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Handbook for green house gas assessment of seafood products

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ABSTRACT
This handbook explain the basic method behind a GHG assessment of seafood products and how simple assessments can be performed. It provides examples of important climate aspects in seafood production systems. The handbook also point to important resources for those that want to perform GHG assessments of seafood products.

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Norsk innledning

Denne håndboken gir en innføring i viktige metodiske valg i klimaregnskap av sjømatprodukter og eksempler på hvordan et slikt klimaregnskap kan gjennomføres.

På samme måte som et økonomisk regnskap bokfører hvordan verdier går inn og ut og genereres i en verdikjede så bokfører et klimaregnskap hvordan utslipp og forbruk av energi og materialer forårsaker utslipp av klimagasser. Der hvor det økonomiske regnskapet bruker økonomiske data så bruker klimaregnskap fysiske data som masse og energi. Et klimaregnskap bokfører ikke bare utslipp direkte fra verdikjeden, men også alle utslipp som oppstår i produksjon og distribusjon av de innsatsfaktorer som underbygger verdikjeden.

Metodikken i et klimaregnskap kalles for livsløpsanalyse – Life Cycle Assessment (LCA) på engelsk. LCA metodikken er standardisert av ISO i deres 14 00 serie for miljøstyring. Med grunnlag i denne er det utviklet flere standarder og retningslinjer for klimaregnskap av produkter og bedrifter. Spesielt viktige for sjømat er den britiske standarden PAS 2050:2 og den norske standarden NS 9418 for klimaregnskap av sjømatprodukter (se kap. 1.3).

Klimaregnskap og LCA er metoder som involverer at den som utfører regnskapet må gjøre metodiske valg og antagelser i henhold til formålet med regnskapet. Disse valgene kan ha stor innvirkning på sluttresultatet. Igjen kan man dra parallellen til økonomi: Man velger ulik metodikk etter hva som er formålet med analysen. Er det å levere et regnskap for å dokumentere hvordan det gikk, eller er det en analyse for å vurdere potensiell lønnsomhet til ulike teknologiske løsninger og strategier? Siden den etablerte LCA metodikken og dens standarder åpner for metodiske valg er det viktig at den som bruker og bestiller klimaregnskap har en forståelse av den grunnleggende metodikken. Ikke nødvendigvis for å kunne gjennomføre regnskapet selv, men for å kunne bestille et regnskap som passer formålet og for å kunne bruke kunnskapen fra klimaregnskapet på en ansvarlig måte. På samme måte som at en bedriftsleder må forstå den grunnleggende metodikken, begrensninger og antagelser bak økonomiske data som benyttes i beslutningsprosesser.

Dette er håndbokens innhold:

- Introduksjon til LCA metoden og viktige klimaspekter i sjømatens verdikjede
- Regnskapsmetoden: Mål og omfang, datainnsamling og beregninger
- Eksempel på gjennomføring av enkelt klimaregnskap av sjømatprodukt, med likninger
- Eksempler på nyttige ressurser for metoden, data og klimaspekter for sjømat.

Ambisjonen med denne håndboken er at den skal utvides og forbedres, vi hører gjerne fra deg om innspill.

Assessing greenhouse gas emissions of seafood products – The elevator pitch

What do we mean by greenhouse gas emissions of seafood products? Sourcing, manufacturing, transporting and consuming seafood products depend on a range of material and energy inputs. In turn, these practices result in a number of impacts, including the release of carbon dioxide and other 'greenhouse gas' emissions, considered to contribute to climate change. Assessing greenhouse gas emissions in seafood products concerns quantifying these impacts as they are generated throughout the product life-cycle.

Why assess greenhouse gases of seafood products? Assessment will identify improvement options in the production and consumption of seafood that helps reducing impacts. Options may include incremental improvements in the product chain (product development, efficiency of operating equipment) but also strategic improvements (fish sourcing, moving into new markets). Assessment can also support documentation and communication of the environmental performance of the product.

How can greenhouse gases of seafood products be assessed? Greenhouse gases in seafood products can either be assessed internally (as a self-assessment by the company) or externally (by academic researchers or consultants). Regardless of who undertakes the assessment, the following steps are generally undertaken:

1. Draw up a diagram of the entire product chain and identify the parts of the chain you need to assess, based on the goal of the study. This diagram establishes the product system to be assessed. This system provides a map, and a set of boundaries, for the remaining work. It is also useful for explaining the assessment to others.

2. Identify a useful unit for the assessment. The unit requires an exact definition of the product to be assessed, for example an assessment of a *chilled cod fillet*. The definition of this unit should include the quality and packaging of the product.

3. Broadly identify the most important sources for greenhouse gas emissions in the system, its known climate aspects. Previously published assessments of seafood products can be useful in doing this.

4. Identify how the inputs of energy and materials to the processes in the system can be quantified. Inputs can be quantified using data from within the system, and using external data (data from other systems previously assessed, usually in generic LCA databases or published product assessments).

5. Collect the data required for the assessment. This should focus on the most important sources of greenhouse gas emissions in the system first, and extending to other parts of the system as necessary.

6. Perform the assessment and document the results, the method used and any limitations.

Figure 1-1 illustrates the most important elements of a simple greenhouse gas assessment of a caught seafood product (in this case a *fish fillet*) and the story behind the calculation.

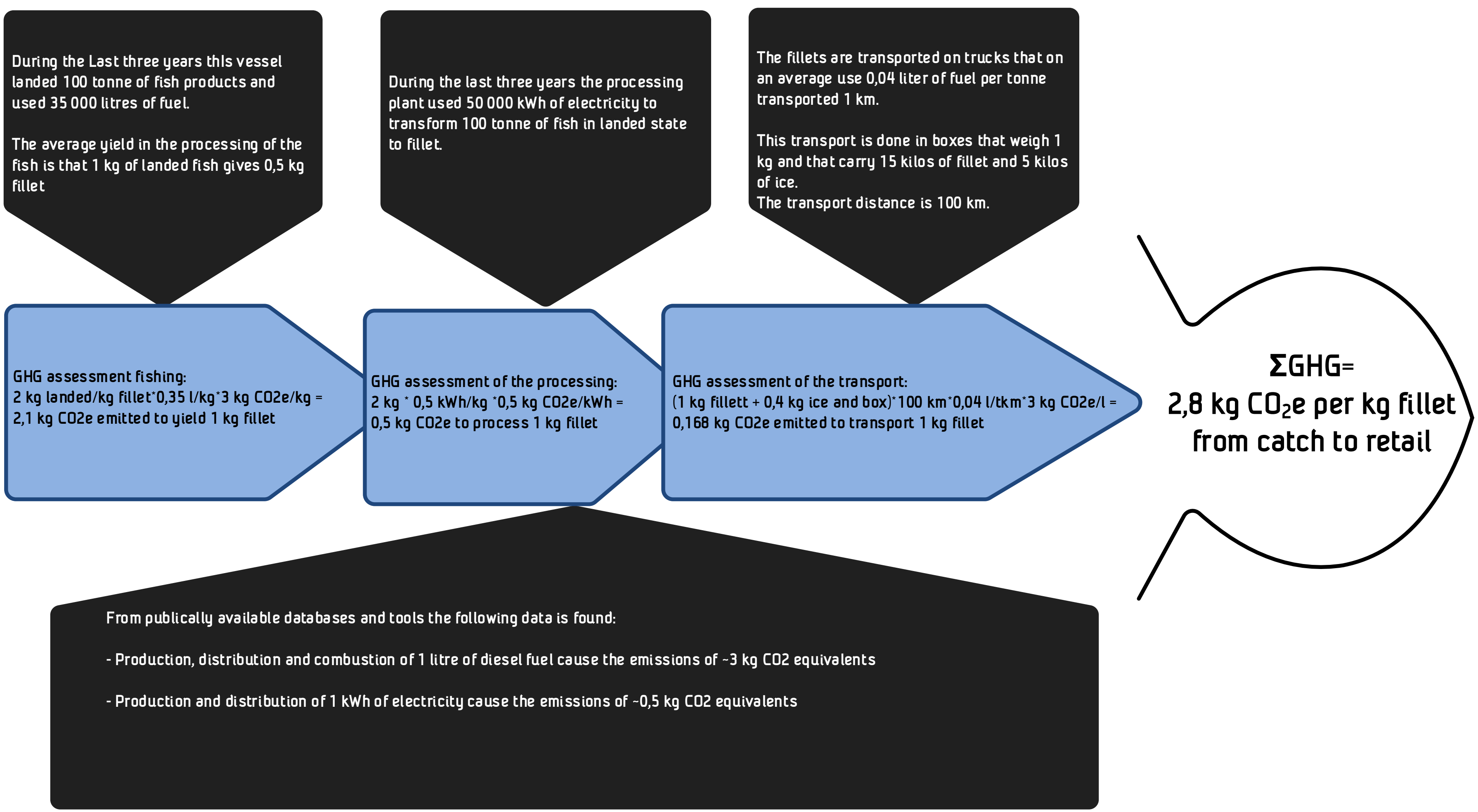

Figure 1-1 Simplified picture showing some important inputs and calculations in the GHG assessment of 1 kg fish fillet originating in capture fisheries and followed from the fishery to the retailer gate. This figure does not cover all the important climate aspects.

