Project no. **288974**

SENSE

'Harmonised Environmental Sustainability in the European food and drink chain'

Grant agreement for: Collaborative project

Theme KBBE.2011.2.5-01
Environmental sustainability in the European food and drink chain

Deliverable: D2.1

Life cycle assessment of aquaculture salmon

Date of deliverable: 15.02.2013
Actual submission date: 24.09.2013

Start date of project: 01/02/2012 Duration: 36 months

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Organisation name responsible for this deliverable: EFLA Consulting Engineers

Project co-funded by European Commission within the Seventh Framework Programme		
Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

DOCUMENT INFO

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Document Control

Document version #	Date	Change
v1.0	30.04.2013	Life cycle inventory
v2.0	10.05.2013	Life cycle impact assessment
v3.0	10.07.2013	Final Report
v4.0	24.09.2013	Final Report updated

Distribution List

Date	Issue	Group
30/04/2013	v1.0	Consortium, for review
10/05/2013	v2.0	Consortium, for review
26/06/2013	v3.0	Consortium
24/09/2013	v4.0	Consortium

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GLOSSARY AND ACRONYMS

AP	Acidification Potential
ARD	Abiotic Resource Depletion
BAP	Best Aquaculture Practice
BOD	Biochemical Oxygen Demand
B2B	Business to Business
COD	Chemical Oxygen Demand
CTU	Comparative Toxic Unit
EID	Environmental Identification Document
EP	Eutrophication Potential
EPS	Expanded Polystyrene
FCR	Feed Conversion Ratio
FIFO	Fish in - fish out
FU	Functional Unit
GWP	Global Warming Potential
HOG	Head on, gutted
HTP	Human Toxicity Potential
KEPI	Key Environmental Performance Indicator
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LCI	Life cycle inventory analysis
PET	Polyethylene Terephthalate
SENSE	Harmonised Environmental Sustainability in the European food and drink chain
SME	Small and medium size enterprise
TSS	Total Soluble Solid
WFM	Whole Food Market
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

The purpose of this analysis is to perform a “cradle to gate” Life Cycle Assessment (LCA) for aquaculture salmon products. The results from this study as well as literature review done in work package 1.1 are used to propose Key Environmental Performance Indicators (KEPIs) for the aquaculture supply chain. This is done in order to develop a system to simplify data collection and information requirements oriented specifically to every stage involved in the life cycle. The KEPIs will be used to identify relevant input data to an innovative software tool (SENSE tool) to provide comprehensive environmental information for small and medium size enterprises (SMEs).

This case study is valid for the operation of a hatchery and a salmon farm located in Iceland and a smokehouse in France. The LCA was done for two different functional units: 1 kg of fresh aquaculture salmon, head on gutted (HOG) and 1 kg of smoked aquaculture salmon fillets. Furthermore, two transportation scenarios were analysed for the fresh aquaculture salmon, sea freight and air freight. The fresh salmon (HOG) is transported from the aquaculture farm in Iceland to Europe where it is delivered at retailer or for secondary processing. Allocation between main products and by-products at hatchery, aquaculture farm and smokehouse was done using economic approach based on the shares of product in annual turnover. Allocation is done in accordance with ISO 14044 and recommendations from ENVIFOOD Protocol (2012).

The midpoint impact assessment methods identified in task 1.3 of the SENSE Project were used for the environmental impact assessment in this study (Aronsson et al., 2013). The Life Cycle Impact Assessment (LCIA) is done for the impact categories: Climate change, eutrophication, acidification, human toxicity, ecotoxicity, land use, abiotic resource depletion and water depletion.

The LCIA shows that for fresh salmon (HOG) transported from Iceland to Europe by sea freight the aquaculture farm including the feed production is by far the dominant life cycle stage in all impact categories. For most of the impact categories this is due to the harvesting and processing of feed ingredients (marine and crop). For the impact category marine eutrophication it is however the release of organic matter to sea which is the major cause of impact at the farm and for the human toxicity potential (non-cancer effects) it is the transportation of the feed from feed mill to the farm.

For the fresh salmon (HOG) transported to Europe by air freight the aquaculture farm is not as dominant but it is still the main contributor to environmental impacts in seven of the 11 assessed impact categories, i.e. for terrestrial, freshwater and marine eutrophication, human toxicity (cancer effects), ecotoxicity, land use and water depletion. For the climate change impacts, acidification, human toxicity (non-cancer effects) and resource depletion, the transportation phase is the main source of impact.

The results for the smoked salmon fillet show that for nine impact categories the aquaculture farm life cycle stage is the main contributor of environmental impacts, mainly due to the feed. In two impact categories, human toxicity (non-cancer effect) and water depletion the operation of the smokehouse in France is the main source of impact.

The allocation method used in this study (economic allocation) is recommended for the SENSE tool.

KEPIs were identified for the aquaculture salmon supply chain and the indicators that are common in all life cycle stages are fossil fuels and electricity use. Feed is identified as a KEPI for the hatchery and the aquaculture farm as well as water use which is also identified for the secondary processing. Additionally, organic waste to sea from the aquaculture farm is identified as a KEPI.

The regional variation affects some of the identified KEPIs. For acidification, eutrophication and water depletion regionalised characterisation factors are available for different countries. It is suggested that these will be applied in the SENSE tool. For other regional impact categories

regionalised characterisation factors are not available yet. Environmental impacts differ for electricity in different countries and information on the different electricity mixes is available and it is important to implement these in the tool. It is recommended that Life Cycle Inventory (LCI) background data for different types of aquaculture feed and feed ingredients will be generated and implemented in the tool. This is necessary for the tool to be accessible, simple and easy to use. Furthermore, datasets for emissions of organic matter to sea need to be available.

1 Introduction

The food and drink industry in Europe, of which 99% are small and medium enterprises, is highly fragmented, and food chains are very complex. Hence, to assess the environmental sustainability of a product there is a need for applying integrated, harmonised and scientifically robust methodologies, together with appropriate communication strategies for making environmental sustainability understandable to the market. However, there are difficulties in developing a commonly agreed methodology for environmental impact assessment that still need to be overcome. Challenges are the complexity of food chains, the large number of agents involved, different suitable indicators depending on the business sector, regional differences related to biodiversity among other challenges, including climate change and complexity of the current sustainability assessment tools - high data intensity, costs and expertise required.

