January 2020

Data set identification

Activity name	
Geography	
Time period	
Reference flow	

System boundaries

Category	Unit	Value	Comments
GENERAL DATA			
Base port			
Fishing zone			
Type of boat			
Fishing gear			
FISHING NET DATA			
Number of nets			
Net material			
Length of the gear	m		
Depth of the gear	m		
Fishing mesh size	mm		
CAPTURED SPECIES			
Target species	kg/year		
Other species captured	kg/year		
Discards (all species returned to the sea)	kg/year		

FISHING NET DATA			
Number of nets			
Net material			
Length of the gear	m		
Depth of the gear	m		
Fishing mesh size	mm		
CAPTURED SPECIES			
Target species	kg/year		
Other species captured	kg/year		
Discards (all species returned to the sea)	kg/year		
CONSUMPTION			
Main engine	Type		
	Power (HP)		
Type of fuel used			
Fuel consumption	L/year		
Auxiliary engines (if any)	Type		
	Power (HP)		
Fuel for auxiliary engines (if any)	L/year		
Lube oil consumption	L/year		
Auxiliary engines (if any)	Type		
	Power (HP)		
Ice consumption	ton/year		
Ice machine type (if any)			
Ice machine consumption of water	m^3/year		
Ice machine consumption of electricity	kWh/Year		
Ice machine consumption of refrigerants and others	quantity/year		
Water	L/year		
Paint consumption (for maintenance)	Type		
	L/year		
Fishing net mending (total amount of net)	kg/year		
Ghost fishing*			
WASTE AND WASTEWATER			
Wastewater	L/year		
Emissions to water (if any)			
Ammonia	kg/L		
Nitrate	kg/L		
Nitrogen	kg/L		
Phosphorus	kg/L		

*Specify if there has been lost or abandoned fishing gear since catches fish goes to waste.

Figure 5 shows an example of a questionnaire for fishing step developed in the project.

Regarding the secondary data for background systems, we strongly recommend using the Ecoinvent® database (Moreno Ruiz et al., 2018), which is one of the most well-known databases worldwide. The Ecoinvent project was launched in late 2000 through a cooperation of several Swiss federal offices and research institutes of the ETH domain. The first database (version 1.0) was published in 2003 and the second version (v2.0) was released in 2007 based on an extension and revision of the first database. The latest version (v3.0) was released in May 2013. The aim of the Ecoinvent database was to harmonise and update several public LCA databases developed by different institutes in Switzerland. In our view, Ecoinvent is the best alternative to obtain a reliable and consistent source of background inventory data. However, we are aware that each LCA practitioner should use the database that best suits their needs, some databases for the collection of background data are listed in **Table A.1.** To maintain the consistency in the background processes, the use of one database or another is a priority, avoiding the uncertainty due to the use of inventory data from different sources.

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

NEPTUNUS PROJECT

Questionnaire for fishing step
January 2020

Data set identification

Activity name	
Geography	
Time period	
Reference flow	

System boundaries

Category	Unit	Value	Comments
GENERAL DATA			
Base port			
Fishing zone			
Type of boat			
Fishing gear			
FISHING NET DATA			
Number of nets			
Net material			
Length of the gear	m		
Depth of the gear	m		
Fishing mesh size	mm		
CAPTURED SPECIES			
Target species	kg/year		
Other species captured	kg/year		
Discards (all species returned to the sea)	kg/year		
FISHING NET DATA			
Number of nets			
Net material			
Length of the gear	m		
Depth of the gear	m		
Fishing mesh size	mm		
CAPTURED SPECIES			
Target species	kg/year		
Other species captured	kg/year		
Discards (all species returned to the sea)	kg/year		
CONSUMPTION			
Main engine	Type		
	Power (HP)		
Type of fuel used			
Fuel consumption	L/year		
Auxiliary engines (if any)	Type		
	Power (HP)		
Fuel for auxiliary engines (if any)	L/year		
Lube oil consumption	L/year		
Auxiliary engines (if any)	Type		
	Power (HP)		
Ice consumption	ton/year		
Ice machine type (if any)			
Ice machine consumption of water	m^3/year		
Ice machine consumption of electricity	kWh/Year		
Ice machine consumption of refrigerants and others	quantity/year		
Water	L/year		
Paint consumption (for maintenance)	Type		
	L/year		
Fishing net mending (total amount of net)	kg/year		
Ghost fishing*			
WASTE AND WASTEWATER			
Wastewater	L/year		
Emissions to water (if any)			
Ammonia	kg/L		
Nitrate	kg/L		
Nitrogen	kg/L		
Phosphorus	kg/L		

*Specify if there has been lost or abandoned fishing gear since catches fish goes to waste.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Figure 5. *Sample questionnaire for data collection at fishing stage.*

4.1.1. Water-related parameters

In the acquisition of data for the calculation of the WF profile, the following parameters shall be considered:

- Quantities (mass or volume) of water as input (water withdrawal) and output (released into the same watershed in the same period, the same watershed but in a different period, a different watershed or ocean).
- Types of water resources used, i.e., surface water, seawater, brackish water, rainwater, groundwater, etc.
- Data describing water quality parameters, e.g., chemical characteristics.
- Geographical location of water used or affected (including for water withdrawal and release), since some environmental condition indicators (e.g., water use impact category) require information on the location where the water use takes place.
- Emissions to air, water, and soil that impact water quality.
- Any other data needed to evaluate the WF profile of seafood products.

4.1.2. Electricity modelling

4.1.2.1. Background

Electricity from the grid shall be modelled as precisely as possible giving preference to supplier-specific data. In case part of electricity is generated from renewable sources, it is important that no double counting occurs. Hence, the supplier shall guarantee that electricity supplied is effectively generated using sources and is not available anymore for other consumers.

The Guarantee of Origin (GO) system enables power companies to be able to tell their customers about the origin of electricity in todays disaggregated and complex power market. Thus, electricity must be tracked from production to consumption. According to the RED II Directive 2018/2001, the GO is the main tracking tool in this regard. Likewise, to make GO system more reliable, it is needed a residual mix since not all consumption is tracked using GOs. A country's residual mix represents the shares of electricity generation after the use of explicit tracking systems (i.e., GO) have been accounted (**Figure 6**). Without a residual mix, renewable electricity sold with GOs would be double counted since the same electricity could be disclosed to consumers buying "regular" electricity: i.e., electricity country mix.

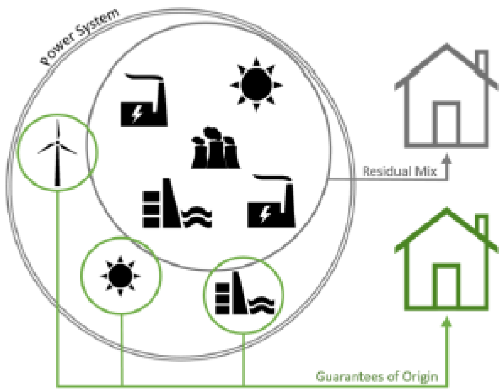

Figure 6. Schematic representation of power and electricity system. Source www.aib-net.org

Given the international nature of electricity markets and tracking systems, the volume of available energy in the domestic residual mix is different from the volume of untracked consumption (i.e., electricity consumption for which energy source is not disclosed by means of tracking instruments). Hence, it is needed the calculation of a residual mix in a coordinated and central way, developing a common pool aimed at balancing electricity generation attributes[1]. The latter can be achieved through the European Attribute Mix (EAM). The EAM acts as an equalising reservoir for generation attributes for national residual mixes. Thus, after the attribute balancing throughout the EAM, the volume of available generation attributes in the residual mix is equal to the untracked consumption in every country. Therefore, EAM is used for

[1] Attribute refers to a piece of information which is tracked to disclose specific consumption. The most important attributes for disclose are the energy source and the associated CO_2 emissions and radioactive waste.

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

balancing surpluses and deficits in national residual mixes caused by international trading of electricity and GOs (**Figure 7**).

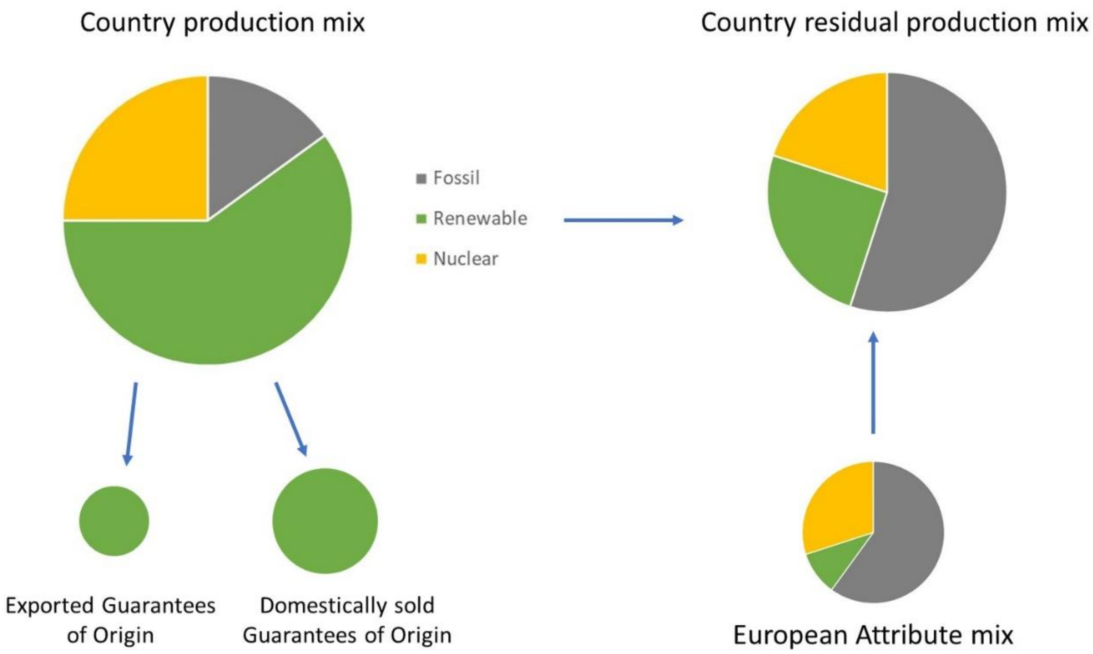

Figure 7. Conceptual framework for country residual mix production calculation

4.1.2.2. General guidelines

The main aim of this guide is to be aligned with PEF method when conducting LCA and environmental foot-printing of seafood product. Therefore, the approach proposed to carry out LCI of electricity consumption follows the guidelines developed for PEF method.

As stated in previous section, two types of electricity mixes are identified: i) the consumption grid mix (country production mix), it reflects the total electricity mix transferred over a defined grid including green claimed or tracked electricity and ii) the residual grid mix, it characterises the unclaimed, untracked, or publicly shared electricity.

According to the PEF methodology and to prevent double counting in energy source, the electricity mix shall be modelled following the hierarchical order:

i. The supplier-specific electricity product.

ii. The supplier-specific total energy mix.

iii. The country-specific residual grid mix.

iv. The average EU residual grid mix (EU-2u+EFTA), or region representative residual grid mix.

A supplier-specific electricity product/mix can only be used in those cases that meet several criteria: i) conveys environmental attributes and give explanation about the calculation method used to determine the mix and ii) be the only instrument that carry the environmental attribute

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

associated with that electricity generated. For those cases where the criteria are not met, the country-specific residual electricity mix shall be modelled for LCI.

4.1.2.3. Electricity grid mix modelling

Reliable datasets for residual grid mix, consumption mix, per country and per voltage must be used. However, if there is no reliable dataset, it should be implemented the following approach:

Determine the country mix (for instance, X% of MWh produced with wind, Y% produced with nuclear, Z% produced with coal, etc.) and combine them with LCI datasets per energy type and country/region, considering transmission, distribution, and voltage conversion losses.

The data to deal with electricity mix modelling can be retrieved from different sources. Firstly, the supplier-specific electricity product/mix shall be directly obtained from power company supplier. Additionally, it must be certified in the case of GO energy claim (i.e., energy generated from renewable energy sources).