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About this handbook – readers guide

The aim of this handbook is to explain the basics of how a GHG assessment of a seafood product can be performed and how GHG assessments can be used in the seafood industry, to reduce GHG emissions from seafood production. The handbook contains the following chapters:

1) Introduction to the life cycle assessment (LCA) method. This covers the basic method of a GHG assessment and examples of important climate aspects of caught and aquaculture seafood products

2) Methodological choices. A walkthrough of the most important methodological choices that a GHG assessment includes and examples of useful data and data sources.

3) Assessment examples. Simplified examples of GHG assessment of seafood products from fisheries and aquaculture with a calculation setup are provided.

4) References and links to useful resources.

Important terms

Allocation	Partitioning of environmental impacts from a production system that give more than one product.
Carbon dioxide equivalent (CO2e)	Unit for comparing the radiative forcing of a greenhouse gas to carbon dioxide
Climate/environmental aspect	Element of an organization's activities. Products or services that can interact with the environment (ISO, 2006)
Emission factor	An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant[1]. Sometimes this expression is also used for the complete carbon footprint of a product or activity.
Functional unit	Quantified performance of a product system for use as a reference unit (ISO, 2006)
Global warming potential (GWP) (= Carbon Footprint)	Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere compared to that of CO2[2]. The GWP is the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide. GWP is also sometimes used to express the carbon footprint of a product, then it is actually the sum of different GHG emissions.
Greenhouse gases (GHGs)	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds
Life cycle assessment (LCA)	Compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle
System boundary	Set of criteria specifying which unit processes are part of a product system
Unit process	Smallest portion of a life cycle for which data are analysed when performing a life cycle assessment
Carbon footprint	The results of a GHG assessment. Accumulated sum of GHG emissions expressed in CO2 equivalents per unit of activity or product (the functional unit).

[1] http://www.epa.gov/ttn/chief/ap42/
[2] http://en.wikipedia.org/wiki/Global-warming_potential

1 Introduction

A greenhouse gas assessment (GHG assessment) of a product is a means to account for the climate impact that a product causes across its life cycle, from "cradle to grave". Just as economic assessment book keep how values goes in and out of a system and is generated, the GHG assessment book keep the global warming potential caused by in and outputs of substances and energy to the system.

The GHG assessment does not only include emissions directly from the value chain of the product, but also from the production and distribution of material and energy commodities and infrastructure that underpins the products life cycle.

The results of a GHG assessment is often referred to as the carbon footprint (CF) of the product.

The existing standards for LCA and GHG assessment involve some degrees of freedom for the practitioner to make methodological choices according to the aim of the assessment. To continue the economic parallel: Is the purpose to document how last year went to a third party? Or is the purpose to evaluate the profitability of different technology solutions or strategies. For sure, these two purposes would require different types of economic assessments.

The methodological choices in a GHG assessment potentially influence the results considerably, this requires that responsible use of GHG assessments understands is based on a understanding of the fundamentals of the method. Just as a decision maker in a business have to understand the methodology and its inherent limitations and assumption for economic assessments.

The scope of the current version of the handbook includes seafood products from both capture fisheries and aquaculture. Given the Norwegian/European/Northeast Atlantic context of this handbook the examples that are presented are mainly derived from Northeast Atlantic fisheries and salmon aquaculture. The handbook follows the value chain of the products from fishing and production of feed ingredients through to product delivery to retailer.

1.1 The LCA method

The method that is used for the GHG assessment is that of Life Cycle Assessment (LCA)[3], but while a LCA should include a complementary set of environmental impacts a GHG assessments only includes the potential climate impacts that the products causes. LCA is standardized by ISO in their ISO 14 000 family[4] on standards for environmental management.

1.2 How can you use GHG assessment?

A company can approach an assessment in at least two different ways:

- The first is for the company to perform assessments themselves. This will often be simplified assessments performed as a part of an internal and external reporting and management system.

- The second and by far the fastest and most common, is to undertake an assessment with the support of LCA professionals with knowledge of the established standards, tools, and data specific to the

[3] Link to more info on the LCA method from the EC Joint Research Centre: http://eplca.jrc.ec.europa.eu/
[4] Link to the ISO web page for their 14 000 standards: www.iso.org/iso/home/standards/management-standards/iso14000.htm

seafood sector. This will ensure that the results are in accordance with the existing standards and it is efficient since LCA professionals should have access to recognized data sources.

Either way, the commissioning and responsible use of the results of a GHG assessment requires that the user of the assessment results, e.g. decision makers in the company, has a clear understanding of the most important methodological aspects of the assessment. As stated previously, the results can be highly influenced by the methodological choices done in the assessment.

1.3 Climate aspects of seafood production

The world of seafood products is wide and extensive. Products are drawn from wild capture and from aquaculture production. Production systems can be localised with relatively short supply chains, but can also be global and reliant on international supply chains. These different practices have a bearing on climate impacts of seafood products.

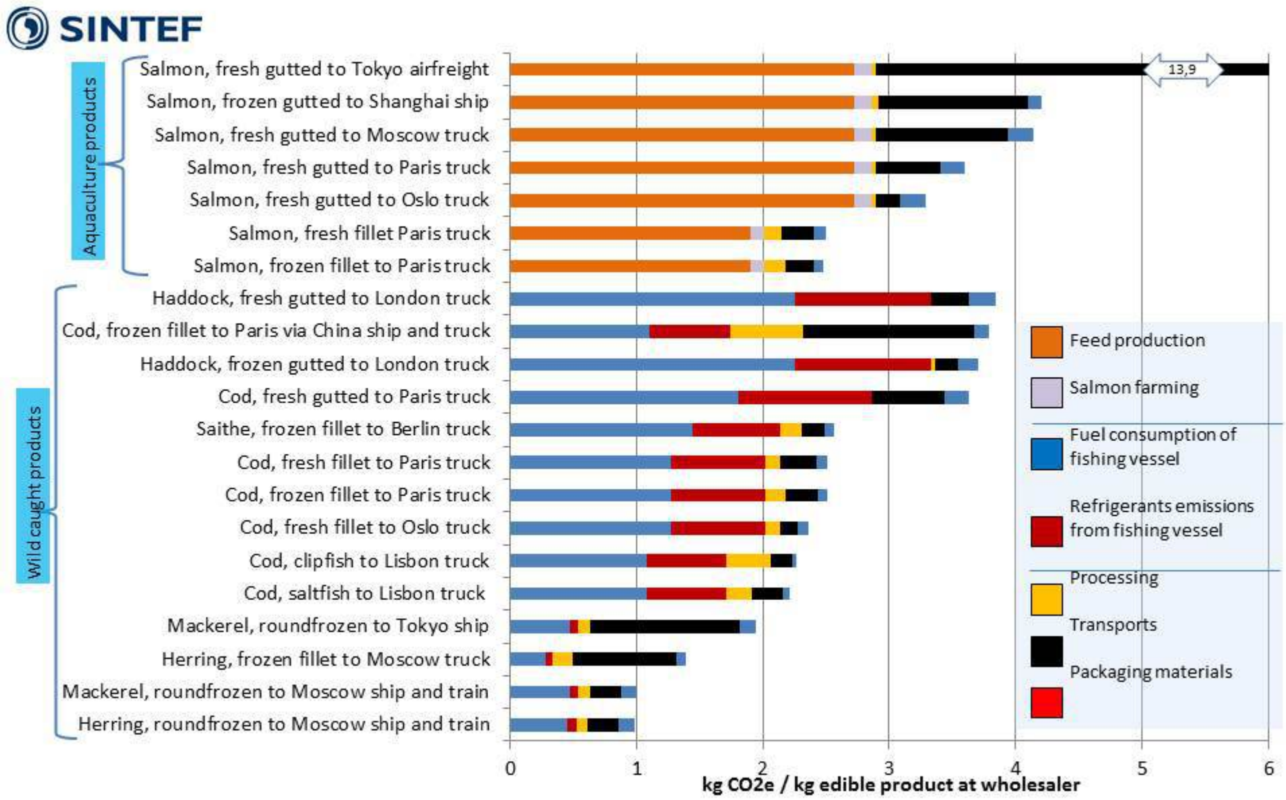
The studies of climate impacts of European seafood products published to date suggest some important and general conclusions; these are often also valid for seafood production in other parts of the world[5]:

- For products from wild capture fisheries fuel consumption and emissions from the refrigeration systems used on board the fishing vessels are the most important sources of GHG emissions
- For products from aquaculture feed production (fishing/growing of feed ingredients, feed processing and feed transport) is the most important contributor
- In addition to these two general findings, it is also clear that transportation can play an important role, especially when fresh products are transported by air.