SENSE aims to deliver a harmonised system for the environmental impact assessment of food and drink products. The research evaluates existing relevant environmental impact assessment methodologies, and considers socio-economical, quality and safety aspects, to deliver a new integral system that can be linked to monitoring and traceability data. The system will integrate:

(a) (regionalised) data gathering system;

(b) matrix of key environmental performance indicators;

(c) methodology for environmental impact assessment; and

(d) a certification scheme.

The methodology will be transferred to food & drink sectors and stakeholders by means of specific communication strategies.

The sustainability information collected along the supply chain of any food stuff and reflected into the EID (Environmental Identification Document) will be accessible by the EID-Communication Platform. This should contribute to making the environmental sustainability part of the usual purchasing behaviour of consumers and provide a competitive advantage to those products (and companies) which choose to use the EID. Through a comprehensive environmental communication between the industry and consumers the latter are empowered to choose food products which are environmentally friendly.

2 Outline of the LCA Study

2.1 Overview

Task 2.1 of the SENSE project investigates current food production and supply systems from a regional perspective. According to the methodology recommended in WP1, three Life Cycle Assessment (LCA) case studies are performed. The followings selected food chains are studied:

- salmon aquaculture in Iceland (see Chapter 3)
- dairy & beef production in Romania (separate report)
- orange juice production in Spain (separate report)

The goal of Task 2.1 is to propose a selection of key attributes and suitable scope of essential input data based on LCA results interpretation and sensitivity analysis. The required information for LCA (i.e.: water, energy, materials consumption) shall be prioritised according to the most important environmental impacts. Moreover, a set of normalised allocation rules for the selected food chains is to be addressed.

Thus, a systematic overview of the life cycle of food and drink products and their environmental impacts associated is to be presented, taking into account the diversity within the sector as well as differences in different regions across the European market.

This report gives the results from a LCA case study of salmon aquaculture supply chain and is complementary to LCA studies performed for juice and beef and dairy products.

Changes needed to be made in the project because of unforeseeable absence of the Norwegian consortium partner. Data was therefore acquired from an Icelandic salmon producer where the production processes and feed composition is similar in both countries.

2.2 System Boundaries

System boundaries for Business to Business (B2B) food chains are considered as cradle to gate approach where all relevant life cycle stages are considered. In this LCA case study the last life cycle stage considered is the production phase including packaging as well as transportation to the next life cycle step. All life cycle steps occurring after that (storage, distribution, retailing and consumption) are not part of the assessments.

2.3 Questions to be answered

The following questions shall be addressed by these case studies:

- What are the most relevant stages in the life cycle?
- What are the key environmental performance indicators (KEPIs) to be applied in the SENSE tool?
- How are the results affected by regional background data?
- How do regional emission models affect the results?
- How are the results affected by a regionalised impact assessment?
- What are the recommendations regarding the allocation rules?
- Which system boundaries shall be applied in the SENSE tool?

2.4 Impact Assessment Methods

One task of the SENSE project is to select a set of consistent environmental impact assessment methods and impact indicators for the three selected food groups (salmon aquaculture, dairy/beef and orange juice) and their supply chains. Based on the key environmental challenges identified in task 1.1 (D 1.1), and the linked impact categories, an evaluation of current life cycle impact assessment (LCIA) methodologies has been made in task 1.3 (Aronsson et al., 2013).

The life cycle impact assessment methodologies identified and which are to be used in the LCA's of the three food supply chains in WP 2 (task 2.1) of the SENSE project are listed in Table 2-1 along with the corresponding indicators. The methods selected by the SENSE project team comply with the ones recommended by ILCD (JRC, 2011).

Table 2-1 Life cycle impact assessment methodologies to be used in SENSE (Aronsson et al., 2013)

Impact category	Selected LCIA method	Indicator unit
Climate change	Bern Model – IPCC (Solomon, 2007)	kg CO_2-eq.
Eutrophication	Terrestrial: Accumulated Exceedance (Seppälä et al., 2006, Posch et al., 2008)	Terrestrial: mol_c N-eq.
	Aquatic: EUTREND Model (Goedkoop et al., 2009)	Freshwater: kg P-eq. Marine: kg N-eq.
Acidification	Accumulated Exceedance (Seppälä et al., 2006, Posch et al., 2008)	molc H^+-eq.
Human toxicity	USEtox Model (Rosenbaum et al., 2008)	CTU_h (Comparative Toxic unit for humans)
Ecotoxicity	USEtox Model (Rosenbaum et al., 2008)	CTU_e (Comparative Toxic Unit for ecosystems)
Land use	Soil organic matter model (Milà i Canals 2007)	kg C deficit
Abiotic resource depletion	CML 2002 (Guinée et al., 2002)	kg antimony (Sb)-eq.
Water depletion	Ecological scarcity model (Frischknecht et al., 2009)	European m^3 water-eq.

2.5 Key Environmental Performance Indicators (KEPI)

The goal of the SENSE project is to develop a harmonised system for the environmental impact assessment of food and drink products. This will be done by defining standard KEPIs and developing a tool which will assist small and medium enterprises (SMEs) to assess their environmental performance. The aim is to simplify data collection and information requirements for every life cycle step of the food chain.

Through the three case studies elaborated in this project and with a literature review on existing LCA studies (Landquist et al., 2013), the key data that the SMEs have to provide are identified. The key data shall be easy to obtain and be readily available from operators of farms and food industries.

3 Life Cycle Assessment of Aquaculture salmon

3.1 Goal and Scope

3.1.1 Object of Investigation

The goal of the study is to evaluate the environmental impacts of an aquaculture salmon product using LCA methodology according to ISO 14040 and ISO 14044. The salmon is produced in Iceland and consumed in Europe. LCA methodology is described in Annex A.

3.1.2 Functional Unit

The study includes two different functional units:

1. *1 kg fresh salmon, head on, gutted (HOG), delivered to retailer or secondary processing.*
2. *1 kg smoked salmon fillets (skin off) delivered to retailer.*

The fresh salmon HOG is produced in Iceland, chilled, packed and transported to Europe where it is sold directly to retailer or processed further. The smoked salmon fillets are brined and smoked, and the product is sold without skin.

3.1.3 System Boundaries for Aquaculture Salmon

The system boundary for the fresh salmon follows the product from "cradle to gate" (Figure 3-1). In this study the life cycle starts with the harvesting and cultivation of feed ingredients (fish and crop) and production of the feed at a feed mill located in Iceland. The feed is delivered and used at a land based hatchery (smolt production site) and at an aquaculture farm in Iceland with marine net pen production system. The fish is slaughtered, gutted and packed in EPS (expanded polystyrene) boxes. The aquaculture salmon is then transported overseas to a retailer or for further processing. The system boundary for the smoked salmon fillets is identical to the fresh fish supply chain up until reception at smokehouse (Figure 3-1). The salmon is brined and smoked at a smokehouse in France and then transported to a regional storehouse/retailer.