Secondly, the country-specific residual electricity mix shall be modelled according to reliable data and following the scheme depicted in **Figure 7**. In this sense, the Association of Issuing Bodies (AIB —www.aib-net.org) publishes the national residual mixes for 32[2] European countries. The purpose of the AIB is to develop, use and promote a standardised system of energy certification for energy carriers. Energy sources in the residual mixes are divided into three main categories: i) renewable, it includes biomass, solar, geothermal, wind, hydro and renewable unspecific; ii) nuclear and iii) fossil, hard coal, lignite, oil, gas, and fossil unspecific.

Thirdly, other relevant data can be found in the publications of the International Energy Agency (IEA —www.iea.org) as well as the corresponding national authorities in this regard: for instance, in the case of Spain, The Red Electrica Group (REE — www.ree.es) and The National Commission of Markets and Competition (CNMC — www.cnmc.es).

Figure 8 depicts the different share of energy sources when comparing production and residual mixes. In this sense, the share of renewable energy is considerably lower for residual mixes whilst nuclear and fossil energy sources increase their share. The rationale behind the latter is the extraction of renewable energy that is claimed and sold as GO domestically or internationally (**Figure 7**).

[2] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Great Britain, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

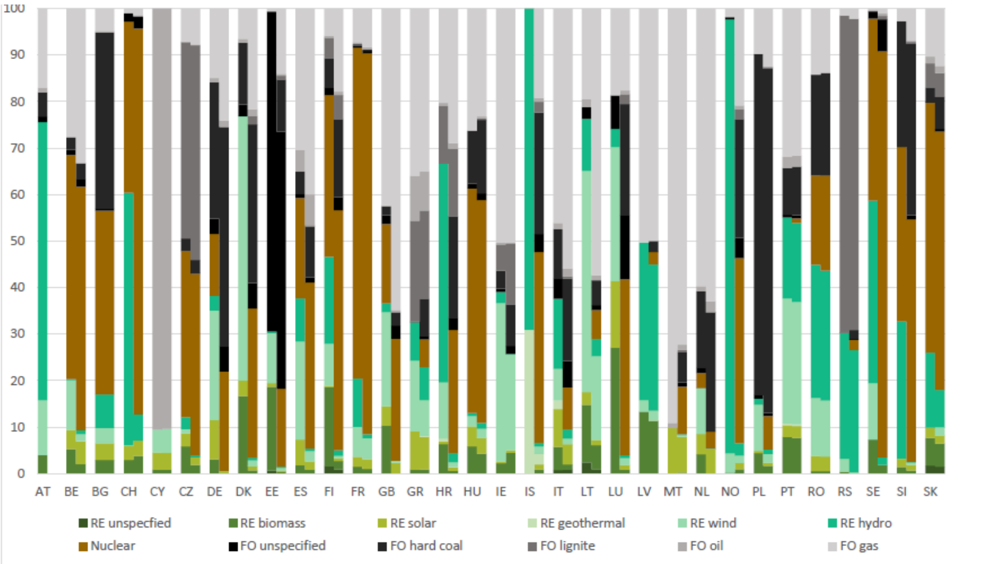

Figure 8. Production mix (left) and final residual mix (right) in 2019. Source: AIB

4.1.2.4. On-site electricity generation

On-site electricity generation is a matter that should be handled properly. In this regard, two different situations can arise. Firstly, for those cases where on-site electricity production is equal to the site own consumption, two different options apply:

i. The electricity produced is not sold to a third party: the own electricity mix shall be modeled in combination with LCI datasets.

ii. The electricity produced is sold to a third party: the electricity mix shall be modeled according to the hierarchical order defined in previous section in combination with LCI datasets.

Secondly, when electricity is produced more than the amount consumed on-site within the defined system boundary and is injected into the grid. This system may be considered as a multifunctional process, providing two functions: product + electricity. In these cases, it shall be applied the following rules:

- System subdivision
- Direct substitution (if subdivision is not possible): The product system produces X amount of product A + Y amount of electricity (e.g., Y MWh of wind or photovoltaic energy) and substitutes (i.e., avoid) Y MWh of country-specific residual mix.

4.1.2.5. Other situations related to electricity

The coming section aims to guide LCA practitioners when dealing with some electricity issues that may arise during LCI stage:

- More than one electricity mix is used: If the consumed electricity comes from more than one electricity mix, each mix source shall be used in terms of its proportion in the total kWh consumed.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

- Multiple locations producing one product: In case a product is produced in different locations or sold in different countries, the electricity mix shall reflect the ratios of production or ratios of sales between EU countries/ regions. To determine the ratio, a physical unit shall be used.
- Electricity use at the use stage: The consumption grid mix shall be used. The electricity mix shall reflect the ratios of sales between EU countries/regions. To determine the ratio, a physical unit shall be used (e.g., number of pieces or kg of product). Where such data are not available, the average EU consumption mix (EU-28 +EFTA), or region-representative consumption mix, shall be used.

Note: the consumption or region grid mix represents the average country or region-specific electricity supply for final consumers, including electricity own consumption, transmission/distribution losses of medium voltage electricity supply and electricity imports from neighboring countries.

4.1.2.6. Other energy sources modelling

Energy supply may imply the consumption of other energy carriers apart from electricity. Thus, these energy flows shall be compiled for LCI modelling. The approach followed for electricity is the recommended approach to model other energy carriers. Hence, energy sources apart from electricity shall be modelled following the hierarchical order:

i. Supplier-specific data: LCI modelled based on supplier specific product origin, composition, energy efficiency/losses, or another intrinsic feature (e.g., natural gas import country, losses, and emissions during storage, etc.)

ii. Country-specific data: LCI modelled based on country average product origin, composition, energy efficiency/losses, or another intrinsic feature.

iii. EU average or regional representative data: based on country average EU or regional representative product origin, composition, energy efficiency/losses, or another intrinsic feature.

Note: correct LCI modelling of fuel composition assures correct calculation of derived emissions.

4.1.3. Specific data for NF – Nutritional databases

For the calculation of the NF is necessary to characterise the nutritional profile of each seafood product. There are several free databases that provide adequate and reliable data on the composition of foods, beverages and their ingredients. To the elaboration of this guideline and characterisation of the seafood products assessed in the NEPTUNUS project two databases were used:

- ***Base de Datos Española de Composición de Alimentos (BEDCA):*** The Spanish Food Composition Database is published by the BEDCA Network of the Ministry of Science and Innovation and funded and coordinated by the Spanish Agency for

Food Safety and Nutrition (AESAN) of the Ministry of Health, Social Services and Equality. Collected food composition values of this database come from many sources like laboratory, industry, and scientific literature or by calculation. The BEDCA Network is composed by several Universities and Research Centres (CSIC) as well as different institutions of the Food and Beverages Companies (FIAB) under the coordination of AESAN and also with the technical and logistical support of the NoE European Community EuroFIR, which activities to stablish an European platform include the national food composition databases (BEDCA, 2006).

- ***Le Centre d'information sur la qualité des aliments (CIQUAL):*** The French Information Centre on Food Quality was created in 1985 following the initiative of the French food industries and authorities: French ministries of Agriculture and Research, National Institute of Agronomic Research (INRA), French Research Institute for Development (IRD), National Institute of Agronomy (INA-PG) and French Institute for Nutrition (IFN). The creation of CIQUAL is the result of a national will to establish a structure to manage and develop a nutrient database on food products produced or consumed in France. This database gathers and manages food composition data, which can be used at national level. The French food composition database is run by CIQUAL in the Observatory of Food, unit of ANSES (the French agency for food, environmental and occupational health safety). The main tasks consist in: (i) input and management of a reference database on food composition, (ii) contribution to risk assessment in nutrition, within the French agency for food, environmental and occupational health safety and (iii) communication and dissemination of food composition data to administrations, researchers, nutritionists, food companies and consumers. The latest version of CIQUAL 2020 includes 3185 foods and 67 components (CIQUAL, 2020).

The **Annex B** presents the nutritional characterisation of the different seafood products assessed in NEPTUNUS per 100 g (BEDCA, 2006).

4.2. Allocation strategies

4.2.1. Handling multi-functional processes

If a process or facility provides more than one function (i.e., it delivers several goods and/or services) it is considered as multi-functional. In these situations, all inputs and emissions derived to the process shall be partitioned between the product/process of interest and the co-products. Hence, in accordance with PEF method and ISO 14044, it is recommended the following decision hierarchy:

i. Subdivision or system expansion: Wherever possible, subdivision or system expansion should be used to avoid allocation. Subdivision refers to disaggregating multi-functional processes to isolate the input flows directly related to each process output. System expansion refers to expanding the system by including additional functions related to the co- products.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

ii. Allocation based on physical properties (mass allocation): When subdivision or system expansion is not possible, allocation should be applied. In this sense, the inputs and outputs of the system should be portioned between its different products or functions in a way that reflects relevant and quantifiable relationships between them. Mass allocation should be prioritised, as it is the simples and most repeated allocation method in scientific papers applied to seafood products and avoids the natural fluctuation of seafood market price.

iii. Allocation based on non-physical properties (economic allocation): Allocation can be based on the proportion to the economic value of the products with primary producer economic data. In this case, if robust economic data are available, it may be interesting to perform sensitivity analysis to check the variability of the results considering the different allocation methods.

a. When primary producer economic data are not available, the economic value of the products can be calculated through official databases (prioritising European information).

b. When the economic data are not available, either from primary sources or from official databases, the inputs should be allocated between the products and functions in a way that reflects the direct relationship between the weights of the products (mass allocation).

Note: In any case, when using economic data, it would be necessary three years average data to avoid market fluctuations.

4.2.1. Multi-functionality in seafood supply chain

This guide aims to help LCA practitioners on how to conduct allocation between the product of interest and the other co-products. The guide defines the allocation rules to be applied according to the PEF method guidelines. The allocation rules are summarized in **Table 2**.

Table 2. *Allocation rules for elementary flows and activity data*

Process	Allocation rule	Modelling instructions
Fishing allocation	Mass	Despite fishing gears selectivity, several species are caught apart from target species. In this sense, allocation shall be done on the basis of the total amount of catches of each species.
Aquaculture co-product allocation	Mass	Aquaculture operations are usually focused on the production of a single species, although in some cases it is possible that several species are produced together. In those cases, the same procedure as in fishing allocation shall be applied.
Seafood processing co-product allocation	Mass	This is an example of a multi-product industry, so that different products can be obtained from a single species of fish. For example, from hake, fillets, tails, fish sticks and croquettes could be obtained. In this case, the total annual production of each production line shall be used to establish the allocation factors. It is important to note that

	the edible weight should be used to establish the annual production.

4.3. End-of-life modelling

The waste of products used during manufacturing, distribution, retail, and use/consumption stage should be included in the overall modelling of LCA. For example, the EoL of the waste streams generated during manufacturing should be modelled and reported at the manufacturing life cycle stage. The PEF methodology recommends modelling EoL using the Circular Footprint Formula (CFF). Additionally, it states that the formula and derived parameters shall be applied to both final products (cradle-to-grave studies) and intermediate products (cradle-to-gate studies). The CCF is a combination of material + energy + disposal as presented in **Figure 9.** The Circular Footprint Formula (CFF):

Material

$$(1-R_1)E_V + R_1 \times \left(AE_{rec} + (1-A)E_V \times \frac{Q_{Sin}}{Qp}\right) + (1-A)R_2 \times \left(E_{recEoL} - E_V^* \times \frac{Q_{Sout}}{Q_P}\right)$$

Energy

$$+$$

$$(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

Disposal

$$+$$

$$(1-R_2-R_3) \times E_D$$

Figure 9. *The Circular Footprint Formula (CFF).*

Parameters of the CFF:

A: allocation factor of burdens and credits between supplier and user of recycled materials.
B: allocation factor of energy recovery processes. It applies both to burdens and credits.
Q_{sin}: quality of the ingoing secondary material, i.e., the quality of the recycled material at the point of substitution.
Q_{sout}: quality of the outgoing secondary material, i.e., the quality of the recyclable material at the point of substitution
Q_p: quality of the primary material, i.e., quality of the virgin material.
R_1: it is the proportion of material in the input to the production that has been recycled from a previous system.
R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore consider the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.
R_3: it is the proportion of the material in the product that is used for energy recovery at EoL.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

$E_{recycled}$ (E_{rec}): specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting, and transportation process.
$E_{recyclingEoL}$ (E_{recEoL}): specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting, and transportation process.
E_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.
E^*_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
E_{ER}: specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g., incineration with energy recovery, landfill with energy recovery, etc.).
$E_{SE,heat}$ and $E_{SE,elec}$: specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
E_D: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
$X_{ER,heat}$ and $X_{ER,elec}$: the efficiency of the energy recovery process for both heat and electricity.
LHV: lower heating value of the material in the product that is used for energy recovery.