A number of GHG assessments of seafood products have been undertaken by industry. Examples include Norway (by SINTEF and SIK) and the United Kingdom (by Seafish and Dalhousie University). **Figure 1-1** presents the results of a GHG assessment of a selection for Norwegian seafood products from fishing and feed production through to product delivery to retailer in various markets and with different modes of transport.

See chapter 4 for guidance to more literature on the climate aspects of seafood products and LCAs.

[5]References: (A. Avadí & Fréon, 2013; A. Avadí & Vázquez-Rowe, 2014; Á. Avadí, Vázquez-Rowe, & Fréon; Ayer & Tyedmers, 2009; Driscoll & Tyedmers, 2010; Ellingsen & Aanondsen, 2006; Hospido & Tyedmers, 2005; N. Pelletier & Tyedmers, 2007; Nathan Pelletier & Tyedmers, 2008, 2010; Schau, Ellingsen, Endal, & Aanondsen, 2009; P. Tyedmers, 2001; Peter Tyedmers, 2004; P Tyedmers, Watson, & Pauly, 2004; Ziegler & Valentinsson, 2008)



Accumulated sum of GHG emissions caused by producing, processing and transport 1 kg edible product of different Norwegian seafood products to different markets. From the report "Carbon footprint and energy use of Norwegian seafood products" by SINTEF and SIK. Full report here: **ww.sintef.no/miljoregnskap-sjomat**

Figure 1-1 Result of GHG assessment of Norwegian seafood products. Note that the first case, fresh gutted salmon to Tokyo by airfreight has a total of 13.9 kg CO_2e/kg edible product.

1.4 GHG assessment standards

Those that perform the assessment should use available and recognized standards for life cycle assessment (LCA) and GHG assessment, but while standards provide clear guidelines for how a GHG assessment should be performed and communicated, these standards do not always provide an explanation of the practicalities and challenges encountered in following these guidelines. This handbook is intended to bridge this gap.

Among many recognized and relevant standards, two are specific for GHG assessment of seafood products.

- BSI PAS 2050-2:2012 Assessment of life cycle greenhouse gas emissions. Supplementary requirements for the application of PAS 2050:2011 to seafood and other aquatic food products by British Standard Institute (BSI, 2012).[6].
- NS 9418:2013 Carbon footprint for seafood - Product category rules (CFP-PCR), Developed by Standards Norway (SN, 2013). This is the only one published in Norwegian.

[6] Link to the BSI web page: http://shop.bsigroup.com/en/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2050/PAS-2050-2/

There are a number of GHG assessment and LCA standards that have been developed and that can be used by *all industry sectors*.

The international standardization organization (ISO) have the most widely used standards for LCA in their ISO 14 000 family for environmental management. This series of standards cover how LCAs can be used, performed, communicated and audited. The newest member to this family is the ISO 14 067 specifying principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product. The ISO 14 000 standards have formed the basis for many sector and/or impact specific standards.

The World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD) developed their “GHG protocol standards” for GHG assessment of businesses (activities) and products. The corporate standard offers methodologies for business and other organizations to quantify and report GHG emissions from their business activities and operations. The products standard enables companies to measure the greenhouse gases associated with the full life cycle of products including raw materials, manufacturing, transportation, storage, use and disposal. These standards are accompanied with guidelines, tools and datasets to facilitate the assessments.

The British Standards Institute developed a publically available specification for GHG assessment of goods and services, the PAS 2050. This guideline is today one of the most applied standards for GHG assessment and products globally.

Although the standards and guidelines presented in this chapter provides substantial support to those wishing to produce a GHG assessment of seafood products, a number of challenges remain in undertaking assessments of seafood products. The following sections of this handbook will consider these challenges and provide additional guidance.

2 Assessment Methodology and Data

This section presents the purpose and potential effects of the most important methodological choices that a GHG assessment includes. Chapter 3 provides examples of how simple GHG assessments can be performed.

Much of this material is extracted from the “ILCD Handbook: General guide for Life Cycle Assessment – Detailed guidance” by the European Commission Joint Research Centre.(EC-JRC, 2010)

The assessment can be divided into four main activities (also se **Figure 2-2**):

1. Goal - and scope: Identifying purpose and target audience and what to analyze and how
2. Life cycle inventory analysis: collecting data and modeling the systems/life cycle.
3. Impact assessment: Calculating the results
4. Interpretation: Identifying hot spots and reporting

Those that commission and only use GHG assessment results as input in decision making processes should at least be a part of the first steps, to make sure that they have a clear understanding of how the results can be used responsibly, and to ensure that the assessment is performed in a way that matches the goal of the commissioner.

A LCA study is an iterative process: once the goal of the work is defined, the initial scope settings are derived that define the requirements on the subsequent work. However, as during the data collection and during the subsequent impact assessment and interpretation more information becomes available, the initial scope settings will typically need to be refined and sometimes also revised. Often it can be wise to perform a screening assessment as soon as some data is in place even if they are uncertain and some data is missing. The output of such a screening assessment will be of high value to give guidance to which data should be documented with higher precision and certainty. This will ensure that the available resources are used on the most important part of the assessment. Figure 2-1 presents an illustration of the iterative work flow in a LCA.

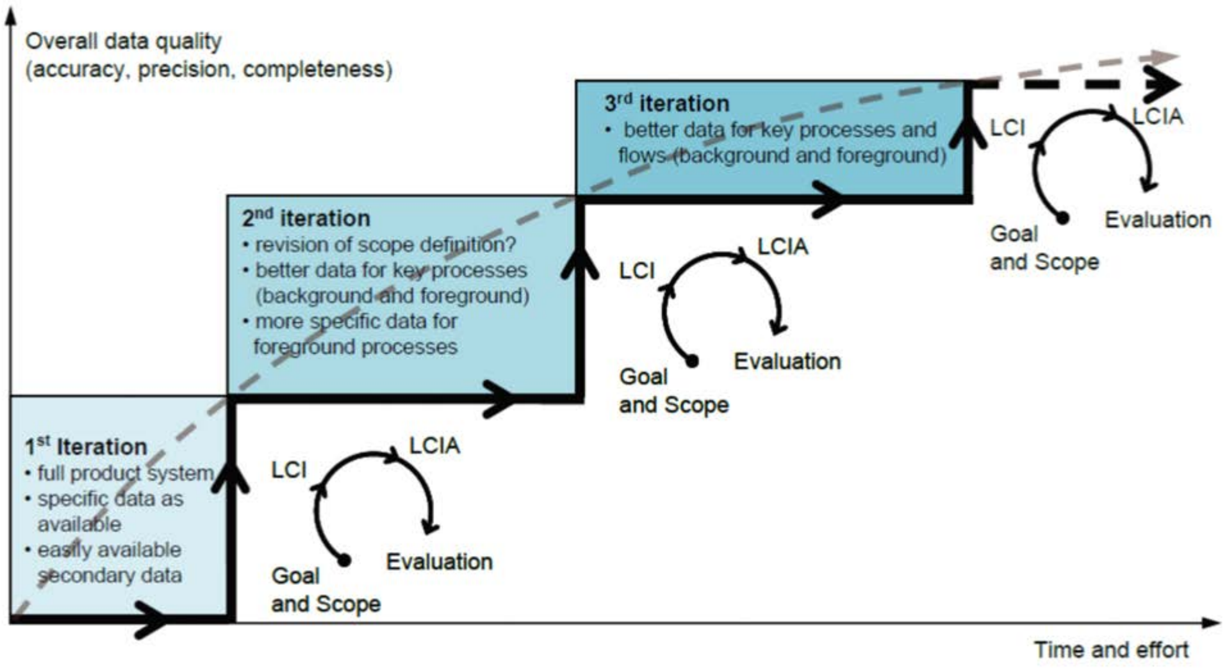


Figure 4 Iterative nature of LCA (schematic). LCAs are performed in iterative loops of goal and scope definition, inventory data collection and modelling (LCI), impact assessment (LCIA), and with completeness, sensitivity and consistency checks (Evaluation) as a steering instrument. This is done - with a possible, limited revision of the goal and scope - until the required accuracy of the system's model and processes and the required completeness and precision of the inventory results has been attained.