In this study the main consumables and infrastructure for operation of every step of the life cycle are included. The life cycle of the fresh and smoked salmon is described in Table 3-1 and in further detail in Annex B. Further description of aquaculture salmon production can be found in SENSE Deliverable 1.1 (Ólafsdóttir et al., 2013).

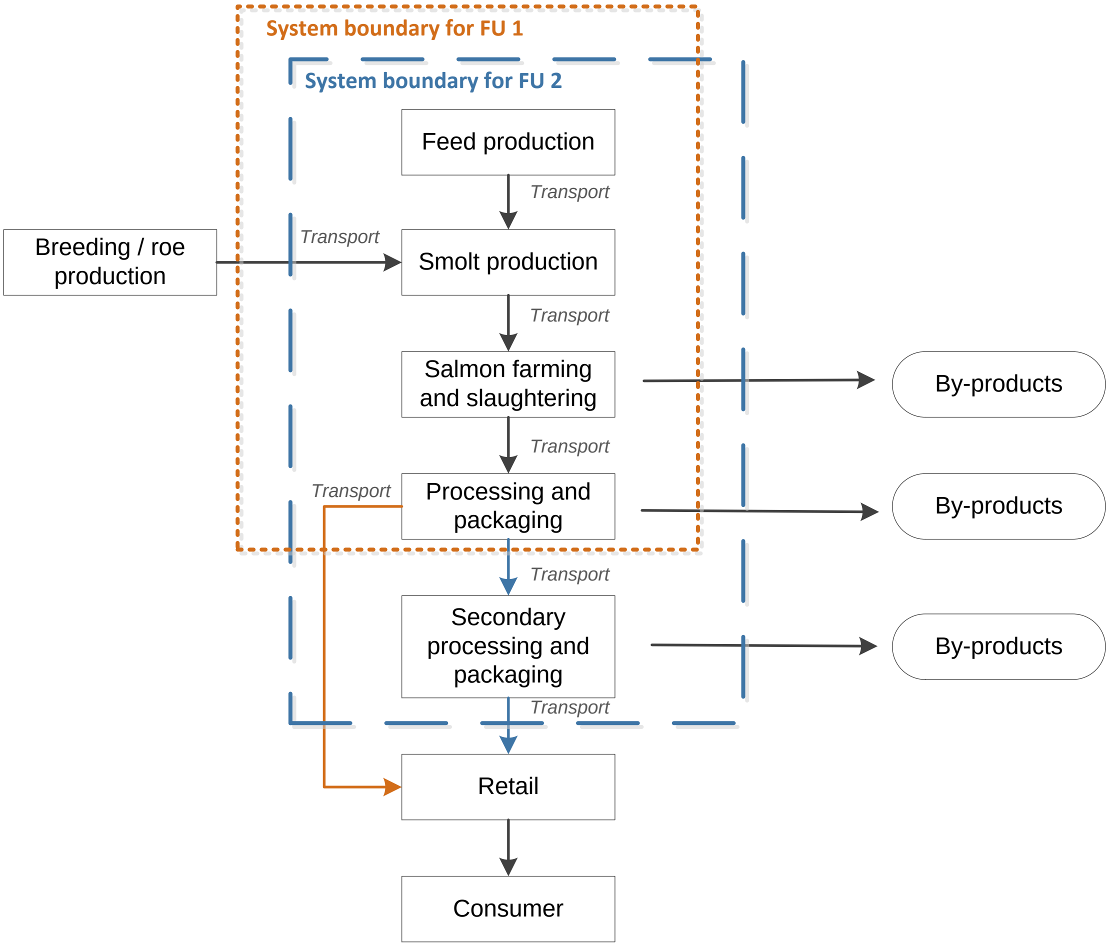

Figure 3-1 Product system for aquaculture salmon products and system boundaries for FU1: 1 kg fresh salmon (HOG) and FU2: 1 kg smoked salmon fillets

Table 3-1 Main steps in the salmon production, "cradle to gate"

Life Cycle Step	Relevant for functional unit	Location	Description
Feed ingredients	FU1 & FU2	Various	Harvesting of marine and crop ingredients for feed.
Feed mill	FU1 & FU2	Iceland/ Denmark	Production and transportation of feed for juvenile/ smolt production and aquaculture farming.
Smolt production	FU1 & FU2	Iceland	On shore hatchery in freshwater and adaptation to seawater.
Salmon farming	FU1 & FU2	Iceland	Salmon is bred in floating marine net-pens for 14 - 25 months.
Slaughtering	FU1 & FU2	Iceland	Salmon is hauled into harvesting boat, where it is stunned and bled by automatic slaughtering equipment.
Pre-processing and packaging	FU1 & FU2	Iceland	Processing of fresh salmon (whole gutted with head on, chilling). Packaging (production of EPS boxes).
Transportation	FU1 & FU2	Iceland to France	Transportation in EPS boxes with ice mats to retailer or secondary processor for smoking in France. Two transportation scenarios are analysed: Scenario 1: The fresh salmon (HOG) is transported by truck and ferry to harbour in Iceland and then by ship to Rotterdam and further by a truck to wholesaler or secondary processor in France. Scenario 2: The fresh salmon (HOG) is transported by truck and ferry to airport in Iceland and then by air from Iceland to Cologne and then by a truck to wholesaler or secondary processing in Europe.
Secondary processing	FU2	France	Secondary processing of fresh salmon (headed, filleted, brined, smoked and packed).
Packaging and chilling	FU2	France	Packaging (production) and cold storage
Transport: Secondary Producer -> Wholesaler	FU2	France	Refrigerated transportation to wholesaler by truck
Transport: Wholesaler -> Retailer	FU1 & FU2	Europe	Refrigerated transportation to retailer by small truck

3.1.4 Main Data Sources

Inventory data for smolt production at hatchery and aquaculture salmon farm in Iceland was provided by Icelandic producers. Data was provided for the operational year 2012 for both operations. Inventory data for the smokehouse was provided by the smoked fish processor, FODIX. The data for the smokehouse was provided for a one year period, 30/11/2011 - 30/11/2012. Data on the quantity of feed was obtained from the producers of smolt and aquaculture salmon. The composition of the feed was estimated using data from Icelandic feed producer and literature data, see section 5.2.1. Data include:

- Production, processing and transportation of feed and feed ingredients.
- Quantities of materials and energy used for operation of the hatchery and aquaculture farm.
- Quantities of materials and energy used to process salmon at smokehouse.
- Fuel usage related to transportation from the aquaculture farm in Iceland to retailer or secondary processing in Europe.