The default values of these parameters are available in the Annex C of "Suggestions for updating the Product Environmental Footprint (PEF) method" (Zampori and Pant, 2019). Also, Annex C is available at https://eplca.jrc.ec.europa.eu/EFtransition.html. The list of values of the Annex C is periodically reviewed and updated by the European Commission.

The material part of the CFF equation integrates the production and EoL of materials throughput the life cycle of a product. It calculates the burdens and potential benefits of the production of virgin and recycled materials in the manufacture of a product and the burdens and potential benefits of recycling the material at EoL.

The energy part of the CFF refers exclusively to EoL activities. It deals with the specific emissions and resources arising from energy recovery and the potential benefits arising from recovering this energy.

The disposal part of the CFF refers exclusively to EoL activities where no recycling occurs, or energy is recovered. These refer to emissions and inputs related to the local waste management system.

Furthermore, the CFF can be arranged in a modular way according to **Figure 10**. In this sense, on the one hand, for intermediate products (cradle-to-gate studies), the CFF shall be applied per material as follows:

- EoL of the product shall be excluded (i.e., setting the parameters R_2, R_3 and E_d equal to 0), but including waste occurring throughout the value chain (e.g., waste during manufacturing process).
- A value shall be equal to 1.

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

- As additional technical information to allow for further use in downstream applications to create EF compliant dataset A = the application- or material-specific default values as listed in the PEFCR shall be used

Note: the guide provides flexibility to LCA practitioners to define the system boundaries of the energy footprint to be performed, allowing users to select the life cycle stages that will be in scope of their own study. Consequently, for cradle-to-gate studies, only the material part of CFF shall be considered: impact of virgin material, impact of recycled material and impacts and benefits from material that will be recycled.

On the other hand, for final products (cradle-to-grave studies), the CFF shall be applied per material and considering all parameters included within the CFF.

Production burdens	$(1 - R_1)E_V + R_1 \times E_{recycled}$	Cradle-to-gate
Burdens and benefits related to secondary materials input	$-(1 - A)R_1 \times \left(E_{recycled} - E_V \times \frac{Q_{Sin}}{Q_P}\right)$	Additional information from the EoL stage
Burdens and benefits related to secondary materials output	$(1 - A)R_2 \times \left(E_{recyclingEoL} - E_V^{*} \times \frac{Q_{Sout}}{Q_P}\right)$	
Energy recovery	$(1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$	
Disposal	$(1 - R_2 - R_3) \times E_D$	

Figure 10. Modular form of the Circular Footprint Formula.

The **Annex C** delves into EoL modelling, providing example on how to deal with CFF parameters and calculation for steel, commonly used as packaging material for canning seafood.

5. Life Cycle Impact Assessment

LCIA is a phase of LCA aiming to assess the contribution of each elementary flow (i.e., emissions or resource use of a product system) to an impact on the environment. Its objective is to examine the product system from an environmental perspective using impact categories and category indicators, providing useful information for subsequent phases: interpretation phase.

The LCIA phase is automated and requires the selection of a LCIA method, as well as other settings, in LCA software. Nonetheless, as it may seem a simple task, it can lead to wrong results interpretation. Hence, according to (ISO, 2006b), the impact categories selection shall ensure that they:

- Are not redundant and do not lead to double counting.

- Do not disguise significant impacts.
- Are complete.
- Allow traceability.

Moreover, the above list is complemented with a set of obligatory criteria that requires a selection of impact categories and characterization models, considering: i) consistency with the goal and scope of the study; comprehensiveness and iii) proper documentation, providing references of the assessment method.

Furthermore, the selection of impact categories, category indicators and characterization models follow a set of recommendations based on international acceptance (i.e., approved by competent body), environmental relevance of the impact category, scientific and technical validation, or even based on own experience or colleague recommendations. However, in general, LCA practitioners rely on the predefined impact category selection of the assessment methods available in LCA software such as: ReCiPe, CML, TRACI, IMPACT 2002+, etc. In this sense, with an increasing number of LCIA methods and indicators available (**Figure 11**), the task of selecting one demands a remarkable effort from the practitioner to understand the main features and keep up to date regarding the LCA field developments.

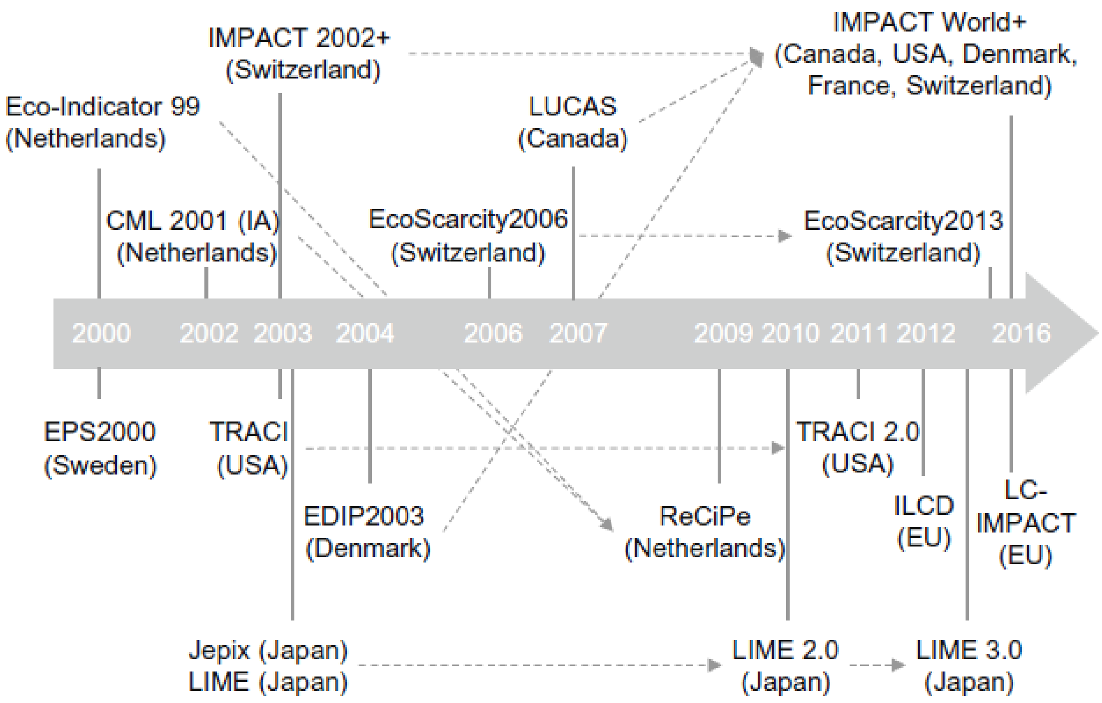

Figure 11. *LCIA methods published since 2000 with country/region of origin in brackets. Dotted arrows represent methodology updates (Rosenbaum, 2017).*

ISO 14040/14044 do not provide recommendations about which LCIA method should be used, but some organizations recommend the use of a specific LCIA method or parts of it. The Environmental Product Declaration (EPD) program - defined as a type III declaration scheme according to ISO (2006c) - recommends the utilization of the EPD method, which is specifically intended for the creation of EPDs (EPD International, 2015). The EPD method includes midpoint impact categories that are taken directly from the CML-IA baseline method (eutrophication, global warming, ozone depletion and abiotic resource depletion) and CML-IA non-baseline method (acidification). In addition, water scarcity category is based on AWARE method and photochemical oxidation is based on ReCiPe 2008. The European Commission has established specific recommendations for midpoint and endpoint impact categories based on a systematic comparison and evaluation of approaches per impact category, leading to the recommendation of a set of Characterisation Factors (ChF_S). As a result, the ILCD method was release by the Joint Research Centre in 2012. However, the ILCD method is no longer supported since the release of the PEF initiative. In the framework of PEF, the European Commission has deployed a specific assessment method (EF method), covering a broad arrange of environmental issues. The EF method covers a total of 16 midpoint impact categories, which are referred to specific characterization models (e.g., human toxicity and ecotoxicity impact categories have been calculated with the USEtox 2.1 model). Similarly, there are some methods, which bring a stronger national focus, recommended by national bodies to be implemented in their respective country: TRACI in the US or LIME in Japan.

6. Water footprint

The WF profile calculation procedures shall be in accordance with ISO 14046 (2014) and aligned with PEF guidance and should be explicitly documented. According to ISO 14046 (2014), the WF profile of a product can comprise impact categories related to both water consumption and water degradation. Water consumption refers to the water removed from, but not returned to, the same watershed and can be because of evaporation, transpiration, integration into a product, or release into a different watershed or to the ocean. It also refers to the water discharged into the same watershed, but in a different time period. Water quality degradation is related to a negative change of the physical, chemical, and biological characteristics of water with respect to its suitability for an intended use by humans or ecosystems. Therefore, the WF profile of the seafood system under assessment comprises one category for water consumption (called water use in the PEF method) and two categories for water degradation (freshwater eutrophication and marine eutrophication). In the WEF nexus methodology, the WF of a product is a single indicator resulting from the sum of the weighted results of each one of these impact categories. Thus, a three-step procedure is needed: characterization, normalization and weighting. Firstly, regarding the characterization, for these impact categories, PEF guidance (European Commission, 2018; Zampori and Pant, 2019) recommends the default methods shown in **Table 3**.

Table 3. *Recommended characterization methods for water use, freshwater eutrophication, and marine eutrophication impact categories*

Impact category	Indicator	Unit	Recommended default LCA method
Water use	User deprivation potential	m^3	AWARE as recommended

	(deprivation-weighted water consumption)	world eq	by UNEP (2016)
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (Phosphorous)	kg P eq	EUTREND model (Struijs et al., 2009) as implemented in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching freshwater end compartment (Nitrogen)	kg N eq	EUTREND model (Struijs et al., 2009) as implemented in ReCiPe

The impact on water use (Equation 1) is estimated using the AWARE ChFs, which are based on the available water remaining in a given watershed according to the world average, after human and aquatic ecosystem demands have been met (Boulay et al., 2018). The AWARE model considers different resolution levels, temporal, and spatial scales (month/year, watershed/country) as well as water use types (agriculture/non-agriculture). However, the PEF method recommends that only the country scale is adopted, without: i) differentiating between agricultural and non-agricultural uses and ii) monthly resolution. **[Equation 1]** shows the calculation of water used based on the AWARE model.

$$\text{Water use} = \sum_{i=1}^{n} [\text{water consumption } (m^3)]_i \times [\text{AWARE ChF} \left(\frac{m^3\ world\ eq}{m^3}\right)]_i \qquad \textbf{[Equation 1]}$$

where, water consumption is the volume of water consumed expressed in m^3 per FU in a process i and the AWARE ChF_i is established for a watershed *i* in m^3 world eq/m^3. The AWARE ChF_S can be found in **Table D.1**.

The volumes of water consumption of each process are calculated in the inventory analysis by the difference between water withdrawal and release flows **[Equation 2]**.

$$\text{Water consumption} = W - R \qquad \textbf{[Equation 2]}$$

where, *W* is the water withdrawal and R is the water release to the same watershed, both expressed in m^3 per FU.

For freshwater eutrophication and marine eutrophication, the environmental impact is calculated by multiplying the amount of each pollutant emission with the corresponding ChF following **[Equation 3]**.

$$\text{(Freshwater/marine) eutrophication} = \sum_{i=1}^{n} [\text{pollutant emission}]_i \times [\text{ChF}]_i \qquad \textbf{[Equation 3]}$$

where, the pollutant emission in a process *i* is expressed in kg per FU and the ChF for the pollutant *i* in kg P eq/kg for freshwater eutrophication and kg N eq/kg for marine eutrophication. The ChF_S for freshwater eutrophication are presented in **Table D.2** while the ChFs for marine eutrophication are provided in **Table D.3** in **Annex D**.