Figure 2-1 Illustration of the iterative LCA work flow from the ILCD handbook (EC-JRC, 2010)

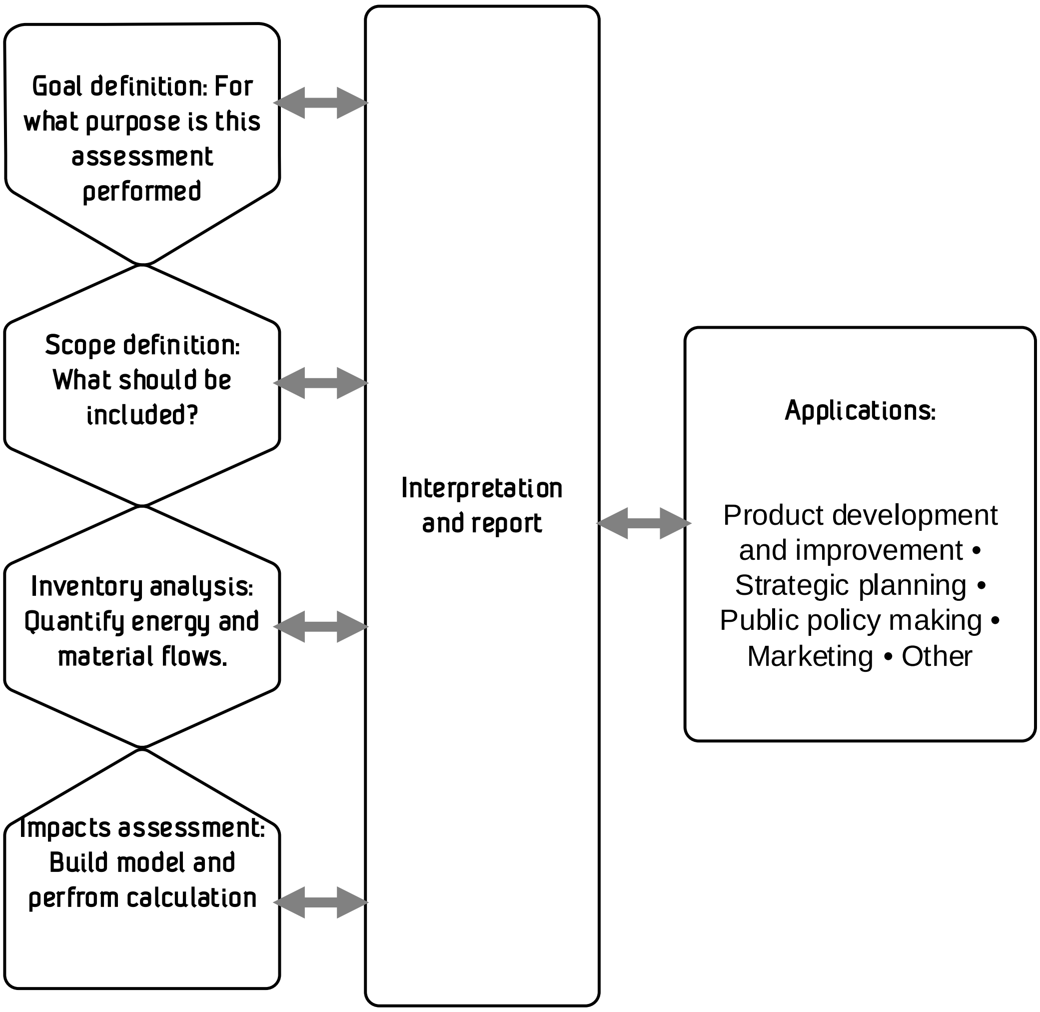


Figure 2-2 The phases of a GHG assessment/LCA

2.1 Goal definition – identifying purpose and target audience

The first step of a GHG assessment is to define the aim of the assessment, this includes:

› Why is it performed? Explain the reasons for carrying out the assessment. Identify the drivers and motivations

› Who will use the results? State the targeted audience of the assessment results. Identify the decision-context in which the results will be used

Examples
- Reasons: To provide documentation to retailer, compare food products and use for internal strategic development and product development
- Driver and motivation: Marketing, fulfil reporting requirements and internal wish to achieve cleaner production
- Decision context: compare products, identify and evaluate improvement options in production system
- Targeted audience: Retailer and business decision makers

It is important to recognise that the goal of the assessment can have an important bearing on the precision required in the assessment and the scope, what should be included that is. If the goal is to make commercial claims, e.g. "my product is better than yours" then a more precise and complete assessment is required. If the aim is "I wish to learn more about the most important climate aspects and improvement options of my product" a much rougher assessment is probably enough.

If the assessment is intended to compare two products and results will be made public this entails a number of additional mandatory requirements under ISO 14 040 and 14 044 (ISO 2006a, b). The standard covers the performance/undertaking, documentation, review and reporting of the LCA study due to the potential consequences the results may have for other stakeholders e.g. external companies, institutions, consumers, etc.

2.2 Defining the scope – What to analyse and how

This phase of the assessment specify exactly what product that is assessed and what part of its life cycle that should be included.

2.2.1 The functional unit – What specific product is to be assessed

The functional unit defines the specific product[7] to be assessed and it should reflect the function of the product, in the case of seafood, the function is to deliver a tasty and nutritional type of food. It forms the fundamental unit for the assessment and is the unit against which all the material and energy flows in the system is measured. The functional unit should also specify what quality the product has, this can e.g. be that it is intended and appropriate for human consumption, but also if it is chilled or frozen.

A typical functional unit for seafood products is: "1 kg of edible product at the retailer gate (with accompanying consumer packaging)".

2.2.2 System boundary – What is included in the assessment

The system boundary defines what is included in the assessment. It is important that the system boundary reflects the aim of the assessment, therefore this is the time to establish which emissions, commodities and processes should be included and how precise the data needs to be.

When discussing and understanding the system boundaries it can be helpful to divide them into two dimensions:

- The vertical system boundaries defines what part of the life cycle that is included in the assessment.
- The horizontal system boundaries defines what in and outputs from the life cycle is included.

[7] The functional unit can also be a service or an activity, but in this context, we look at products.

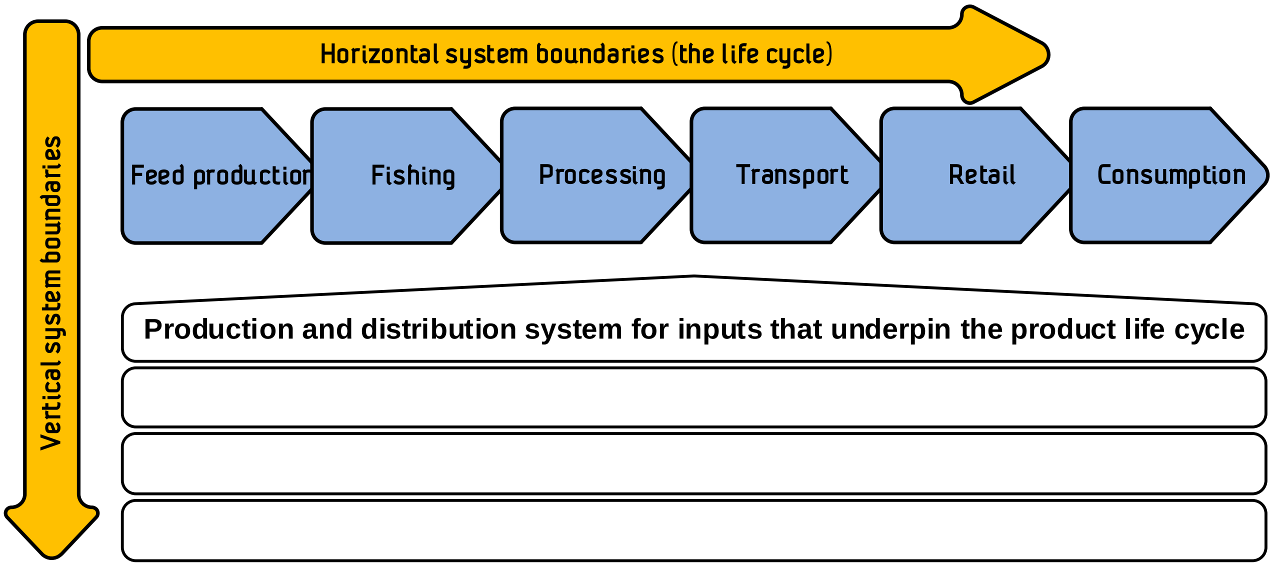


Figure 2-3 Suggestion for how system boundaries can be discussed in being horizontal or vertical

When the GHG assessment and the LCA method is described it is often said that the complete life cycle of a product, from cradle to grave, is include. To cover the complete life cycle should always be the ambition of the LCA, that is the only way to make sure that the whole and complete understanding of the environmental properties of the product is understood, but in practise most assessment are often performed as “cradle to gate”: For seafood this can be from fishing and production of feed ingredients and up to retailer gate. Still, such assessments will not cover very important climate aspects such as shelf life. How much is actually consumed that is. So selecting certain parts of the life cycle of a product for the GHG assessment is often done, but then it is especially important to map the climate aspects that are not covered quantifiably. The GHG assessment practitioner must be very precise on what is included in the assessment, but must also explain what potentially important climate aspects that are not included.