When operational data is insufficient additional data or information is obtained by using data from literature, results from previous studies of members of the SENSE consortium as well as data from databases. The primary source of background inventory data, e.g. production of diesel oil, feed ingredients etc. used in this study is from the Ecoinvent 2.2 database. The software used is GaBi 6 from PE International.

3.1.5 Inventory Assumptions

The LCI methodology follows in many aspects the methodology applied to the Ecoinvent background data (Frischknecht et al. 2007). The following main assumptions are considered:

- Infrastructure is included with lifetime of buildings of 60 years, lifetime of tanks at hatchery of 30 years and the pens at aquaculture farm of 50 years. Construction time of buildings is estimated 2 years.
- For tanks at hatchery and pens at aquaculture farm the production of construction materials are accounted for, not the assembly of the infrastructure.
- Waste management is included.
- Recycling processes are not included.
- Country specific datasets for electricity and water is used.
- Transportation of crop ingredients for smolt- and salmon feed from farmer to feed mill were not included. However, transportation of feed from feed mill to users is included.

3.1.6 Allocation

The environmental impacts from the production of smolt, sold from the hatchery (smolt producer) to aquaculture salmon farms are allocated based on the economic share of smolt sold to the Icelandic farm which is the focus of this study (50%) and to smolt that is sold to other farms (50%). In this case mass allocation would give the same results as all products have the same economic value.

At the aquaculture farm the guts from the salmon are given away for free and used as feed for farmed animals used for fur (e.g. mink). The guts represent 10% of the total biomass at the farm. Environmental impacts at the aquaculture salmon farm are allocated between the production of salmon (HOG) and the guts using economic allocation. Therefore all impacts are associated with the production of salmon (HOG).

For the smokehouse operation 99.6% of the total products by weight and 99.7% by turnover are smoked salmon products, therefore no allocation is performed for the smokehouse operation and all impacts are allocated to the smoked salmon fillets.

3.1.7 Scenarios

Two different scenarios for transportation from aquaculture farm are considered.

Scenario 1: Transportation of fresh salmon (HOG) from aquaculture farm in Iceland to Europe by container ship.
Scenario 2: Transportation of fresh salmon (HOG) from aquaculture farm in Iceland to Europe by air freight.

3.2 Life Cycle Inventory Analysis (LCI)

In this chapter an overview of the life cycle inventory analysis (LCI) is presented. The full LCI is documented in a confidential annex, which is only available for the project consortium.

Mass flow between production stages can be seen in **Figure 3-2**. In order to produce 1 kg of fresh salmon (HOG) in total 1.5 kg of feed is needed, for both the production of smolt at hatchery and the salmon at farm. For the production of 1.0 kg of smoked salmon fillet, in total 2.6 kg of feed is needed. Key figures per kg output for the different aquaculture salmon supply chain life cycle steps are presented in Annex C. Further description of the input and output data for the production of salmon can be found in chapters 3.2.1 - 3.2.8.

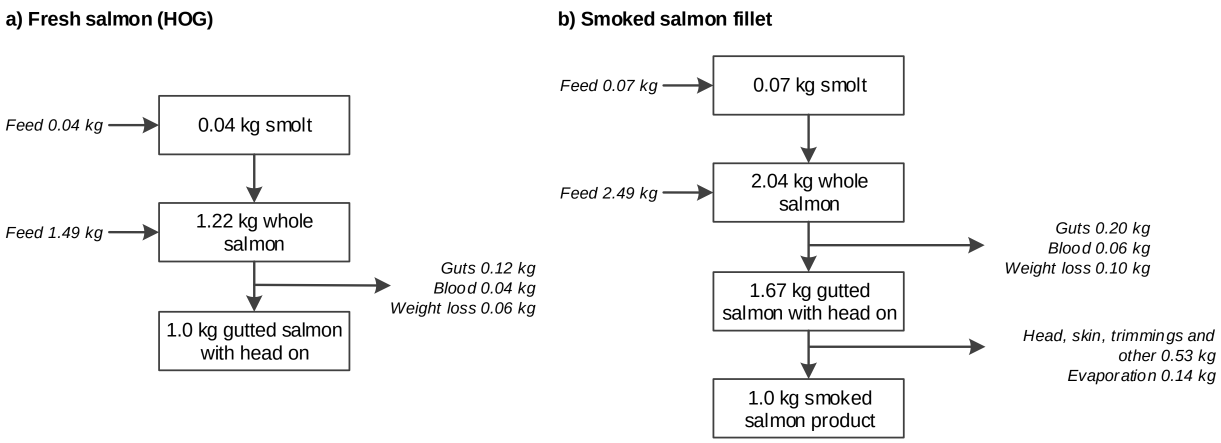

Figure 3-2: Mass flow of feed, smolt and salmon related to a) 1 kg of fresh salmon (HOG) and b) 1 kg of smoked salmon fillet

3.2.1 Feed

Information on the quantity and origin of feed used for smolt production at hatchery and at the salmon aquaculture farm is obtained from the questionnaires filled in by the smolt and salmon producers.

For the feed used at the hatchery the feed ingredients (imported and domestic) are either mixed at a feed mill in Iceland (89%) or ready to use feed is imported from Denmark (11%). All feed for the aquaculture salmon farm is from an Icelandic feed mill. The composition of the feed is estimated using data from an Icelandic feed producer and literature data (Ellingsen and Aanondsen, 2006; Ytrestøyl et al., 2011). In Table 3-2 the estimated composition of feed for juvenile fish (smolt feed) and the aquaculture salmon can be seen. For the smolt feed, the composition of the domestic and imported feed are assumed to be the same.

Data for the impact assessment of the crop feed ingredient production are derived from the Ecoinvent 2.2 database and the marine feed ingredients from an LCA study on global salmon farming systems (Pelletier et al., 2009). Information on the data used for the marine feed ingredients and feed mill can be found in Annex D.