Secondly, in the normalization step, the results obtained during the characterization must be divided by a normalization factor recommended in the PEF method with the same units of each impact category. The results obtained from this procedure for each impact category are dimensionless **[Equations 4-6]**.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

$$\frac{Water\ use\ (m^3 world\ eq)}{Normalization\ factor\ (m^3 world\ eq)}$$ **[Equation 4]**

$$\frac{Freshwater\ eutrophication\ (kg\ P\ eq)}{Normalization\ factor\ (kg\ P\ eq)}$$ **[Equation 5]**

$$\frac{Marine\ eutrophication\ (kg\ N\ eq)}{Normalization\ factor\ (kg\ N\ eq)}$$ **[Equation 6]**

Thirdly, in the weighting step, the results obtained from the normalization step in each impact category are multiplied by the respective weighting factor recommended in the PEF method, obtaining results in points units (Pt) **[Equations 7-9]**.

$$Water\ use\ (dimensionless) \times Weighting\ factor = Water\ use\ (Pt)$$ **[Equation 7]**

$$Freshwater\ eutrophication\ (dimensionless) \times Weighting\ factor = Freshwater\ eutrophication\ (Pt)$$ **[Equation 8]**

$$Marine\ eutrophication\ (dimensionless) \times Weighting\ factor = Marine\ eutrophication\ (Pt)$$ **[Equation 9]**

Then, the weighted results of each impact category can be added with the purpose of obtaining a single value for the WF expressed in Pt units **[Equation 10]**.

$$WF = \sum Water\ use\ (Pt) + Freshwater\ eutrophication\ (Pt) + Marine\ eutrophication\ (Pt)$$ **[Equation 10]**

7. Energy footprint

Natural resources are the basis of our societies and economic way of life and, to respect the principle of sustainability, we must assure resources availability to meet future generation's needs. In the context of LCA, (Udo De Haes et al., 1999) define natural resource as those elements that are extracted for human use, comprising both abiotic, such as fossil fuels and mineral ones and biotic resources, such as wood and fish. Water and land can be also considered a resource, but since both cause direct impacts on environment, they are treated as individual impact categories. Hence, resource use impact category covers mostly fossil fuels, minerals, and metals.

There is debate within LCA developers and experts as to what exactly the impact category resource depletion should reflect. In this regard, impact from resource use is divided into four different categories according to the impact pathway (**Figure 12**): i) based on an inherent property (e.g., energy or exergy), irrespective of the level of depletion; ii) relating natural resource consumption to resource stocks; iii) methods specifically intended for water and iv) relating current natural resource consumption to consequences of future extraction.

The consideration of energy as a resource implies that the analysis from a life cycle perspective at midpoint level shall fall under categories "i" or "ii". In this regard, because of the strong focus of energy consumption of seafood industry supply chain and the need of an indicator (impact category) understandable and easy to communicate to general public, policy makers and stakeholders, the selection of a method based on an inherent property —in this particular case

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

energy— is the recommended approach to evaluate energy use. Therefore, the selection of the impact category recommended shall express impact in units of energy: e.g., MJ.

Regarding the life cycle impact assessment in terms of energy consumption, energy consumption falls within the resource depletion impact categories. Concretely, they can be modeled following different approaches based on scope and methodology. However, the implementation of a method based on an inherent property shall account the energy use throughout the entire life cycle of a given process, product, or service, including the direct and indirect (i.e., embedded in construction and raw materials) energy use of energy thereby. In this sense, there are many methodological approaches to determine energy consumptions (**Table 4**).

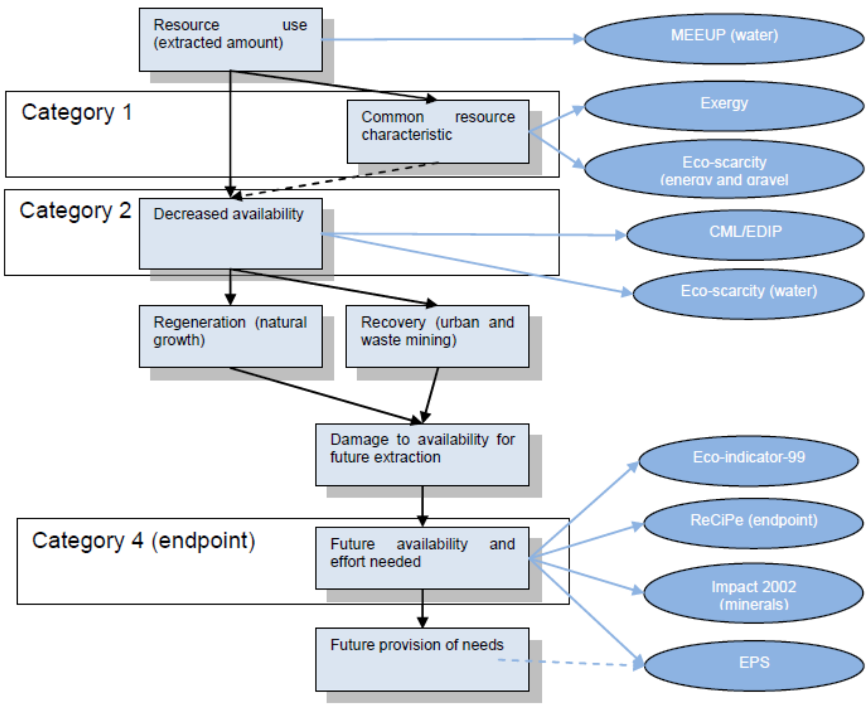

Figure 12. *Resources depletion impact pathway and detail of methods.*

Table 4. *Selection of LCIA methods that includes energy consumption as impact category.*

LCIA method	Impact category	Unit	Characterization model	Comments
EF (Environmental Footprint -PEF)	Resource use, fossil	MJ	CML 2002 (Guinée et al., 2001) and van Oers et al. (2002)	Lower Heating Value (LHV) of fuels.
CML	Abiotic depletion (fossil fuels)	MJ	CML 2002 (Guinée et al., 2001)and van Oers et al. (2002)	LHV of fuels
EPD	Abiotic depletion (fossil fuels)	MJ	CML 2002 (Guinée et al., 2001) and van Oers et al. (2002)	LHV of fuels
CED	Non-renewable energy	MJ eq	VDI-Richtlinien (1997) and	LHV of fuels / Higher

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

	Renewable energy	Frischknecht et al. (2007)	Heating Value (HHV) of fuels.

As **Table 4** depicts, there are different LCIA methods for determine the energy consumption. One may choose from methods that use lower/higher heating values to those that include renewable and non-renewable energy carriers. Thus, the Cumulative Energy Demand method allows to choose the lower or the upper heating value of primary energy carriers, making the difference between renewable and non-renewable energy sources. Moreover, CED is divided into six categories based on energy source origin (**Table 5**), not providing an aggregated value. However, the user can combine these categories as intended for own calculations and analysis since they are expressed in the same units: MJ equivalents. The other LCIA methods do not allow to disaggregate between energy carries or heating values. Additionally, the impact categories of both CML and EPD LCIA methods do not include nuclear energy sources explicitly in their characterization model. Therefore, for energy foot-printing purposes, the CED (LHV; using the lower heating values) method shall be the LCIA method implemented because it:

- Disaggregates energy carriers.
- Includes lower or higher heating values for calculation.
- Includes nuclear energy carriers in the characterization model.
- Is aligned to PEF method impact category: to do so is necessary to set lower heating values for CED calculation and only consider the subcategories non-renewable resources (fossil + nuclear), disregarding the remaining subcategories.

Table 5. *Impact assessment method CED with detail of the categories and subcategories included.*

Category	Subcategory	Includes
Non-renewable resources	Fossil	Hard coal, lignite, crude oil, natural gas, coal mining off-gas, peat.
	Nuclear	Uranium
	Biomass	Wood and biomass from primary forests
Renewable resources	Biomass	Wood, food products, biomass from agriculture
	Wind, solar, geothermal	Wind energy, solar energy (used for heat & electricity), geothermal energy
	Water	Run-of-river hydro power, reservoir hydro power

8. Carbon footprint

As it is well known, the food system is one of the main drivers of the climate changes, since it is responsible for about one third of global the GHG emissions from anthropogenic sources; in this context, global GHG emissions from the food system reached 18 Gt CO_2 eq in 2015, with 27% emitted by industrialized countries, and the remaining 73% emitted by developing countries (Crippa et al., 2021). Furthermore, the world population has been growing exponentially within the last century, and especially from the last decades of the 20th century to the present.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

According to the most recent estimations, the total world population is projected to be almost ten billion people by the year 2050 (United Nations, 2019). It is for this reason that some authors estimate that global food production will have to grow substantially. In this context, according to the last and revised projections made by FAO, food production will have to increase, in order to reach worldwide food security for all humans, at about 50% between 2014 and 2050 (FAO, 2017). Therefore, there is an urgent need to achieve a more sustainable food system considering the climate crisis we are facing, and the even greater environmental impact expected with the growth of the world population.

Understanding the GHG emissions caused by a particular activity, and where they come from, is necessary in order to reduce them. In this context, the CF from an LCA perspective is one of the most consolidated indicators in terms of environmental impact assessment for seafood products. Measuring the CF of products across their life cycle is a powerful way to reduce GHG emissions, identify cost saving opportunities, incorporate emissions impact into decision making on suppliers, demonstrate environmental responsibility leadership, meet customer demands for information on product carbon footprint, differentiate and meet demands from "green" consumers. The principles, requirements and guidelines for the quantification and reporting of the CF of a product are in the ISO 1067 (ISO, 2019) , in a manner consistent with the International Standards on LCA (i.e., ISO 14040, 14044). However, focusing on carbon footprinting, there are several standards recognized internationally:

- Publicly Available Specification 2050:2011 or "PAS 2050", developed by the British Standards Institution (BSI).
- GHG Protocol, one of the first initiatives aimed at accounting for greenhouse gas emissions. It was developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).
- ISO 14064:2006, provides governments, businesses, and other corporations with a set of tools to quantify and verify their greenhouse gas emissions.
- ISO 14067:2013, specifies the principles, requirements and guidelines for the quantification and communication of a product's carbon footprint; it is based on the international standards for life cycle analysis (ISO 14040 and ISO 14044) for quantification and on the standards for eco-labelling and environmental declarations (ISO 14020, ISO 14024 and ISO 14025) for communication.

Before proceeding with CF calculation, a series of decisions must be taken, already detailed in the previous sections. The FU, system boundaries and allocation factors must be established and the LCI must be prepared. Once all the inputs and outputs flow of material and energy are quantified, the CF of the system can be calculated. Thus, it is necessary to be meticulous in considering all flows of inputs and outputs of each element. **Figure 13** shows the procedure to follow to calculate the carbon footprint of a component.

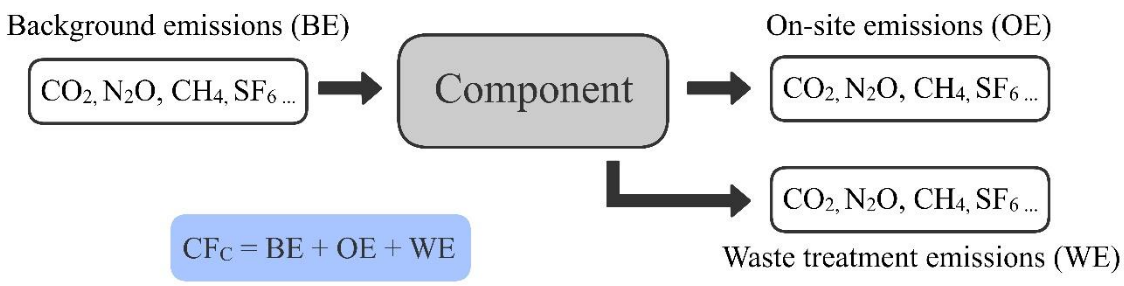

Figure 13. *Source of GHG emissions produced during the life cycle of products.*

Once the source of GHG emissions have been exhaustively determined, it is necessary to quantify the GHG emitted by each of the sources (BE, OE and WE). **Figure 14** shows an example for the calculation of the background emissions (BE) in a life cycle stage of seafood products. The calculation of the on-site emissions should be carried out only for the elements whose use phase causes GHG emissions. Waste emissions can be determined in a similar way to BE, as in some cases inputs such as energy or chemical are required, e.g., in anaerobic digestion or in wastewater treatment plants.