The vertical system boundaries needs to be wide enough to make sure that all important climate aspects of the products in captured and that potential effects of changes in its life cycle will be captured by the assessment. At the same time the system boundaries needs to be set so that the assessment is possible to perform. Endless system boundaries equals endless amounts of data to model the system and endless effort. It is wise to study published studies of similar products to see what system boundaries that is considered a minimum to match the goal of the study.

The following approach is suggested:

1. Draw a map of the products life cycle from fishing/farming to the retailer where the chain is divided into unit processes.**Figure 2-4** gives a good starting point. A unit process is simply a clearly defined part of the production system that is studied, e.g. “fishing”, “transport” and “processing”. Dividing the system into unit processes is necessary to structure the data collection and calculations and finally to be able to quantify the contribution from each part of the production system. Each unit process must be quantitatively linked to the functional unit of the assessment and it must be possible

to quantify the inputs and emissions associated with each unit process required to deliver the functional unit.

2. Identify which stages of the production chain are expected to generate the most climate impact. For example, are there stages requiring major inputs of electricity; fuel and materials? There is often a link between costs and environmental impacts: If a stage has significant costs this is probably also an important place for the GHG assessment. Published assessments can also be helpful to identify important climate aspects associated with the product. Chapter 4 provides references to reviews and links to literature resources. Literatuer will also help you make sure that your system boundaries includes the important unit processes

3. Indicate the important mass and energy in- and outputs of each unit process. This means use of raw materials, energy and other inputs and generation of products, waste and emissions leaving each unit process

4. Finally, quantify the mass and energy flows that have been identified. This activity is often refeered to the life cycle inventory phase, see chapter.

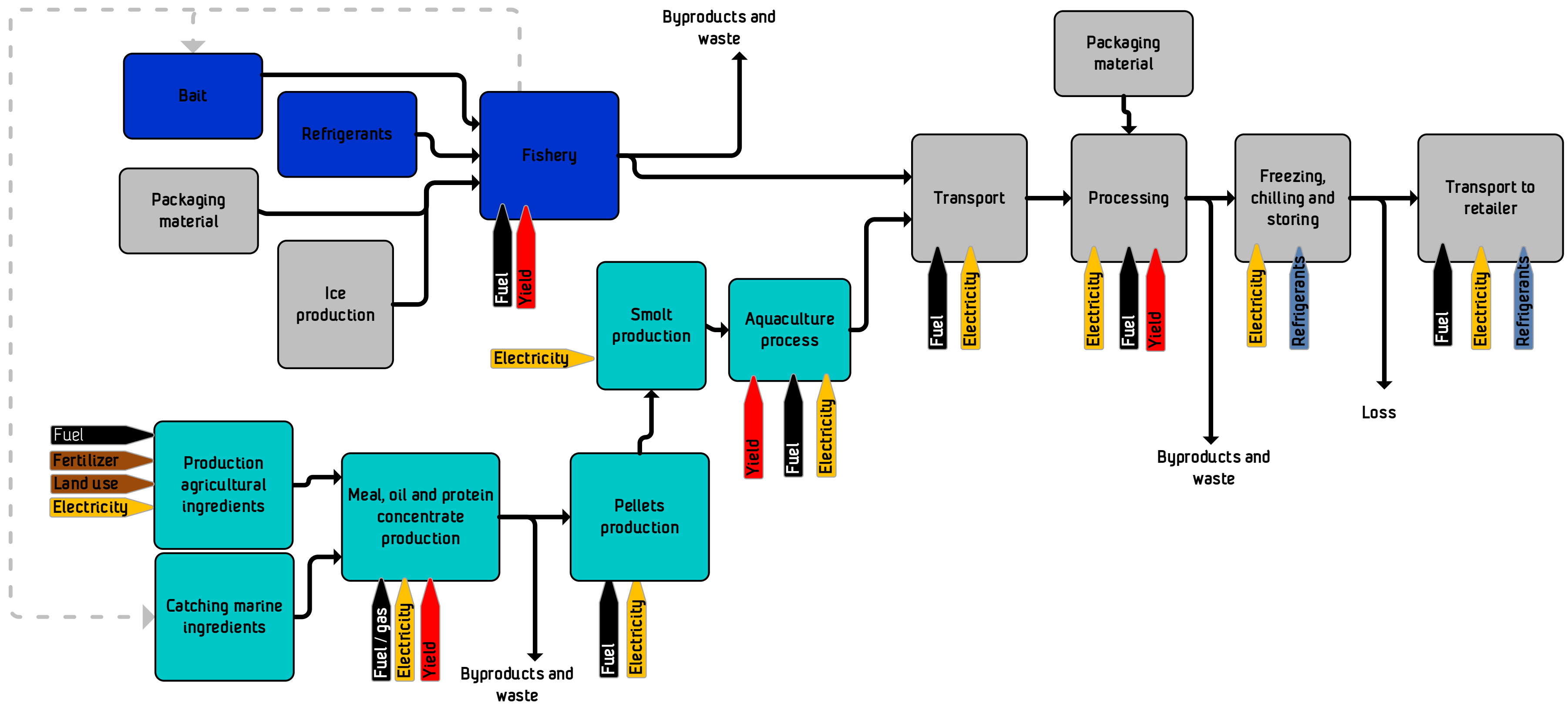


Figure 2-4 Example of flow chart for seafood production and distribution system from field and water to retailer gate. Direct emissions from the processes not included in this flow chart. The expected important mass and energy flows are indicated.

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A useful categorization when presenting and discussing the system is:

- Upstream process: all inputs of mass and energy *to your business*
- Downstream process: all outputs of mass and energy *from your business* including the remaining part of your products life cycle.

This means that each unit process in the life cycle will have their own up- and downstream processes, and one unit process will be the upstream and the downstream process of another unit process.

For example: in **Figure 2-4** the upstream process for the fish processor will be everything on the left side (fishery, landing and transport to processing plant) and downstream everything on the right side (transport to and activities at the wholesaler, retailer and in the consumer phase including waste treatment).

GHG assessment of seafood products often includes the life cycle of the product from:

- Farming and fishing of feed ingredients to retailer for aquaculture products
- From fishing to retailer for caught products.

2.3 System inventory analysis – modelling and data

Modelling the system/life cycle can be thought of the phase where the quantitative understanding of the production system is translated into a system of equations and a structure to put in the data to make the final equation. In other ways this is the phase where the flow chart produced while deciding the system boundaries are turned into a mathematical model. Very often this is done in Excel or built for purpose programs such as Siampro[8]. The process of drawing the process flow chart is thus an important part of the modelling of the system.

The data collection is often the most resource demanding part of a GHG assessment. It is therefore critical that published assessments, standards and the examples and introduction chapters of this handbook are used to ensure that data collection efforts are directed at the most important GHG sources.

In short the data collection for a GHG assessment of a seafood product involves:

1. Quantifying energy and material inputs required by each unit process (e.g. fuel, electricity and materials).
2. In addition, emission factors are required for each of these inputs. An emission factor is the amount of greenhouse gases emitted, expressed as CO_2 equivalents per unit of activity or product. Life cycle inventories and databases can support this task.

The data in a GHG assessment can be divided into two main categories:

- Specific data. This is the data that is expected to be of especial importance and thus gathered specifically for the product that is studied OR it can be process for which it not found generic data or data from renowned LCA data sources.