Table 3-2: Ingredients for smolt (juvenile salmon) feed and aquaculture salmon feed.

	kg feed ingredient per kg smolt feed	Smolt feed: operation of hatchery (tonnes/year)	kg feed ingredient per kg salmon feed	Salmon feed: operation of aquaculture farm (tonnes/year)
Capelin meal	0.315	86	0.25	419
Herring meal	0.315	86	0.25	419
*Herring main product meal**	*(0.16)*	*(43)*	*(0.13)*	*(209)*
*Herring by-product meal**	*(0.16)*	*(43)*	*(0.13)*	*(209)*
Capelin oil	0.150	41	0.160	268
Wheat	0.120	33	0.140	235
Plant protein	0.076	21	0.180	302
*Rape seed meal***	*(0.017)*	*(4)*	*(0.040)*	*(66)*
*Maize wheat gluten***	*(0.017)*	*(4)*	*(0.040)*	*(66)*
*Soybean meal***	*(0.029)*	*(8)*	*(0.068)*	*(114)*
*Soybean oil***	*(0.014)*	*(4)*	*(0.034)*	*(57)*
Vitamin	0.010	3	0.010	17
Minerals	0.007	2	0.005	8
Colour (Astaxanthin)	0.007	2	0.005	8

** Herring meal in feed consists of both main product meal (50%) and by-product meal (50%).*
*** Plant protein in feed consists of rape seed meal (22%), maize wheat gluten (22%), soybean meal (38%) and soybean oil (18%).*

Data Cut offs

Vitamins, minerals and colour are not included in the LCA analysis. In total these micro ingredients represent 2.4% by weight of the juvenile fish feed and 2.0% by weight of the salmon feed. The reason for not including these ingredients is due to lack of data on resource use and environmental impacts of these ingredients.

Data on the impacts for marine feed ingredients is obtained from Pelletier et al., 2009 and cover energy use, biotic resource use, climate change, acidification and eutrophication. Impact assessment for other impact categories (water depletion, land use, ecotoxicity and human toxicity) are underestimated for the marine feed ingredients share of the smolt and salmon feed.

3.2.2 Transportation of roe and feed to hatchery

Salmon roe (eggs) are delivered by truck to the hatchery from an Icelandic breeding firm. The roes are transported 100 km. The total amount of feed used at the hatchery in 2012 was 272 tonnes. For the smolt production the feed is either domestic production (89%) or imported from Denmark (11%). The domestic feed is transported from the feed producer to the hatchery by truck (425 km), and the imported feed is transported to Iceland by ship (2300 km[1]) and inland by truck (55 km). Road transportation distances are obtained from the Icelandic Road Administration[2]. Total feed inputs for the hatchery can be seen in Table 3-3.

[1] http://sea-distances.com/
[2] http://www.vegagerdin.is/vegakerfid/vegalengdir/tafla-yfir-ymsar-leidir/

Table 3-3 Feed inputs to the hatchery (smolt production) and transportation modes and distances

Type of feed	Amount (tonnes/yr)	Origin	Type of transportation	Proportion of feed (%)	Remarks
Smolt feed (imported)	30	Denmark	Ship and truck	11%	Transport distance (ship) 2300 km; transport distance (truck) 55 km
Smolt feed (domestic)	242	Iceland	Truck	89%	Transport distance (truck) 425 km
Total amount of feed	***272***			***100%***	

Data Cut offs

The transportation of roe from the breeding firm to the hatchery is modelled as operation of a vehicle for 100 km, i.e. the load is not included.

3.2.3 Smolt Production

The life cycle inventory for the smolt production is obtained from a questionnaire filled in by an Icelandic hatchery as well as personal communication with the person responsible at the production site. The reference year for the data collected is operation of the plant in 2012. In 2012, 50% by weight of the smolt produced at the site was sold to the aquaculture farm in question for the LCA analysis. All LCI data is allocated accordingly.

Smolt Production Land Use and Infrastructure

Data on land use and infrastructure of the hatchery can be seen in Table 3-4. The total lot size is 40,000 m^2, where a part of the lot is built up (11,000 m^2). In total 91 tanks for smolt production are at the hatchery, of which 74 are located inside the factory hall (1,000 m^2) and 17 concrete tanks are located outdoors (320 m^2). For land occupation, two years for construction and 60 years of building infrastructure lifetime is assumed.

Infrastructure includes factory hall (1,000 m^2) modelled as an average concrete building in Iceland. The modelling of buildings includes the building materials (concrete, reinforcement steel, rock wool insulation, glulam, galvanized steel and wood), transportation of building materials from producer to construction site and the energy and water used to operate the building for 60 years. Furthermore, the manufacturing of construction materials (fibreglass, concrete and reinforcement steel) and maintenance of tanks is included in the model. Average lifetime of tanks is 30 years. During operation in 60 years the tanks need to be replaced two times.

Table 3-4: Input data for infrastructure and land use for the hatchery

	Amount	Unit	Comment
Type of area/land use			
Total land area covered by the production site	40,000	m^2	Area covered by fence.
Area covered by factory halls	1,000	m^2	1 storey high building.
Area covered by outdoor tanks and buildings	10,000	m^2	Total area includes walkways, car parking areas, outdoor concrete tanks cover in total 320 m^2 and an office building 60 m^2 (1 storey high).
Tanks			
Number of tanks	74	#	Fiberglass tanks located indoors
	17		Concrete tanks located outside
Circumference of tanks	6	m	Fiberglass tanks located indoors
	12		Concrete tanks located outside

Smolt Production Inputs

The total electricity use for the smolt production in 2012 is 1,960 MWh. Electricity is supplied through the Icelandic electricity grid (75% hydropower, 25% geothermal). Diesel oil is used to operate a fork lift and one passenger vehicle, in total 5,700 litres in 2012. The environmental burdens from the burning of diesel oil in fork lift are modelled as a passenger car (diesel car). Additionally, 12 litres of machinery lubrication are utilised, see Table 3-5.

Table 3-5 Use of electricity, diesel oil and lubrication at hatchery

	Amount	Unit/year	Remark
Electricity used for the production	1,760,000	kWh	
Electricity used for other purposes	200,000	kWh	
Total electricity used	***1,960,000***	**kWh**	
Diesel for operation of fork lift	3,907	L	Fork lift
Diesel for operation of vehicles	1,793	L	One car
Total amount of diesel oil used	***5,700***	***L***	
Machinery lubrication	12	L	Pump lubrication

The total annual water use is 1,020,450 m^3, mostly cold groundwater (59%) and sea water (29%) (Table 3-6). List of other materials used at the smolt production facilities can be seen in Table 3-7. Dataset for vaccine was not available, in order to avoid data cut off the production of vaccine used at the hatchery is assessed using Ecoinvent background data for pesticides production.