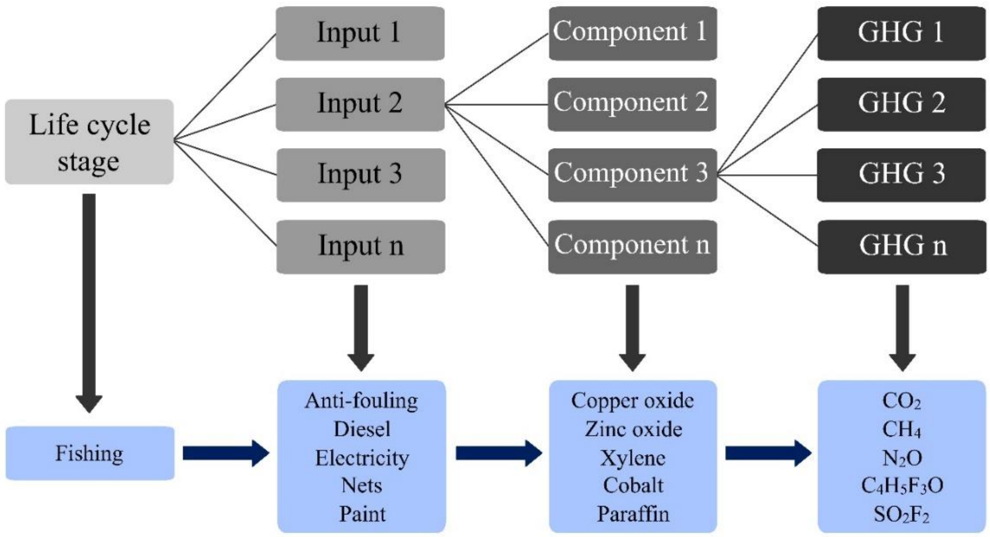

Figure 14. *Example of the breakdown to be made to obtain GHG flows for each life cycle stage.*

Once all the flows of GHG corresponding to each component of the inputs have been quantified, the CF is calculated by multiplying the amount of each greenhouse gas with its corresponding characterisation factor following the equations shown in **Figure 15**.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

$$CF = \sum_{LCS=1}^{n} CF_{LCS}$$

$$CF_{LCS} = \sum_{I=1}^{n} CF_{I}$$

$$CF_{I} = \sum_{C=1}^{n} CF_{C}$$

$$CF_{c} = \sum_{X=1}^{n} GHG_{X} \cdot F_{X}$$

Figure 15. *Method for the manual calculation of the CF of products. Legend: LCS: Life-cycle stage; I: Input; C: Component; X: Greenhouse gas.*

9. Nutritional footprint

In 2005, the *Dietary Guidelines for Americans* identified additional nutrients of concern that were underrepresented in the typical US diet (Guenther et al., 2008). For instance, fibre, vitamins A, C and E, calcium, potassium and magnesium were the case for children and adolescents (Fulgoni et al., 2009). However, other authors, such as (Drewnowski et al., 2009a, 2009b), selected a number of nutrients to be included in nutrient-rich foods (NRF) index to test and validate against the Healthy Eating Index (HEI), a score used to estimate the diet excellence as a whole and the quality of a set of dietary components (https://epi.grants.cancer.gov/hei/). This index, named NRF*n*.3, was based on *n* nutrient to encourage and on 3 to be limited (LIM). ***Table 6*** shows that the number of nutrients to encourage was variable (n=6-15) whereas the LIM were always constant: saturated fat, added sugar and sodium.

Table 6. *Nutrients to encourage and to be limited LIM in selected NRF nutrient profile models.*

NRF models	Macronutrients	Vitamins	Minerals	LIM
LIM				Saturated fat, added sugar, Na
LIM_t				Saturated fat, added sugar, Na
NRF6.3	Protein, fibre	A, C	Ca, Fe	Saturated fat, added sugar, Na
NRF9.3	Protein, fibre	A, C, E	Ca, Fe, Mg, K	Saturated fat, added sugar, Na
NRF11.3	Protein, fibre	A, C, E, B12	Ca, Fe, Mg, Zn, K	Saturated fat, added sugar, Na
NRF15.3	Protein, fibre, monounsaturated fat	A, C, D, E, thiamine, riboflavin, B12, folate	Ca, Fe, Zn, K	Saturated fat, added sugar, Na

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

This guideline chose to use a modified version of NRF9.3 index since it is the index that correlates the best with the health-related nutritional impacts of products. The algorithm used to calculate this NRF9.3 index is the unweighted sum of percentage daily values (DVs) for 9 nutrients to encourage, minus the sum of percentage maximum recommended values (MRVs) for 3 nutrients to limit, calculated per reference amount. Percentage DVs are capped at 100% so that foods containing very large amounts of a single nutrient would not obtain a disproportionately high index score (Drewnowski et al., 2009b). For our concerning case (seafood products) the modified version of NRF9.3 was the NRF12.2 index, in which a macronutrient (fibre) and one nutrient to be limited (added sugar) were excluded because they are absent in this type of food. On the other hand, one fatty acid - docosahexaenoic acid (omega-3) - and two minerals - iodine and selenium -, were considered in our specific seafood nutritional index (NRF12.2), since seafood products are an important source of these nutrients in the diet (Burk, 2007; Kris-Etherton et al., 2002; Nerhus et al., 2018). Therefore, the NRF12.2 is based on twelve nutrients to encourage and two nutrients to be limited (LIM) per reference amounts customarily consumed (RACC). All the data used in this methodology are referenced per 100 g of final product, as well as the formulas **[Equations 11-13]** needed to apply:

$$NR12_{100\,g} = \sum_{1}^{12} \left({nutrient_i}/{DV_i} \right) \times 100$$ **[Equation 11]**

$$LIM_{100\,g} = \sum_{1}^{2} \left({nutrient_i}/{MRV_i} \right) \times 100$$ **[Equation 12]**

$$NRF12.2_{100\,g} = NR12_{100\,g} - LIM_{100\,g}$$ **[Equation 13]**

Where *nutrient*$_i$ is the weight of each nutrient per serving (100 g in this case), *DV*$_i$ is the daily value for the nutrient and *MRV*$_i$ is the maximum recommended value for the nutrient. These values (in **Table 7**) were calculated with nutrient reference values, on average for male and female adults, published by (EFSA, 2019), while in the case of protein and saturated fat the following references used were from FDA (2020) and EFSA (2012), respectively. On the other hand, given that omega 3 DV recommended is easily exceeded by omega 3 content of most seafood species, it was decided to set the maximum recommended daily value as a threshold level, thus decreasing high differences between species and obtaining nutritional footprint values more suitable to a healthy diet point of view.

When the seafood product assessed is a processed product composed by different ingredients, such as typical ingredients in the processing of fish products (e.g., olive oil, vinegar, tomato, etc…), it is necessary to adapt the NRF index to each case study. In this case, weighting factors should be applied that depend on the proportion in which each ingredient is found in the final product **[Equation 14]**.

$$NRF12.2_{processed\ product} = \sum_{j=2}^{j} w_j \cdot NRF12.2_j$$ **[Equation 14]**

Where w_j is the weighting factor of the ingredient j.

***Table 7**. Daily recommended values (DV) and maximum values (MRV) per capita* (*EFSA,

2019; **EFSA, 2012 ***FDA, 2020).

Nutrients	Unit	DV_i	MRV_i
Protein	g	57**	-
Omega 3	mg	250*	-
K	mg	3500*	-
Ca	mg	950*	-
Fe	mg	13.5*	-
Mg	mg	325*	-
I	µg	175*	-
Se	µg	70*	-
Vitamin A	µg	700*	-
Vitamin C	mg	102.5*	-
Vitamin D	µg	15*	-
Vitamin E	mg	12*	
Saturated fat	g	-	20***
Na	g	-	2*

10. NEXUS Eco-label methodology

Eco-labels and recommendations are created as "abstract systems" of communication, to create trust and security for consumers in production systems that are removed from their daily experience and that are too complex and incomprehensible to communicate in full detail (Roheim et al., 2018). In this sense, eco-labels simplify consumers´ decision-making process and it signals that they are choosing a "green" good or service (Thøgersen et al., 2012). Eco-labels emerge as an outcome of the implementation of novel and sustainable practices along the business process; in this way, an ecolabel is a visible manifestation of an eco-innovation process (Prieto-Sandoval et al., 2016). In the specific case of seafood, more than 30 guides and certifications programmes developed by NGOs (Parkes et al., 2010), in addition to governmental certification schemes (Samerwong et al., 2018) and community-supported fisheries (Bolton et al., 2016), contribute to a crowded "seascape" of consumer-facing advice (Alfnes et al., 2018). It has been demonstrated that the proliferation of sustainable seafood certification has brought new challenges to achieve more sustainable fisheries and aquaculture production as, for example, sustainability criteria are imperfectly measured and open to interpretation (Roheim et al., 2018). Once all the footprints included in the present project are estimated for each considered species, it is intended to design an ecolabel, applicable to the entire Atlantic Area to clearly disseminate the information to stakeholders, consumers or other interested parties. However, it is important to mention that these footprints do not include fishery specific impact categories and do not cover stock management, species level of conservation status, or ecosystem impact from the fishing gear operation (e.g., destruction of the seafloor structures as corals and another benthic organism).

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Water, energy and food are essential for human well-being, poverty reduction, and sustainable development. In this context, it is expected that demand for freshwater, energy, and food will increase significantly over the next decades under the pressure of population growth and mobility, economic development, international trade, urbanization, diversifying diets, cultural and technological changes, and climate change (UNPAR, 2017). As mentioned in previous sections the food system is responsible of 70% of freshwater withdrawals (Ritchie and Roser, 2020). At the same time, the food production and supply chain is also responsible of 30% of the total energy consumed globally, since energy is required to produce, transport and distribute food as well as to extract, pump, lift, collect, transport and treat water (FAO, 2012).

The NEXUS approach is the selected methodology for the integration of the footprints evaluated in this project (i.e., water, energy, carbon, and nutritional footprints) for each of the species considered. In this context, the term "NEXUS" implies that an action in one of the systems has also consequences on the others and it is for this reason why it is important to understand the synergies and trade-offs in order to develop response options to ensure a more sustainable environment (Laso et al., 2018). Therefore, the NEXUS index can be useful to develop strategies based on the circular economy approach in search of optimal management patterns that minimises water and energy consumption, as well as GHG emissions, while maximizing their nutrient content.

Water, energy, and food are basic requirements for everyday life and are key activities advancing the seafood sector. In this sense, the lack of a secure and economical provision of one of them might lead to disruption in the supply and accessibility of the two others (Machell et al., 2015). LCA is particularly important for understanding the interconnections in the nexus, as it enables the consideration of entire supply chains. Overall, the nexus approach can support the identification of synergies and trade-offs between water and energy systems and food systems aiming at resources efficiency and environmental impacts reduction (Mannan et al., 2018). Advancements towards a greater linkage between terrestrial and marine systems, however, are necessary for fishing activities within a nexus framework (Ruiz-Salmón et al., 2021).