[8] Link to Simapro web page: www.pre-sustainability.com

- Background/generic data. These are the data that also play an important role, but because they are generic may have already been quantified by others (e.g. in previous studies). Established LCA databases and recommended GHG assessment data from acknowledged sources can be used (see chapter 4). Typical generic data are emission factors for common commodities such as production of fuel and electricity,

A common approach to data collection is to start with the most accessible data, that is often a generic database, to perform a screening assessment and then to use this screening to evaluate which data should be more precise, either by adjusting database data or collecting specific data (see Figure 2-1).

2.3.1 Allocation – how to handle processes with multiple outputs

When a process has several outputs, then the emissions from all processes up to that stage and from that stage, needs to be shared between the different outputs. Typical multiple output processes are:

- Fishing, delivering both the targeted species and landed by-catch species , headed and gutted fish and by-products (guts, blood and cut offs)

- Processing: Delivering several types of edible products, such as different types of fillet, mince non-edible parts such as trimmings

Sharing the environmental impacts between products from multi output processes is called "allocation".

Allocation refers to sharing/splitting emissions across multiple outputs. Allocation requires some kind of quantitative relation to be established. There are several ways and two that are often used for seafood products are:

1. Mass allocation. The split is done based on the mass ratio of the products.

2. Economic allocation. The split is done based on the relative economic value of each output.

> You must decide what type of allocation method that you want to use when modelling your system since this will influence what data that is needed and how you divide your production system into unit processes.
> The current standards for GHG assessment of seafood products (British and Norwegian standards) recommend the use of mass allocation which is what is used in the examples in chapter 3.

2.4 Impact assessment – calculations

This is the stage where the data on emissions and energy and material use in the production systems is combined with emission factors and characterization factors to form the final carbon footprint.

Emission factor can be generic data that is found in LCA databases on the carbon footprint of commodities, E.g. the carbon footprint of producing, distributing and using one unit of fuel can be found in these databases

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(see chapter 4.3). Be aware that the term emission factor can also refer to the mass of a specific substance per unit of activity, e.g. it can be the emission of CO_2 from a car exhaust pipe per litre of fuel combusted.

Once the sum of different GHG emissions is calculated each one of them is calculated into CO_2 equivalents. Methods provided by e.g. the International Panel on climate change provide what is called characterization factor that translate specific GHG emissions into CO2 equivalents based on their physical and chemical properties such as lifetime and radiative properties (IPCC, 2007).

Chapter 3 gives a more concrete example of how simple carbon footprint are actually calculated.

3 Step by step guide for GHG assessment

This section presents an example of how a simple GHG assessment of a product from capture fisheries and one from salmon aquaculture. For each step in the production chain (unit process), the most important climate aspects are presented followed by a suggested calculation setup.

In this simplified example, it is assumed that the only difference between the fished product and the salmon aquaculture product are the stages of the production chain up to processing.

First the aim and scope of the assessment must be clearly defined:

- The aim of the assessment is to identify important climate aspects in the production chain of the product. The results will be used for internal improvement and strategic decisions.

- The functional unit (FU) for the assessment will be '1 kilo of edible product (skinless fillet), at the retailer gate'

- Mass allocation is used, i.e. when processes yield several different products the climate impacts up to that point will be shared among these products according to their mass.

- System boundaries: The assessment includes processes in the life cycle of the fillet from fishing and until it is delivered to the retailer. All relevant inputs of energy and substances is covered by data from a complete cradle to gate assessments.

3.1 Fishing

The most important GHG sources from the fishing activity is the use of fuel and ice and/or emission of refrigerants. In addition to this the use of packaging, bait, fishing gear and construction of the vessel may also be important, but are not included here.

3.1.1 Fuel use

Quantify the volume of fuel spent and the weight of landing for a defined period of time as well as the fate of non-edible by-products generated both at sea and, later, on land.

- It is important that the fuel volume includes *all* fuel spent over that period, also fuel that is spent on non-fishing activities, but that is needed to perform fishing activity: Steaming to and from fishing fields, maintenance, harbour activities etc.

- To make sure that different seasons, weather conditions, gear use etc. are captured the fuel consumption should make sure to be an average for a time periode including all of these variations

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and the different activities mentioned in the previous point. For special purposes, e.g. to compare two fishing gears this must off course be considered.

- The mass of fish landed should include everything that is landed and somehow utilized, i.e. also non-edible parts such as guts blood, cut offs etc. that are used for other purposes than direct human consumption.

- $$F_{fuel} = \frac{litres\ of\ fuel\ spent\ over\ time\ periode\ t_f}{kg\ of\ fish\ landed\ over\ time\ period\ t_f} = \frac{l\ fuel}{kg\ landed}$$

3.1.2 Ice

Climate impacts from the use of ice produced on shore mainly arise from the energy used to produce the ice. The assessment needs to 1) quantify the mass of ice used by the vessel for a defined period and 2) quantify the electricity spent on producing ice. Many vessels will produce ice on board, if that is the case make sure that the fuel consumption (3.1.1) and the refrigerants emission per mass landed (3.1.3) includes this production.

- $$F_{ice} = \frac{Kg\ of\ ice\ spent\ over\ time\ periode\ t_f}{kg\ of\ fish\ landed\ over\ time\ period\ t_f} = \frac{kg\ Ice}{kg\ landed}$$

- $$I_{el} = \frac{kWh\ electrity\ spent\ on\ ice\ production}{kilos\ of\ ice\ produced} = \frac{kWh}{kg\ ice}$$

3.1.3 On board refrigeration system

Identify what kind of refrigerant is used and if it is associated with climate impact. Many modern refrigeration systems use ammonia or CO_2. Even though these refrigerants are also emitted through leaks and accidents they are not expected to be an important climate aspect since the global warming potential of these substances are low. If the refrigerant is R22 or another hydro-chloro-fluoro-carbon (HCFC)[9] gas, the loss must be quantified as even a small emission can have severe climate impact[10]. The global warming potential of R22, commonly used in fisheries, is more than 1 800 times that of CO_2 (per unit of mass) and oth refrigerants such as R404a or R507, which are used to replace R22 (since they don't deplete the ozone layer), typically have a global warming potential of 3-4000 times that of CO_2. See section 3.6 for more global warming potentials for refrigerants. For each refrigerant the mass of refrigerant emitted per mass of fish needs to be decided, this will be the emission factor for the refrigerant.

- $$F_{ref} = \frac{kg\ of\ refrigerant\ refilled\ or\ emitted\ over\ time\ periode\ t_f}{kg\ of\ fish\ landed\ over\ time\ period\ t_f} = \frac{kg\ refrigerant}{kg\ landed}$$

[9] Link to webpage with more info on HCFCs: http://apps.sepa.org.uk/spripa/Pages/SubstanceInformation.aspx?pid=120
[10] Link to webpage with GWP data for HCFCs: http://www.epa.gov/ozone/defns.html

3.2 Salmon aquaculture

The most important input of salmon aquaculture in terms of climate impacts is the production of feed. Therefore, the assessment needs to: 1) quantify the feed conversion ratio (FCR), 2) the carbon footprint of the feed that is used and 3) quantify fuel and electricity spent in the operation of the farm site.

3.2.1 Feed

A feed recipe can easily consist of 20-30 ingredients of varying origin and every input is an entire production system in itself. A GHG assessment of feed production therefore encompasses:

- The use of electricity, fuel and fertilizers used in the growing and fishing of each ingredients
- For agricultural ingredients, the land use change they are associated with must be considered as this leads to biogenic GHG emissions. This is a good example of GHG emissions arising from other sources than fossil fuels. A GHG assessment should include all important GHG sources and sinks.
- Energy used in the process from crop and fish to meal and oil. For these processes the yield will be a very important parameter. E.g. the yield from round fish to meal and oil can vary highly between different species and over time for one species. Since the yield in these processes can play a major role in the final calculations, the precision of these yields should be considered carefully.
- Yield and energy used in the pellets factory, where meal, oil, binding agents, micro ingredients and other additives is turned into pellets.
- Transports from harbour and field to meal/oil factory; to pellets factory and then to the aquaculture site should be included in the GHG assessment of the feed.

Doing all of this can hardly be called a simple GHG assessment. Therefore, in this example it is assumed that the carbon footprint of the feed can be supplied by the feed producer.