Table 3-6 Use of water at hatchery

	Amount	Unit/year
Groundwater	600,000	m^3
Hot water	120,450	m^3
Seawater	300,000	m^3
Total water use	***1,020,450***	***m^3***

Table 3-7 Use of auxiliary substances at hatchery

	Amount	Unit/year
Oxygen	211	tonnes
Detergents/ Soap	50	kg
Formaldehyde (formalin)	20	kg
Vaccine	2	kg

Smolt Production Outputs

The total production at the facility can be seen in Table 3-8. In 2012 half of the production is sold to the salmon producer of interest in this study, in total 132 tonnes or 1,050,000 individuals.

Table 3-8 Total production at hatchery

	Produced amount	Unit/year	Remarks
Main products	1,850,000	Pcs.	
Juvenile fish to salmon producer	132	tonnes	1.050.000 pcs
Juvenile fish to other aquaculture farms	130	tonnes	650.000 pcs
Total products	***262***	***tonnes***	

In 2012 500 kg of dead or out sorted fingerlings is disposed of (Table 3-9). The organic matter is discarded to sea and is accounted for as nitrogen equivalent emissions to sea (Fennema, 1996; Matis, 2013). The unsorted waste (4,000 kg) is sent to landfill for municipal solid waste, waste paper (100 kg) is sent to recycling and waste oil (30 kg) is sent to hazardous waste incineration. Wastewater is disposed directly to sea. Waste water quality from the hatchery is not monitored, in this study it is therefore assumed that emissions to sea are 58 kg N equivalents per tonne fish and 6 kg P equivalents per tonne fish is due to faeces and feed sediment. Organic emissions to sea all origin from the feed used at the hatchery, even for hatchery with low amount of feed sediments the waste from feed ends up in the water, see Figure 3-3 (Heldbo et al., 2013).

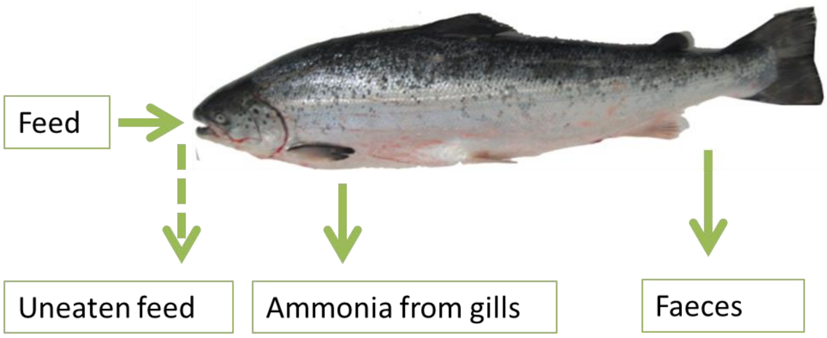

Figure 3-3 Excess nutrients and excretion from the fish contribute to N and P emissions to sea (Adapted from Heldbo et al., 2013)

Table 3-9 Waste and wastewater from the operation in 2012 at hatchery

	Amount	Unit/year	Remarks
Waste			
Biological waste	500	kg	Dead fingerlings and out sorted. Disposed to sea.
Unsorted waste	4,000	kg	Public garbage. Sent to municipal landfill.
Paper	100	kg	Egg package, vaccine package. Sent to recycling.
Lubrication oil	30	kg	From fork lift and car. Sent to hazardous waste incineration plant.
Wastewater disposal			
Direct discharge to sea	1,000,000	m^3	No data available on waste water quality.
Nitrogen	15,272	kg N-eq.	Emissions from faeces, feed sediment, dead fish
Phosphorus	1,584	kg P-eq.	

3.2.4 Transportation of smolt and feed to aquaculture farm

In order to produce the annual 1,370 tonnes of salmon (whole fish) at the aquaculture salmon farm the farm needs 44 tonnes of smolt. The smolt is bought from an Icelandic smolt producer. The smolt is transported from the smolt producer by ship (sea) to the aquaculture farm, 400 km, see Table 3-10.

Table 3-10 Smolt input, transportation mode and distances for the aquaculture farm

	Amount (tonnes/yr)	Origin	Type of transportation	Remarks
Smolt	44	Iceland	Ship	Transport distance (ship) 400 km

In total 1,675 tonnes of feed were used at the aquaculture salmon farm in 2012 to produce the 1370 tonnes of slaughtered fish. The average feed conversion ratio at the farm is 1.2 - 1.3 kg/kg. All feed for the aquaculture salmon farm is from an Icelandic producer (feed mill). The feed is transported by truck (815 km) from the feed producer to the aquaculture farm. Road transportation distance is obtained from the Icelandic Road Administration[3]. The amount of feed, transportation modes and distances for the salmon farm can be seen in Table 3-11.

Table 3-11 Feed inputs and transportation modes and distances for the aquaculture farm

	Amount (tonnes/yr)	Origin	Type of transportation	Proportion of feed (%)	Remarks
Salmon feed (domestic)	1,675	Iceland	Truck	100%	Transport distance (truck) 815 km
Total amount of feed	***1,675***				

3.2.5 Aquaculture farm

Life cycle inventory for the aquaculture farm in Iceland is obtained from a questionnaire filled in by the producer as well as personal communication with the person responsible at the farm. The reference year for the data collected is operation of the facilities in 2012.

Aquaculture Farm Land Use and Infrastructure

Data on land use of the smolt production facilities can be seen in Table 3-12. The total land area, excluding buildings, is 1,500 m^2. Buildings cover 1,250 m^2 of land, and include a 2,000 m^2 processing hall (1,000 m^2 each floor) and a 250 m^2 office building. For land occupation, two years for construction and 60 years of infrastructure lifetime is assumed.

In 2012 there were six pens operated in two fjords, covering in total 1.9 km^2 of sea surface and 2 km of shoreline, see example of pens in Figure 3-4. Each pen covers 100 m^2, but due to restrictions on sea traffic, 200 metres from pens, the total occupation of sea surface does include larger area than only the total area of pens. Sea traffic between the pens and shore is forbidden and thus 2 km of shoreline occupation is documented.

Infrastructure includes in total 2,250 m^2 of buildings modelled as an average concrete building in Iceland. The modelling of buildings includes the building materials (concrete, reinforcement steel, rock wool insulation, glulam, galvanized steel and wood), transportation of building materials from producer to construction site and the energy and water used to operate the building for 60 years. Furthermore, the manufacturing of materials for pens and their maintenance is included in the model. Average lifetime of nets and frameworks of pens is 9 years. During operation in 60 years this needs to be replaced five times. The pen consists of a framework which is made of PEH plastic as well as nylon ropes and nets.