The NEXUS Water-Energy-Food calculation comprises the following stages (Benini et al., 2014; He and Gu, 2016):

i. **Selection of product environmental footprints:** Establishment of representative environmental footprints to be included within the NEXUS eco-label. In this case, the WF, EF, CF and NF were selected to be included.

ii. **Calculation:** The assessment of the different footprints is carried out following the guidelines and procedures detailed in this guide.

iii. **Normalisation:** Normalisation is used to express the indicator data in a way that could be compared among all types of product environmental footprints. Since the spectrum of species, fishing gears and processing analysed within the project are representative for the Atlantic Area, the results obtained in terms of each environmental footprint will be used as a model for linear normalisation, using the maximum and minimum footprint results taking into account the whole sample evaluated within the NEPTUNUS project (Sousa et al., 2021). In this way, whilst the product with the lowest footprint in terms of WF, EF and CF is assigned a score of 100, the rest of the products decrease the score in proportion, considering as score 0 the highest footprint. Conversely, since the NF should be as good as possible, the product with the highest value will be assigned the value 100 and 0 will be assigned to the lowest value **[Equations 15-18]**:

$$WF_{n_i} = \frac{WF_{max} - WF_i}{WF_{max} - WF_{min}}$$ **[Equation 15]**

$$EFn_i = \frac{EF_{max} - EF_i}{EF_{max} - EF_{min}}$$ **[Equation 16]**

$$CFn_i = \frac{CF_{max} - CF_i}{CF_{max} - CF_{min}}$$ **[Equation 17]**

$$NFn_i = \frac{NF_i - NF_{min}}{NF_{max} - NF_{min}}$$ **[Equation 18]**

Where WFn_i, EFn_i, CFn_i and NFn_i represent the score of the normalised footprints (water, energy, carbon and nutritional, respectively) for the analysed product (i). WF_i, EF_i, CF_i and NF_i represent the individual footprint value for the analysed product (i). WF_{min}, EF_{min}, CF_{min} and NF_{min} represent the minimum footprint value taking into account the whole sample evaluated within the project. WF_{max}, EF_{max}, CF_{max} and NF_{max} represent the maximum footprint value considering the whole sample evaluated. So that the final score for each footprint will be 0-100.

iv. **Weighting:** Assign weights to the different types of product environmental footprints based on their perceived importance to emphasize the most important potential impacts with the consideration of design requirements. It would obviously alter the results with different weights. Each indicator has a correlative weight, denoted as w_1, w_2, w_3, w_4 $(\sum_{n=1}^{4} w_n = 1)$, respectively for WFni, EFni, CFni, and NFni. In the present case study, all the indicators are given equal importance, so the weight by which they are multiplied would be 0.25, so that the final result of the NEXUS indicator for the product i will be in the desired range between 0-100. The resulting multi-criteria value of the NEXUS is obtained as follow **[Equation 19]**:

$$NEXUS_i = w_1 \cdot WFn_i + w_2 \cdot EFn_i + w_3 \cdot CFn_i + w_4 \cdot NFn_i$$ **[Equation 19]**

Where i represent the product i under assessment.

v. **Communication and dissemination of results:** Once the NEXUS results are obtained, it is just as important to carry out good communication to disseminate the information to the interested audience in an effective way; It is for this reason that the next steps focus on the design of a NEXUS ecolabel.

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION
This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

12. References

AIB, 2020. European Residual Mix [WWW Document].

Alfnes, F., Chen, X., Rickertsen, K., 2018. Labeling farmed seafood: A review. Aquac. Econ. \& Manag. 22, 1–26. https://doi.org/10.1080/13657305.2017.1356398

Avadí, A., Vázquez-Rowe, I., Symeonidis, A., Moreno-Ruiz, E., 2020. First series of seafood datasets in ecoinvent: setting the pace for future development. Int. J. Life Cycle Assess. 25, 1333–1342. https://doi.org/10.1007/s11367-019-01659-x

BEDCA, 2006. The Spanish Food Composition Database [WWW Document].

Benini, L., Mancini, L., Sala, S., Manfredi, S., Schau, E.M., Pant, R., 2014. Normalisation method and data for envieonmental footprints. https://doi.org/10.2788/16415

Bolton, A.E., Dubik, B.A., Stoll, J.S., Basurto, X., 2016. Describing the diversity of community supported fishery programs in North America. Mar. Policy 66, 21–29. https://doi.org/10.1016/j.marpol.2016.01.007

Boulay, A.M., Bare, J., Benini, L., Berger, M., Lathuillière, M.J., Manzardo, A., Margni, M., Motoshita, M., Núñez, M., Pastor, A.V., Ridoutt, B., Oki, T., Worbe, S., Pfister, S., 2018. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). Int. J. Life Cycle Assess. 23, 368–378. https://doi.org/10.1007/s11367-017-1333-8

Bouwman, A.F., Beusen, A.H.W., Overbeek, C.C., Bureau, D.P., Pawlowski, M., Glibert, P.M., 2013. Hindcasts and future projections of global inland and coastal nitrogen and phosphorus loads due to finfish aquaculture. Rev. Fish. Sci. 21, 112–156. https://doi.org/10.1080/10641262.2013.790340

BSI, 2012. PAS 2050-2:2012 Assessment of life cycle greenhouse gas emissions. Supplementary requirements for the aplication of PAS 2050:2011 to seafood and aquatic food products.

Burk, R.F., 2007. Selenium in Nutrition and Health, The American Journal of Clinical Nutrition. https://doi.org/10.1093/ajcn/86.1.270

CIQUAL, 2020. French Food Composition Table [WWW Document].

CNMC, 2020. Comisión Nacional de los Mercados y la Competencia, n.d. Energía [WWW Document].

Crippa, M., Solazzo, E., Guizzardi, D., Tubiello, F.N., Leip, A., 2021. Food system are responsible for a third of global GHG emissions. Nat. Food. https://doi.org/10.1038/s43016-021-00225-9

Drewnowski, A., Maillot, M., Darmon, N., 2009a. Should nutrient profiles be based on 100kcal, 100g or serving size? Eur. J. Clin. Nutr. 63, 898–904. https://doi.org/10.1038/ejcn.2008.53

Drewnowski, A., Maillot, M., Darmon, N., 2009b. Testing nutrient profile models in relation to energy density and energy cost. Eur. J. Clin. Nutr. 63, 674–683. https://doi.org/10.1038/ejcn.2008.16

EFSA, 2019. Dietary Reference Values for nutrients Summary report. EFSA Support. Publ. 14. https://doi.org/10.2903/sp.efsa.2017.e15121

EFSA, 2012. Scientific Opinion on Dietary Reference Values for protein. Eur. Food Saf. Auth. 10, 1–66. https://doi.org/10.2903/j.efsa.2012.2557

EMEP/EEA, 2019. EMEP/EEA air pollutant emission inventory guidebook (EMEP CORINAIR emission inventory guidebook) 2019: Technical guidance to prepare national emission inventories. EEA Report 13/2019. EEA Tech. Rep.

EPD International, 2015. General programme Instructions of the International EPD® System. Version 2.5.

European Commission, 2018. Product Environmental Footprint Category Rules Guidance (Version 6.3 - May 2018).

European Commission, 2008. CPA 2008 framework Regulation (EC) No 451/2008 of the European Parliament and of the Council of 23 April 2008.

FAO, 2017. The future of food and agriculture: trends and challenges, The future of food and agriculture: trends and challenges.

FAO, 2012. Policy Brief: The Case for Energy-Smart Food Systems. Food Agric. Organ. United Nations 1–16.

FDA, 2020. Daily Value and Percent Daily Value: Changes on the New Nutrition and Supplement Facts Labels 1–6.

Fréon, P., Avadí, A., Vinatea Chavez, R.A., Iriarte Ahón, F., 2014. Life cycle assessment of the Peruvian industrial anchoveta fleet: Boundary setting in life cycle inventory analyses of complex and plural means of production. Int. J. Life Cycle Assess. 19, 1068–1086. https://doi.org/10.1007/s11367-014-0716-3

Frischknecht, R., Jungbluth, N., Althaus, H.J., Bauer, C., Doka, G., Dones, R., Hischier, R., Hellweg, S., Humbert, S., Köllner, T., Loerincik, Y., Margini, M., Nemecek, T., 2007. Implementation of Life Cycle Impact Assessment Methods. ecoinvent report nº. 3, v2.0.

Fulgoni, V.L., Keast, D.R., Drewnowski, A., 2009. Development and Validation of the Nutrient-Rich Foods Index: A Tool to Measure Nutritional Quality of Foods. J. Nutr. 139, 1549–1554. https://doi.org/10.3945/jn.108.101360

Gephart, J.A., Troell, M., Henriksson, P.J.G., Beveridge, M.C.M., Verdegem, M., Metian, M., Mateos, L.D., Deutsch, L., 2017. The ' seafood gap ' in the food-water nexus literature — issues surrounding freshwater use in seafood production chains. Adv. Water Resour. 110, 505–514. https://doi.org/10.1016/j.advwatres.2017.03.025

Guenther, P.M., Reedy, J., Krebs-Smith, S.M., 2008. Development of the Healthy Eating Index-2005. J. Am. Diet. Assoc. 108, 1896–1901. https://doi.org/10.1016/j.jada.2008.08.016

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Sleeswijk, A.W., Suh, S., de Haes, H., 2001. Life cycle assessment. An operational guide to the ISO standards. Leiden (The Netherlands): Centre of Environmental Science.

Hauschild, M.Z., Olsen, S.I., Rosenbaum, R.K., 2018. Life Cycle Assessment: Theory and Practice, 1st ed. 20. ed. Springer International Publishing.

He, B., Gu, Z., 2016. Sustainable design synthesis for product environmental footprints. Des. Stud. 45, 159–186. https://doi.org/10.1016/j.destud.2016.04.001

Helmes, R., Ponsioen, T., Blonk, H., Vieira, M., Goglio, P., Linden, R. Van Der, Rojas, P.G., Verweij-novikova, I., 2020. Hortifootprint Category Rules: towards a PEFCR for horticultural products.

Hospido, A., Tyedmers, P., 2005. Life cycle environmental impacts of Spanish tuna fisheries. Fish. Res. 76, 174–186. https://doi.org/10.1016/j.fishres.2005.05.016

Interreg Atlantic Area — European Regional Development Fund — EUROPEAN UNION

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

IEA, 2020. Data and statistics. IEA - International Energy Agency [WWW Document].

IPPC, 2006. Chapter 2.2: Stationary Combustion. 2006 IPCC Guidel. Natl. Greenh. Gas Invent. 2, 1–47.

ISO, 2019. ISO 14067 - Greenhouse gases – Carbon footprint of products – requirements and guidelines for quantification and communication. Geneve.

ISO, 2014. ISO 14046 - Environmental Management - Water Footprint - Principles, requirements and guidelines.

ISO, 2006a. ISO 14040 - Environmental Management - Life Cycle Assessment - Principles and Framework.

ISO, 2006b. ISO 14044 - Environmental Management - Life Cycle Assessment - Requirements and Guidelines.

ISO, 2006c. ISO 14025 - Environmental labels and declarations - Type III environmental declarations - Principles and procedures.

Kris-Etherton, P.M., Harris, W.S., Appel, L.J., 2002. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation 106, 2747–2757. https://doi.org/10.1161/01.CIR.0000038493.65177.94

Laso, J., Margallo, M., García-Herrero, I., Fullana, P., Bala, A., Gazulla, C., Polettini, A., Kahhat, R., Vázquez-Rowe, I., Irabien, A., Aldaco, R., 2018. Combined application of Life Cycle Assessment and linear programming to evaluate food waste-to-food strategies: Seeking for answers in the nexus approach. Waste Manag. 80, 186–197. https://doi.org/10.1016/j.wasman.2018.09.009

Machell, J., Prior, K., Allan, R., Andresen, J.M., 2015. The water energy food nexus-challenges and emerging solutions. Environ. Sci. Water Res. Technol. 1, 15–16. https://doi.org/10.1039/c4ew90001d

Mannan, M., Al-Ansari, T., Mackey, H.R., Al-Ghamdi, S.G., 2018. Quantifying the energy, water and food nexus: A review of the latest developments based on life-cycle assessment. J. Clean. Prod. 193, 300–314. https://doi.org/10.1016/j.jclepro.2018.05.050

Moreno Ruiz, E., Valsasina, L., Brunner, F., Symeonidis, A., FitzGerald, D., Treyer, K., Bourgault, G., Wernet, G., 2018. Documentation of changes implemented in the Ecoinvent Database v3.5. Ecoinvent, Zurich, Switzerland.

Nerhus, I., Markhus, M.W., Nilsen, B.M., Øyen, J., Maage, A., Ødegård, E.R., Midtbø, L.K., Frantzen, S., Kögel, T., Graff, I.E., Lie, Ø., Dahl, L., Kjellevold, M., 2018. Iodine content of six fish species, Norwegian dairy products and hen's egg. Food Nutr. Res. 62, 1–13. https://doi.org/10.29219/fnr.v62.1291

Parkes, G., Young, J.A., Walmsley, S.F., Abel, R., Harman, J., Horvat, P., Lem, A., MacFarlane, A., Mens, M., Nolan, C., 2010. Behind the Signs—A Global Review of Fish Sustainability Information Schemes. Rev. Fish. Sci. 18, 344–356. https://doi.org/10.1080/10641262.2010.516374

Prieto-Sandoval, V., Alfaro, J.A., Mejía-Villa, A., Ormazabal, M., 2016. ECO-labels as a multidimensional research topic: Trends and opportunities. J. Clean. Prod. 135, 806–818. https://doi.org/10.1016/j.jclepro.2016.06.167

REE, 2020. Red Eléctrica de España [WWW Document].