The feed conversion ratio is an important parameter and it must be clearly defined exactly what it includes, for the GHG assessment the FCR should represent the total mass off feed delivered to the salmon producer per mass off fish delivered and somehow used, e.g. per mass of salmon sold. This is often called the economic FCR. Another FCR is the biological FCR that says something about how much feed is needed to increase the weight of one salmon with 1 kg. This can be helpful, but in the GHG assessment the mass of feed delivered per mass of fish delivered is what is interesting. Dead salmon, escape and other mass that is not somehow utilized should not be included in the "mass of fish delivered", denominator in this equation:

- $A_{FCR} = \frac{kg\ of\ feed\ used\ over\ time\ period\ t_f}{kg\ of\ fish\ produced\ and\ delivered\ to\ processing\ in\ liwe\ weight\ over\ time\ periode\ t_f} = \frac{kg\ feed}{kg\ fish}$

- $CF_{feed} = Complete\ GHG\ assessment\ of\ the\ feed\ up\ to\ farm\ site = \frac{kg\ CO2e}{kg\ feed} =$

3.2.2 Grow out/farm site

Climate impact from the grow out phase of the fish, the farm site, arises from use of fuel and electricity in the operation and maintenance of the farm and the transport involved. To ensure that all the activities that are necessary to produce the fish is captured it is wise to use average value over a time period that is at least as long as the production cycle. Longer periods should be considered, e.g. 3 years. Many aquaculture producers use sub-contractors to perform net operations and other energy intensive operations, their energy use should be included as well. The sum of fuel and electricity should be defined per mass of fish delivered and somehow utilized:

› $A_{fuel}= \frac{litres\ of\ fuel\ spent\ over\ time\ periode\ t_f}{kg\ of\ fish\ produced\ over\ time\ period\ t_f} = \frac{l\ fuel}{kg\ produced}$

› $A_{el} = \frac{kWh\ of\ electricity\ used\ over\ time\ periode\ t_f}{kg\ of\ fish\ produced\ over\ time\ period\ t_f} = \frac{kWh}{kg\ produced} =$

3.2.3 Smolt production

The assessment of the smolt production is very similar to that of the salmon production. It requires the quantification of the FCR, the carbon footprint of the feed and the use of fuel and electricity. One important difference from the grow out of the salmon is the potentially high input of electricity for water treatment and circulation.

Hatcheries are not considered important contributors to the GHG of products from salmon aquaculture, this due to the hug mass of fish that is derived from each egg.

It is necessary to document how many kilos of smolt that is needed to produce one kilo of salmon. This should be the actual number of smolts that are let into the sea and the mass of fish delivered to slaughter to make sure that losses during the grow out are included.

› $A_{smolt} = \frac{kg\ smolt\ let\ into\ sea}{kg\ of\ fish\ produced\ from\ that\ mass\ of\ smolt} = \frac{kg\ smolt}{kg\ fish}$

› $CF_{smolt} = Complete\ GHG\ assessment\ of\ the\ smolt\ up\ to\ farm\ site = \frac{kg\ CO2e}{kg\ smolt}$

3.3 Processing

Quantify the electricity and fuel spent per mass of fish processed and the total edible product yield and fate of non-edible co-products. Ensure the estimate captures all electricity spent by the processing plant from the actual handling of the fish, e.g. internal transports, storing, ventilation, cleaning and offices.

Input and emissions of refrigerants can also be important to include for the processing. See 3.1.3.

› It is important that all activities that are necessary for the processing plant to operate is included. It should be considered to use data for a longer time periode, e.g. a three-year average.

› $P_{el} = \frac{kWh\ electricty\ used\ by\ factory\ during\ timeperiod\ t_p}{kg\ of\ production\ by\ the\ processing\ plant\ during\ period\ t_p} = \frac{kWh\ electricity}{kg\ produced}$

- $P_{fuel} = \frac{litres\ of\ fuel\ used\ during\ timeperiod\ t_p}{kg\ of\ commercial\ product\ out\ of\ processing\ plant\ during\ period\ t_p} = \frac{l\ fuel}{kg\ from\ processing}$

- The yield here is the ratio between the mass/volume of products from processing utilised in some way and the mass/volume of raw materials processed. For example, when a kilo of product is generated from two kilos of landed fish, the yield would be 0.5.

- $Y_p = \frac{kg\ of\ fish\ into\ processing\ plant}{kg\ of\ fish\ product\ from\ processing\ and\ utilized} = \frac{kg\ landed}{kg\ utilized}$

3.4 Packaging

Different types of packaging are used throughout the seafood production chain, but two that almost all production chains will contain is packaging used in the fishery (and to deliver the fish to processing plant) and consumer packaging (used from processing to retailer). Here we give an example that assumes that the carbon footprint of the box is provided by the producer. However, it should be considered if the assessment should include a more specific assessment of the packaging, especially with regard to how the end of life treatment is performed.

- $m_{pack} = \frac{weight\ of\ one\ unit\ of\ packaging\ in\ kilos}{kg\ fproduct\ per\ unit\ of\ packaging} = \frac{kg\ packaging\ material}{kg\ product}$

- $m_{p.ice} = \frac{Weight\ of\ ice\ per\ box}{Weight\ of\ fish\ in\ each\ box} = \frac{kg\ ice}{kg\ product}$

- $CF_{material} = Carbon\ footprint\ of\ 1\ kg\ of\ packaging\ material$

3.5 Transport

The GHG assessment of transport is concerned with quantifying how much fuel a particular mode of transport burns per kilometre and how much load it carries. Emissions of refrigerants and fuel used to run refrigeration systems should also be included. An alternative to calculate the "T_{fuel}" is to use data on common transport modes from databases, but then the option to be precise on how well utilized the transport capacity is more lost.

- $T_{fuel} = \frac{Litres\ of\ fuel\ used\ for\ distance\ k}{tonnes\ of\ average\ load * distance\ k} = \frac{l\ fuel}{tonn*km}$

3.6 Emission factors

To complete the assessment the different inputs electricity, fuel and material flows identified in the previous steps needs to be multiplied by relevant emissions factors (with values for the climate impacts from producing, distributing and using/emitting them). In other words the result of a complete GHG assessment of each of these commodities from cradle to gate. These data are typically collected from databases such as EcoInvent and literature (see chapter 4).

The following emission factors are necessary in this example:

- $CF_{fuel} = \frac{kg\ CO_2\ equivalents}{ltres\ fuel\ produced, distributed\ and\ combusted}$

- $CF_{refrig} = \frac{Kg\ CO_2\ equivalents}{kilos\ of\ refrigerant\ produced, distributed\ and\ emitted\ to\ air}$

- $CF_{el} = \frac{Kg\ CO_2\ equivalents}{kWh\ of\ electricity\ produced, distributed\ and\ used}$

3.7 Final calculation

The following equations calculate the carbon footprint up to gate for each of the steps in the production chain.

- Fishing:
$$CF_{Fishing} = FU * Y_p(F_{fuel} * CF_{fuel} + F_{ice} * I_{el} * CF_{el} + F_{ref} * CF_{ref})$$
- Aquaculture:
$$CF_{Aquaculture} = FU * Y_p(A_{FCR} * CF_{feed} + A_{fuel} * CF_{fuel} + A_{el} * CF_{el} + A_{smolt} * CF_{smolt})$$
- Processing:
$$CF_{Processing} = FU(P_{fuel} * CF_{fuel} + P_{el} * CF_{el})$$
- Packaging and ice:
$$CF_{Packaging} = FU(m_{pack} * CF_{material} + m_{ice} * I_{el} * CF_{el})$$
- Transport $CF_{Transport} = \left(FU + FU(m_{pack} + m_{p.ice})\right) * km * T_f * CF_{fuel}$

Then the final carbon footprint of each product will be:

For the caught product:
$$CF_{fished} = CF_{fishing} + CF_{processing} + CF_{packaging} + CF_{transport}$$

For the aquaculture product:
$$CF_{farmed} = CF_{aquaculture} + CF_{processing} + CF_{packaging} + CF_{transport}$$

4 Resources: Data, databases, literature and other useful resources

4.1 Web based tool for carbon footprint of seafood

The Seafish Industry Authority together with Dalhousie University and FINTEF Fisheries and aquaculture has developed the web based tool (spreadsheet), the “Greenhouse Gas Emissions Profiling Tool”, that helps to structure the calculation of the carbon footprint of wild caught seafood products and provides useful data on important processes.

- Link to the tool: http://seafish.tictocdesign.com/co2emissions/2013site/

4.2 Resources LCA methodology

In addition to the standards for LCA and GHG assessments presented in chapter 1.3 there are several useful guidelines for different aspects of the LCA methodology:

- The European Commission's Joint Research Centre have published several useful handbooks on LCA. These are highly recommended: http://lct.jrc.ec.europa.eu/assessment/publications.

- The GHG protocol guidelines

4.3 Literature on LCA and GHG Assessments of seafood products and activities

- The report "Review of life cycle assessment research on products derived from fisheries and aquaculture"[11] by Robert Parker for *Seafish* is a good starting point for an overview of LCAs and GHG assessment of seafood production systems performed around the globe.