[3] http://www.vegagerdin.is/vegakerfid/vegalengdir/tafla-yfir-ymsar-leidir/

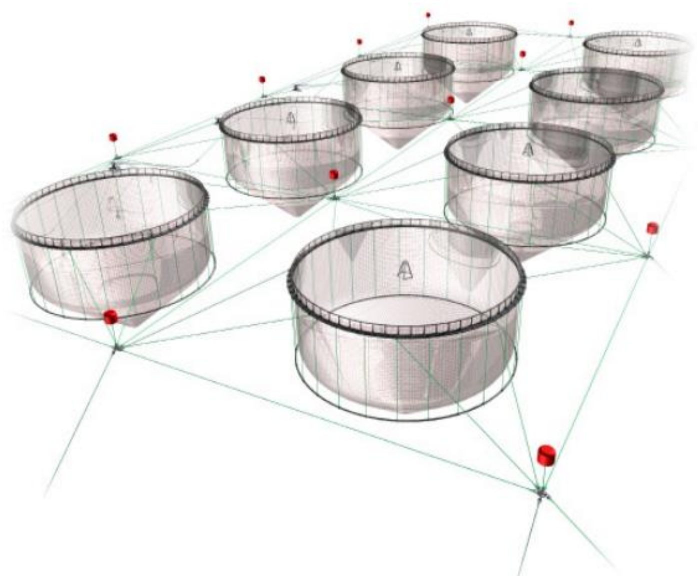

Figure 3-4: Example of net pens (picture obtained from www.vonin.com)

Table 3-12 Land use, use of sea surface and shoreline as well as infrastructure for the operation of the aquaculture farm in 2012

	Amount	Unit	Remarks
Total land area covered by the production site (excluding buildings)	1,500	m^2	Operation in 2 fjords.
Area covered by factory halls	1,000	m^2	One processing hall (2000 m^2) for processing and packaging, 2 storey high building (the 2nd floor is canteen, offices etc.) 1000 m^2 each floor.
Area covered by (office) buildings	250	m^2	1 storey high building
			Storage for feed + main office + equipment storage
Total area of buildings	2,250	m^2	Processing hall and office building
Total number of pens	6	#	The average lifetime of nets/ropes (nylon) and framework (PEH) is estimated to 9 years. Pens are located 500-700 m offshore
Cage circumference	160	m/pen	Plastic (PEH 80) cages, ø315 mm
Pen: Mooring frame rope ø54 mm	6,100	m	Nylon rope
Pen: Mooring frame rope ø32 mm	3,600	m	Nylon rope
Total number of floats	15	#	1,000 L plastic (PEH) floats
Lead line	960	m	160 m per pen. Lead line weight: 3 kg/m
Cage nets	21	tonnes	Weight of net in each pen. 3.5 tonnes
Total number of anchors	18	#	Steel anchors, each weighing 1.5 tonnes
Use of sea surface	1	km^2	Fjord 1: 4 pens, total area covered by pens (100 m^2/pen) and area restricted for other sea traffic (200 m from pens)
	0.9		Fjord 2: 2 pens (total area covered by pens (100 m^2/pen) and area restricted for other sea traffic (200 m from pens)
Use of shoreline		m	Sailing is forbidden between pens and land/shoreline
	1,000		Fjord 1
	1,000		Fjord 2

Aquaculture Farm Inputs

The total electricity use for the salmon aquaculture farm in 2012 is 333 MWh (Table 3-13). Electricity is supplied through the Icelandic electricity grid. Diesel oil is used to operate fork lifts, vehicles, and boats as well as for electricity production, in total 116,723 litres the same year. In total 6,294 litres of petrol are used for one vehicle and two outboard engines. Additionally, 300 litres of machinery lubrication are utilised. Anti-fouling agents are not used at the farm.

Table 3-13 Energy use at aquaculture farm

	Amount	Unit/year	Remark
Electricity used for the production	263,000	kWh	
Electricity used for other purposes	69,970	kWh	
Total electricity used	***332,970***	***kWh***	
Diesel for operation of fork lift	4,380	L	Four fork lifts – two on feeding stations and two in the packing factory
Diesel for operation of vehicles (staff work cars)	15,700	L	Five cars
Diesel for operation of generators	63,198	L	For electric production
Diesel for operation of boats	33,445	L	Well boat and working boat
Total amount of diesel oil used	***116,723***	***L***	
Petrol for operation of vehicles (staff work cars)	3,294	L	One car
Petrol for Outboard motor	3,000	L	Outboard engine on two small boats
Transport of slaughtered fish for packaging	1,800	L	Driving slaughtered fish to packing factory – 60 km tur/retur 2-3 times every week (August – December)
Total amount of petrol used	***8,094***	***L***	
Machinery lubrication	300	L	For cars and machines

The total annual water use at the salmon aquaculture farm is 262,542 m^3 (Table 3-14). Fresh water, hot and cold, is used at the salmon packaging station and river water is used as cooling water at the feed stations. In total 1,200 kg of detergents were used at the packaging factory in 2012 (Table 3-15).

Table 3-14 Use of water at the salmon aquaculture farm

	Amount	Unit/year	Remark
Fresh water (hot)	100,334	m^3.	Salmon Packing station
Fresh water (cold)	100,000	m^3	Salmon Packing station
River water	62,208	m^3	2 feed stations: Cooling water
Total water use	***262,542***	***m^3***	

Table 3-15 Use of auxiliary substances at the aquaculture farm

	Amount	Unit/year	Remarks
Detergents (soap and disinfectants)	1,200	kg	Fish packing factory

The salmon is packed in EPS boxes, 25 kg fresh salmon (HOG) and one cooling mat (1 kg) is placed in each box (Table 3-16). The EPS boxes and cooling mats are produced by Promens Tempra in Iceland[4]. The cooling mats are plastic bags filled with water (Figure 3-5). The aquaculture farm receives the mats unfrozen where they are put into the freezer; therefore energy use for ice production is included in the electricity use at the farm.