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Ritchie, H., Roser, M., 2020. Environmental impacts of food production [WWW Document]. Our World Data.

Roheim, C.A., Bush, S.R., Asche, F., Sanchirico, J.N., Uchida, H., 2018. Evolution and future of the sustainable seafood market. Nat. Sustain. 1, 392–398. https://doi.org/10.1038/s41893-018-0115-z

Rosenbaum, R.K., 2017. Selection of Impact Categories, Category Indicators and Characterization Models in Goal and Scope Definition, in: Curran, M.A. (Ed.), Goal and Scope Definition in Life Cycle Assessment. Springer Netherlands, Dordrecht, pp. 63–122. https://doi.org/10.1007/978-94-024-0855-3_2

Ruiz-Salmón, I., Laso, J., Margallo, M., Villanueva-Rey, P., Rodríguez, E., Quinteiro, P., Dias, A.C., Almeida, C., Nunes, M.L., Marques, A., Cortés, A., Moreira, M.T., Feijoo, G., Loubet, P., Sonnemann, G., Morse, A.P., Cooney, R., Clifford, E., Regueiro, L., Méndez, D., Anglada, C., Noirot, C., Rowan, N., Vázquez-Rowe, I., Aldaco, R., 2021. Life cycle assessment of fish and seafood processed products – A review of methodologies and new challenges. Sci. Total Environ. 761. https://doi.org/10.1016/j.scitotenv.2020.144094

Samerwong, P., Bush, S.R., Oosterveer, P., 2018. Implications of multiple national certification standards for Thai shrimp aquaculture. Aquaculture 493, 319–327. https://doi.org/10.1016/j.aquaculture.2018.01.019

Sousa, S.R., Soares, S.R., Moreira, N.G., Severis, R.M., de Santa-Eulalia, L.A., 2021. Internal Normalization Procedures in the Context of LCA: A Simulation-Based Comparative Analysis. Environ. Model. Assess. 26, 271–281. https://doi.org/10.1007/s10666-021-09767-5

Struijs, J., Beusen, A., Jaarsveld, V.H., Huijbregts, M.A.J., 2009. Aquatic Eutrophication. Chapter 6 in: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R. (2009). ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and.

Thøgersen, J., Jørgensen, A.-K., Sandager, S., 2012. Consumer Decision Making Regarding a “Green” Everyday Product. Psychol. Mark. 29, 187–197. https://doi.org/10.1002/mar

Udo De Haes, H.A., Jolliet, O., Finnveden, G., Hauschild, M., Krewitt, W., Müller-Wenk, R., 1999. Best available practice regarding impact categories and category indicators in life cycle impact assessment. Int. J. Life Cycle Assess. 4, 66–74. https://doi.org/10.1007/bf02979403

UNEP, 2016. Global guidance for life cycle impact assessment indicators. Volume 1.

United Nations, 2019. World Population Prospects 2019, Department of Economic and Social Affairs. World Population Prospects 2019. New York.

UNPAR, 2017. UNPAR International Student Conference on Global Citizenship 2017 [WWW Document].

van Oers, L., Koning, J.B., Guinée, J., Huppers, G., 2002. Abiotic resource depletion in LCA : improving characterisation factors for abiotic resource depletion as recommended in the new Dutch LCA Handbook.

Vázquez-Rowe, I., Moreira, M.T., Feijoo, G., 2012. Environmental assessment of frozen common octopus (Octopus vulgaris) captured by Spanish fishing vessels in the Mauritanian EEZ. Mar. Policy 36, 180–188. https://doi.org/10.1016/j.marpol.2011.05.002

VDI-Richtlinien, 1997. Cumulative energy demand: Terms, definitions, methods of calculation.

Zampori, L., Pant, R., 2019. Suggestions for updating the Product Environmental Footprint (PEF) method, Publications Office of the European Union. https://doi.org/10.2760/424613

Annex A. LCA datasets

Table A.1. *Some of the world´s best-known LCA datasets.*

Database	Field	Geographical scope	Free / For purchase
Agri-footprint	Agriculture and food sector	Worldwide	For purchase
AGRYBALISE	Agriculture and food sector	Worldwide	Free
ARVI	Wood-polymer	Finland	For purchase
BioEnergieDat	Bioenergy	Europe	Free
Ecoinvent	Several areas	Worldwide	For purchase
ELCD	Several areas	Worldwide	Free
ESU World LCA food	Agriculture and food sector	Worldwide	For purchase
IDEA	Several areas	Japan	For purchase
LCA commons	Several areas	United States	For purchase
Product Environmental Footprint	Several areas	Europe	Free*
UVEK LCI Data	Energy, transport and waste treatment	Worldwide	For purchase

*Can only be used for those products included in the framework of PEF pilot and transition phase

Annex B. Nutritional characterisation of seafood products and different ingredients

Table B.1. *Nutritional characterisation of fresh seafood species per 100 g (source:* (BEDCA, 2006)*)*

Protein (g)	Omega 3 (mg)	K (mg)	Ca (mg)	Fe (mg)	Mg (mg)	I (mcg)	Se (mcg)	Vit. A (mcg)	Vit. C (mg)	Vit. D (mcg)	Vit. E (mg)	Sat. fat (g)	Na (mg)
18.68	796	386	12	1.2	30	51	39	45	0	4	1.3	3.449	84
11.93	266	294	33.1	1.1	25.1	27	36	trace	0	trace	0.35	0.35	101
19	0	480	120	2.4	38	58	51	trace	trace	trace	0.4	0.23	270
22	648	400	16	1.3	33	8	82	26	trace	7.2	1	0.96	47
15.4	211	420	17	1	31	10	36.5	36	2.8	16	1.3	0.41	39
17.9	140	230	144	1.2	28	64	44.8	70	0	trace	2.1	0.3	363
18.1	676	24	43	1.1	29	16	30	64	0	8	1.6	2.64	100
30	0	277	9	1.6	28	0	65.7	26	trace	3.5	0.9	1.2	43
16.5	0.542	230	30	0.7	29	30	44	trace	trace	trace	1.1	0.18	100
28.89	0	554	232	4.63	69	trace	68.1	67.4	0	11.8	3.33	2.203	3668
18.2	0	340	13	0.1	24	170	27	5	0	trace	0.47	0.17	68
17	0	75	20	1	36	18	22	50	2.7	40	1.71	6.4	2610
16.1	0.303	290	22	1	20	16	36.5	14	trace	trace	0	1.12	114
10.8	0.7	92	80	4.5	23	35	56	trace	trace	trace	0.9	0.41	210
8.145	0.159	240	116	6	43	20	63.7	75	trace	3	0.85	0.3739	395
17	0.527	300	30	0.9	25	7	28	9	trace	14	1.25	1.49	73
18	0.461	340	20	1.1	26	7	36.5	trace	trace	trace	0.5	0.27	69
15.7	0.916	250	26	1	28	3	25	14	0	2.1	1.5	0.43	58

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Species
Atlantic mackerel (*Scomber scombrus)*
European hake (*Merluccius merluccius*)
Atlantic scallop (*Pecten maximus*)
Skipjack tuna (*Katsuwonus pelamis*)
Horse mackerel (*Trachurus trachurus*)
Octopus (*Octopus vulgaris*)
Pilchard (*Sardina pilchardus*)
Albacore (*Thunnus alalunga*)
Common sole (*Solea solea*)
European anchovy (*Engraulis encrasicous*)
Cod (*Gadus gadidae*)
Atlantic herring (*Clupea harengus*)
Turbot (*Scophthalmus maximus*)
Mussel (*Mytilus galloprincialis*)
Oyster (*Ostreidae spp.*)
Gilthead sea bream (*Sparus aurata*)
Sea bass (*Lateolabrax japonicus*)
Rainbow trout (*Oncorthynchus mykiss*)

Table B.2. *Nutritional characterisation of different ingredients of processed seafood products per 100 g (source:* (BEDCA, 2006)*)*

Ca (mg)	Fe (mg)	Mg (mg)	I (mcg)	Se (mcg)	Vit. A (mcg)	Vit. C (mg)	Vit. D (mcg)	Vit. E (mg)	Sat. fat (g)	Na (mg)
0	0	0	0	0	3	0	0	12	17.06	0
trace	trace	trace	0	0	34	0	0	18.34	14.21	trace
0	trace	0	0	0	0	0	trace	56	10.62	0
6	0.45	4	trace	trace	0	0.5	0	trace	0	8
11	0.5	10	2.2	0.99	82	19	0	0.89	trace	18
6	0.45	4	trace	trace	70	0	0	2.1	0.3	363
646	8.68	264	2.7	23.9	53	1.2	0	0.67	0.249	60
110	2	70	74	0	0	0	0	0	trace	35000
266	14.3	90	0	3	0	21	0	2.5	0.63	5

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Ingredient	Protein (g)	Omega 3 (g)	K (mg)
Olive oil	0	0	0
Extra virgin olive oil	trace	0	trace
Sunflower oil	trace	0	0
Wine vinegar	0.4	0	39
Tomato	0.9	0	236
Onion	1.125	0	162
Garlic, powder	16.55	0	1193
Salt	0	0	56
White pepper	10.4	0	73

Annex C. Example of application of the CFF for steel packaging material

This annex provides an example on how to model recycled content and EoL for steel packaging material throughout the CFF. Firstly, the recycled content as input material must be done following the material part of the CFF: impact of virgin material and impact of recycled material, disregarding the benefits from material that will be recycled (Figure C1). Secondly, EoL stage (waste treatment scenario) must be modelled according to the CFF with recycling (material part for benefits from material that will be recycled), incineration (energy part) and landfill (disposal part). The Table C1 details the CFF parameters to be applied for steel packaging materials in Spain. The Figure C1 details the procedure to deal with CFF and inventory modelling, detailing the calculation for each formula part.

Table C.1. *CFF parameters for steel which shall be applied based on PEF guidance, Annex C*

Parameters	Value	Source
R1	0.58†	1.Supply chain specific value 2. Application of specific default value
R2	0.87†	1. Company specific values 2. Application of specific default value
R3	0.018*	Default value
A	0.2	Default value
B	0	Equal to 0 as default
Q-values	1	Default value
E-values, X-values and LHV	-	Life cycle inventory dataset
Incineration share (Spain)	14%	Default value
Landfill share (Spain)	86%	Default value

†default value; *(1 – R2) x Incineration share.