- For scientific journal articles on the subjects there are several good search engines:
  - Science Direct: www.sciencedirect.com
  - Springer link: www.link.springer.com

4.4 Useful sources for generic data

The Ecoinvent life cycle assessment databases[12] is probably the most commonly used database for LCA data and often met through the LCA software Simapro[13]. It provides a compilation of life cycle data for more than 4500 processes/commodities mainly from Europe. For GHG assessment of seafood Ecoinvent can e.g. provide data on the production and distribution of fuels, electricity, packaging materials and transport processes.

The Greenhouse Gas Protocol (GHG Protocol) is a widely used international accounting tool to quantify, and manage greenhouse gas emissions. They also provide recommendations for GHG data on commonly used energy carriers and some other commodities in their tool set [14].

4.5 Emission factors for fuel

Seafood production system encompass many different types of fuels and combustion/engine technologies. Unless the goal of studies is to compare fuels one can probably use a generic carbon footprint for the production, distribution and combustion of fuels as petrol and diesel.
The GHG protocol provides values for the combustion of fossil fuels in the range of 2.3 to 2.7 kilos of CO_2e per litre
In addition to this comes production and distribution of the fuel. The LCA database EcoInvent v2.2 contains data on production and distribution of a range of fuels:

- Diesel, at regional storage: 0.46 kg CO_2e/litre

[11] Link to report: www.seafish.org/media/583639/seafish_lca_review_report_final.pdf
[12] Link to the Ecoinvent Centre web page: http://www.ecoinvent.ch/
[13] Link to PRé Consultants web page: http://www.pre-sustainability.com/simapro
[14] Link to the Greenhouse Gas Protocoll tools: http://www.ghgprotocol.org/calculation-tools/all-tools

- Petrol, unleaded at regional storage: 0.64 kg CO_2e/litre
- Heavy fuel oil, at regional storage: 0.41 kg CO_2e/litre
- Light duel oil, at regional storage: 0.46 kg CO_2e/litre

To summarize it is clear that if the purpose of the assessment is to evaluate what fuels are used one should seek very specific data on emissions from both combustion and production, but for other purposes, a factor of 3.2 kg CO_2e/litre of fuel used should be good starting point.

4.6 Emission factor for electricity

How to calculate GHG emissions per kWh of electricity produced is highly debated. The obvious solution is to gather data from the exact source from where the electricity is bought, but in practice this is not straight forward as the global or regional electricity production is strongly linked through grids, economic systems such as certificate arrangements and even politics. The global electricity production mix is somehow steered by political climate goals. We recommend that you use the average production mix on the market where the electricity is bought. For example: Norway and the UK would use the European production mix as power is sold and bought freely across these countries. The approach of using the production mix of the market is fair to call conservative as it would avoid over-optimistic assumptions (and in some cases the opposite).

For electricity produced and used in Europe EcoInvent v2.2 provides a value of 0.53 kg CO_2e/kWh electricity at grid.

4.7 Transport data

For examples and data on different transport means used in the seafood industry look at the reports “Carbon footprint and energy use of Norwegian seafood products” (Winther et al., 2009) and “Life cycle approach to Norwegian seafood logistics” (Emanuelsson et al., 2010). Also for a very thorough introduction of freight transport the report “Guidance on measuring and reporting Greenhouse Gas (GHG) emissions from freight transport operations” by the UK Government Department for Environment, Food & Rural Affairs and their accompanying tools[15] is recommended (DEFRA). Finally the Ecoinvent database includes many different transport modes.

[15] Link to the DEFRA web page on GHG assessment: www.gov.uk/measuring-and-reporting-environmental-impacts-guidance-for-businesses

5 References

Avadí, A., & Fréon, P. (2013). Life cycle assessment of fisheries: A review for fisheries scientists and managers. *Fisheries Research*, *143*(0), 21-38. doi: http://dx.doi.org/10.1016/j.fishres.2013.01.006

Avadí, A., & Vázquez-Rowe, I. (2014). Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework. *Journal of Cleaner Production*(0). doi: http://dx.doi.org/10.1016/j.jclepro.2014.01.047

Avadí, Á., Vázquez-Rowe, I., & Fréon, P. Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework. *Journal of Cleaner Production*(0). doi: http://dx.doi.org/10.1016/j.jclepro.2014.01.047

Ayer, N. W., & Tyedmers, P. H. (2009). Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. *Journal of Cleaner Production*, *17*(3), 362-373. doi: 10.1016/j.jclepro.2008.08.002

BSI. (2012). 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. http://shop.bsigroup.com/en/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2050/PAS-2050-2/.

DEFRA. Guidance on measuring and reporting Greenhouse Gas (GHG) emissions from freight transport operations www.gov.uk/government/uploads/system/uploads/attachment_data/file/218574/ghg-freight-guide.pdf. Retrieved 22.11., 2013, from https://www.gov.uk/measuring-and-reporting-environmental-impacts-guidance-for-businesses

Driscoll, J., & Tyedmers, P. (2010). Fuel use and greenhouse gas emission implications of fisheries management: the case of the new england atlantic herring fishery. *Marine Policy*, *34*(3), 353-359. doi: 10.1016/j.marpol.2009.08.005

EC-JRC. (2010). International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition. In E. C.-J. R. C.-I. f. E. a. Sustainability (Ed.). Luxembourg.

Ellingsen, H., & Aanondsen, S. A. (2006). Environmental Impacts of Wild Caught Cod and Farmed Salmon - A Comparison with Chicken (7 pp). *The International Journal of Life Cycle Assessment*, *11*(1), 60-65. doi: 10.1065/lca2006.01.236

Emanuelsson, A., Skontorp Hognes, E., Ziegler, F., Sund, V., Winther, U., & Ellingsen, H. (2010). *Life cycle approach to Norwegian seafood logistics – new ways to model food transports*. Paper presented at the LCAFood VII international conference on life cycle assessment in the agri-food sector, Bari, Italy.

Hospido, A., & Tyedmers, P. (2005). Life cycle environmental impacts of Spanish tuna fisheries. *Fisheries Research 2005;76:174*.

IPCC. (2007). Intergovernmental Panel on Climate Change, Fourth Assessment Report: The Physical Science Basis.

ISO. (2006). ISO 14040 Environmental management - life cycle assessment - principles and framework. ISO 14040:2006(E). International Organization for Standardization. Geneva. Switzerland.

Pelletier, N., & Tyedmers, P. (2007). Feeding farmed salmon: Is organic better? *Aquaculture*, *272*(1-4), 399-416.

Pelletier, N., & Tyedmers, P. (2008). Life Cycle Considerations for Improving Sustainability Assessments in Seafood Awareness Campaigns. *Environmental Management*, *42*(5), 918-931. doi: 10.1007/s00267-008-9148-9

Pelletier, N., & Tyedmers, P. (2010). Life Cycle Assessment of Frozen Tilapia Fillets From Indonesian Lake-Based and Pond-Based Intensive Aquaculture Systems. *Journal of Industrial Ecology, 14*(3), 467-481. doi: 10.1111/j.1530-9290.2010.00244.x

Schau, E. M., Ellingsen, H., Endal, A., & Aanondsen, S. A. (2009). Energy consumption in the Norwegian fisheries. *Journal of Cleaner Production, 17*(3), 325-334. doi: 10.1016/j.jclepro.2008.08.015

SN. (2013). Carbon footprint for seafood - Product category rules (CFP-PCR) / Klimaspor for sjømat - Produktkategoriregler (CFP-PCR): Standards Norway.

Tyedmers, P. (2001). *Energy Consumed by North Atlantic Fisheries*. School for Resource and Environmental Studies, Dalhousie University, 1312 Robie Street, Halifax, NS, B3H, 3E2, Canada.

Tyedmers, P. (2004). Fisheries and Energy Use. In J. C. Editor-in-Chief: Cutler (Ed.), *Encyclopedia of Energy* (pp. 683-693). New York: Elsevier.

Tyedmers, P., Watson, R., & Pauly, D. (2004). Fueling global fishing fleets. *AMBIO: A Journal of the Human Environment, 2004:34:635*.

Winther, U., Ziegler, F., Skontorp Hognes, E., Emanuelsson, A., Sund, V., & Ellingsen, H. (2009). Project report: Carbon footprint and energy use of Norwegian seafood products www.sintef.no/Fiskeri-og-Havbruk-AS/Prosjekter/2011/Miljoregnskap-og-klimasporing-av-sjomat/. Trondheim, Norway: SINTEF Fisheries and aquaculture.

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

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