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

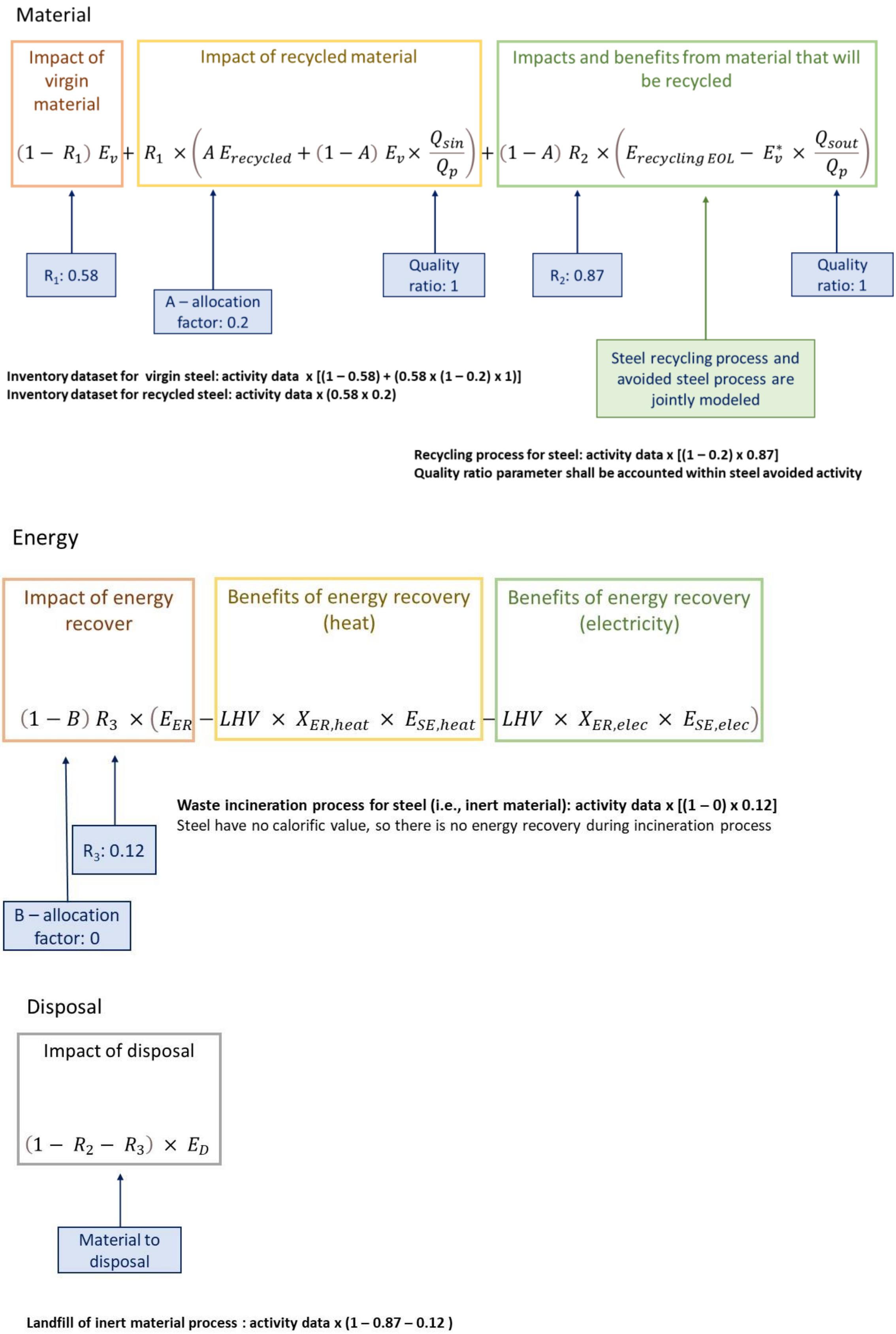

Figure C.1. *Material input and EoL modelling for steel according to the CFF*

Annex D. Water footprint characterization factors

Table D.1. *Characterizsation factors to assess water use as defined in Fazio et al. (2018). *Most recent characterisation factors can be used if available*

Country	ChF	Country	ChF	Country	ChF	Country	ChF
AD	74.7	DK	3.54	KP	2.5	QA	73.4
AE	18.6	DM	5.5	KR	1.66	RE	9.61
AF	57.2	DO	9.69	KW	53.8	RO	8.33
AG	13.7	DZ	64.5	KZ	52.6	RS	13.7
AI	22.4	EC	4.06	LA	5.71	RU	12.5
AL	23.1	EE	1.97	LB	85.1	RW	80.7
AM	85.4	EG	98.4	LC	41.5	SA	18.7
AN	88.8	EH	42	LI	0.761	SB	1.11
AO	7.99	ER	50.1	LK	24.6	SD	38.2
AR	47.1	ES	77.7	LR	0.675	SE	4.41
AS	4.42	ET	28.6	LS	19.3	SG	0.926
AT	1.27	FI	1.94	LT	1.23	SI	0.917
AU	72.1	FJ	1.38	LU	0.851	SK	1.3
AW	100	FK	14.3	LV	1.45	SL	1.06
AZ	85.9	FO	0.877	LY	51.6	SM	12.2
BA	1.16	FR	6.98	MA	86.4	SN	81.8
BB	10.5	GA	1.09	MC	3.04	SO	49.5
BD	2.43	GB	3.5	MD	1.7	SR	0.563
BE	1.37	GD	11.8	ME	8.73	ST	14.6
BF	15.9	GE	74.2	MG	2.74	SV	1.65
BG	25.6	GF	0.607	MK	34.2	SY	75.5
BH	9.93	GH	20.8	ML	15.7	SZ	1.93
BI	76.9	GI	46.2	MM	5.02	TC	12.7
BJ	7.29	GL	0	MN	29.8	TD	22.6
BN	0.221	GM	11.8	MQ	9.64	TG	15.3
BO	6.62	GN	15.1	MR	91.3	TH	7.82
BR	2.17	GP	15	MS	10.5	TJ	72
BS	24.9	GQ	0.233	MT	62.6	TL	9.08
BT	1.03	GR	68.4	MU	3.34	TM	65.7
BW	22.5	GT	1.2	MW	5.44	TN	69.3
BY	3.39	GW	5.01	MX	33.4	TO	12.3
BZ	2.13	GY	2.39	MY	1.64	TR	55.6
CA	7.4	HN	1.11	MZ	4.42	TT	14.5
CD	7.11	HR	9.06	NA	37.8	TW	4.99
CF	10.6	HT	2.56	NC	6.9	TZ	19.5
CG	0.862	HU	1.26	NE	8.67	UA	26.8
CH	1.34	ID	23.6	NG	8.91	UG	83.3
CI	6.85	IE	0.716	NI	2.17	VE	4.55
CL	80.1	IL	82	NL	1.17	VG	14.6
CM	8.51	IM	4.07	NO	0.634	VI	12.8
CN	42.4	IN	29.4	PG	1.43	VN	13.4
CO	0.679	IQ	56.4	PH	7.82	VU	2.75
CR	0.933	IR	66.6	PK	61.4	WS	0.843
CU	5.3	JP	0.897	PL	1.96	YE	37.6
CV	1.05	KE	19.5	PM	12.4	ZA	36.4
CY	74.3	KG	68.9	PR	7.93	ZM	5.58
CZ	1.79	KH	6.53	PS	82.2	ZW	4.97
DE	1.36	KM	9.2	PT	49.6		
DJ	13.4	KN	4.59	PY	1.29		

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Table D.2.*Characterizsation factors to assess freshwater eutrophication as defined in Fazio et al. (2018). *Most recent characterisation factors can be used if available*

Flow class	Sub-compartment	Flow name	ChF
Emissions to soil	Emissions to agricultural soil	phosphate	0.016
Emissions to soil	Emissions to agricultural soil	phosphoric acid	0.016
Emissions to soil	Emissions to agricultural soil	Phosphorus	0.05
Emissions to soil	Emissions to agricultural soil	phosphorus. total	0.05
Emissions to soil	Emissions to non-agricultural soil	phosphate	0.016
Emissions to soil	Emissions to non-agricultural soil	phosphoric acid	0.016
Emissions to soil	Emissions to non-agricultural soil	Phosphorus	0.05
Emissions to soil	Emissions to non-agricultural soil	phosphorus. total	0.05
Emissions to soil	Emissions to soil. unspecified	phosphate	0.016
Emissions to soil	Emissions to soil. unspecified	phosphoric acid	0.016
Emissions to soil	Emissions to soil. unspecified	Phosphorus	0.05
Emissions to soil	Emissions to soil. unspecified	phosphorus. total	0.05
Emissions to water	Emissions to fresh water	phosphate	0.33
Emissions to water	Emissions to fresh water	phosphoric acid	0.32
Emissions to water	Emissions to fresh water	Phosphorus	1
Emissions to water	Emissions to fresh water	Phosphorus	1
Emissions to water	Emissions to fresh water	phosphorus. total	1
Emissions to water	Emissions to water. unspecified	phosphate	0.33
Emissions to water	Emissions to water. unspecified	phosphoric acid	0.32
Emissions to water	Emissions to water. unspecified	Phosphorus	1
Emissions to water	Emissions to water. unspecified	phosphorus. total	1
Emissions to water	Emissions to water. unspecified (long-term)	phosphate	0.33
Emissions to water	Emissions to water. unspecified (long-term)	phosphoric acid	0.32
Emissions to water	Emissions to water. unspecified (long-term)	Phosphorus	1
Emissions to water	Emissions to water. unspecified (long-term)	phosphorus. total	1

Interreg Atlantic Area European Regional Development Fund EUROPEAN UNION

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Table D.3.*Characterizsation factors to assess marine eutrophication as defined in Fazio et al. (2018). *Most recent characterisation factors can be used if available*

Flow class	Sub-compartment	Flow name	ChF
Emissions to air	Emissions to air. unspecified	ammonia	0.092
Emissions to air	Emissions to air. unspecified	ammonium	0.087
Emissions to air	Emissions to air. unspecified	nitrate	0.028
Emissions to air	Emissions to air. unspecified	nitrogen dioxide	0.389
Emissions to air	Emissions to air. unspecified	nitrogen monoxide	0.596
Emissions to air	Emissions to air. unspecified	nitrogen oxides	0.389
Emissions to air	Emissions to air. unspecified (long-term)	ammonia	0.092
Emissions to air	Emissions to air. unspecified (long-term)	ammonium	0.087
Emissions to air	Emissions to air. unspecified (long-term)	nitrate	0.028
Emissions to air	Emissions to air. unspecified (long-term)	nitrogen dioxide	0.389
Emissions to air	Emissions to air. unspecified (long-term)	nitrogen monoxide	0.596
Emissions to air	Emissions to air. unspecified (long-term)	nitrogen oxides	0.389
Emissions to air	Emissions to lower stratosphere and upper troposphere	ammonia	0.092
Emissions to air	Emissions to lower stratosphere and upper troposphere	ammonium	0.087
Emissions to air	Emissions to lower stratosphere and upper troposphere	nitrate	0.028
Emissions to air	Emissions to lower stratosphere and upper troposphere	nitrogen dioxide	0.389
Emissions to air	Emissions to lower stratosphere and upper troposphere	nitrogen monoxide	0.596
Emissions to air	Emissions to lower stratosphere and upper troposphere	nitrogen oxides	0.389
Emissions to air	Emissions to non-urban air or from high stacks	ammonia	0.092
Emissions to air	Emissions to non-urban air or from high stacks	ammonium	0.087
Emissions to air	Emissions to non-urban air or from high stacks	nitrate	0.028
Emissions to air	Emissions to non-urban air or from high stacks	nitrogen dioxide	0.389
Emissions to air	Emissions to non-urban air or from high stacks	nitrogen monoxide	0.596
Emissions to air	Emissions to non-urban air or from high stacks	nitrogen oxides	0.389
Emissions to air	Emissions to urban air close to ground	ammonia	0.092
Emissions to air	Emissions to urban air close to ground	ammonium	0.087
Emissions to air	Emissions to urban air close to ground	nitrate	0.028
Emissions to air	Emissions to urban air close to ground	nitrogen dioxide	0.389
Emissions to air	Emissions to urban air close to ground	nitrogen monoxide	0.596
Emissions to air	Emissions to urban air close to ground	nitrogen oxides	0.389
Emissions to water	Emissions to fresh water	ammonia	0.824
Emissions to water	Emissions to fresh water	ammonium	0.778
Emissions to water	Emissions to fresh water	nitrate	0.226
Emissions to water	Emissions to fresh water	nitrite	0.304
Emissions to water	Emissions to fresh water	nitrogen. total	1

This project is co-financed by the Interreg Atlantic Area Programme through the European Regional Development Fund (EAPA_576/2018 –NEPTUNUS)

Emissions to water	Emissions to water. unspecified	ammonia	0.824
Emissions to water	Emissions to water. unspecified	ammonium	0.778
Emissions to water	Emissions to water. unspecified	nitrate	0.226
Emissions to water	Emissions to water. unspecified	nitrite	0.304
Emissions to water	Emissions to water. unspecified	nitrogen. total	1
Emissions to water	Emissions to water. unspecified (long-term)	ammonia	0.824
Emissions to water	Emissions to water. unspecified (long-term)	ammonium	0.778
Emissions to water	Emissions to water. unspecified (long-term)	nitrate	0.226
Emissions to water	Emissions to water. unspecified (long-term)	nitrite	0.304
Emissions to water	Emissions to water. unspecified (long-term)	nitrogen. total	1