Table 3-16 Use of packaging at the aquaculture farm

	Amount	Unit/year	Remark
EPS boxes	42,744	kg	EPS boxes from Promens Tempra. 25 kg per box, each fish 3-5,5 kg
Cooling mats	54,800	kg	Cooling mats from Promens Tempra. One cooling mat (1 kg) per box

Figure 3-5: Cooling mat filled with water (picture obtained from http://tempra.promens.com)

Aquaculture farm outputs

In total 1,370 tonnes of salmon (whole fish) were produced at the farm in 2012. The main product is whole, gutted salmon with head on (1,123 tonnes). The guts are collected and given away as feed for fur animals (137 tonnes) and 41 tonnes of blood is directed to the sewer system and treated as organic matter in wastewater. Additionally, the salmon loses considerable weight before it is slaughtered as a result of starvation. The slaughter weight is 5% less than the total biomass produced at the farm (Table 3-17).

Table 3-17 Total production at the salmon aquaculture farm

	Produced amount	Unit/year	Remarks
Main products:			
Whole fish (gutted with head on)	1,123	tonnes	82% whole gutted fish with head on
Other products/outputs:			
Guts	137	tonnes	10% of total weight is given away as feed for fur animals (guts)
Blood	41	tonnes	3%, to sewer system
Weight loss as a result of starvation before slaughter	69	tonnes	5% weight loss as a result of starvation before slaughter
Total products	***1,370***	***tonnes***	

[4] http://tempra.promens.com/static/files/Tempra_eps_2008.pdf

Solid waste from the aquaculture farm amounts to 8.2 tonnes in 2012. The main waste category is unsorted waste and plastic materials (Table 3-18). The unsorted waste is sent to sanitary landfill, but the sorted plastic fraction is recycled. Hazardous waste from the farm consists of lubrication oil and batteries which are disposed of at certified hazardous waste facilities. Organic waste is production losses due to dead fish, feed that falls to the bottom of the fjords, faeces and blood. 40% of organic matter, 45% of nitrogen and 36% of phosphorus in the feed is preserved in the fish, while the rest is introduced into the marine environment in the form of faeces and dissolved matter (Heldbo et.al 2013).

The organic matter is accounted for as BOD_5, nitrogen or phosphorus equivalent emissions to sea. The organic matter due to dead fish is accounted for as nitrogen equivalent emissions to sea (Fennema, 1996; Matis, 2013). Other organic emissions due to faeces and feed are assumed to be 505 kg BOD_5 equivalents per tonne fish, 41 kg N equivalents per tonne fish and 8 kg P equivalents per tonne fish (Heldbo et al., 2013).

Wastewater from the farm is cooling water from the processing hall. The cooling water is discharged directly to sea without treatment.

Table 3-18 Waste and wastewater from operation of the salmon aquaculture farm in 2012

	Amount	Unit/year	Disposal treatment and specifications
Waste			
Unsorted waste	5,658	kg	
Plastic material	2,000	kg	Feed pipes – packing material
Hazardous waste	80	kg	Used battery – 15 kg pc
Used engine lubrication Oil	300	kg	
Organic waste to sea			
Product loss	96	tonnes	Dead fish approx. 7% of the total number of fish
Nitrogen	58,533	kg N-eq.	Emissions from faeces and feed sediment (96%) and dead fish (4%)
Phosphorus	10,960	kg P-eq.	Emissions from faeces and feed sediment
Biochemical oxygen demand	691,850	kg BOD_5-eq.	
Wastewater disposal			
Direct discharge to sea	31,536	m^3	Cooling water from processing

Data Cut offs

Use of shoreline and sea surface is not accounted for in the LCA due to lack of methodology to account for this use of the earth's surface.

3.2.6 Transportation to Europe

Two scenarios for the transportation of whole salmon (HOG) to Europe are analysed. Scenario 1 is transportation by containership where the fish is kept in refrigerated containers during the whole transportation period. For scenario 2 the fish is transported by air freight, where the fish is not kept in a refrigerated environment during the air freight. Same transportation distances are assumed for both functional units, i.e. the fresh salmon (HOG), delivered to retailer or secondary processing and salmon transported to the smokehouse in France.

Scenario 1

The inputs of whole gutted salmon, transportation modes and distances to the smokehouse are given in Table 3-19. The smokehouse in France receives 1,526 tonnes of salmon (with head on) from Iceland.

The salmon is transported by truck from the farm in Iceland to harbour in Reykjavík (400 km). The salmon is further transported by ship from Reykjavík to Rotterdam (2,200 km) and truck transport from Rotterdam to Boulogne-sur Mer (350 km).

During transportation in trucks and ship the fish is kept in refrigerated freight containers. These containers therefore include cooling agents. Data on refrigerant charge and leakage (R134a) and energy use for maintaining -1°C in the refrigerated containers is estimated using literature data (Heap & Lawton, 1999).

Table 3-19 Amount of whole, gutted salmon with head on, delivered at the smokehouse for 1 year operation, and transportation mode and distances from the aquaculture farm in Iceland for scenario 1

	Amount (tonnes/yr)	Origin	Type of transportation	Remarks
Whole, gutted salmon with head on	1,343	Iceland	Truck & ship	Truck in Iceland: 260 km Ship to Rotterdam: 2,200 km Truck to smokehouse: 350 km Total use of refrigerant (R134a): 0.02 kg Diesel to operate refrigerated container: 5.2 kg

Scenario 2

Salmon is transported by truck from the farm to airport in Iceland (450 km), air freight from Keflavík to Cologne (2,250 km) and truck transport to Boulogne-sur Mer (440 km), see Table 3-20.

Transportation in trucks is in refrigerated freight containers, and therefore includes cooling agents. During the air freight, the fish is not kept in a refrigerated container, but is kept cold with the cooling mats which are placed inside the EPS boxes.

Table 3-20 Amount of whole, gutted salmon with head on, delivered at the smokehouse for 1 year operation, and transportation mode and distances from the aquaculture farm in Iceland for scenario 2

	Amount (tonnes/yr)	Origin	Type of transportation	Remarks
Whole, gutted salmon with head on	1,343	Iceland	Truck & air freight	Truck in Iceland: 310 km Flight to Cologne: 2,250 km Truck to retailer/smokehouse: 440 km Total use of refrigerant (R134a): 0.002 kg Diesel to operate refrigerated container: 0.57 kg

3.2.7 Smokehouse

Life cycle inventory of the smokehouse were obtained from a questionnaire filled in by the smoked fish producer FODIX[5]. The reference period for the inventory data is one year, from 30/11/2011 - 30/11/2012.

During the operational year approximately 74% by weight of the fresh salmon (HOG) delivered to the smokehouse in France is assumed to come from the producer in Iceland. In the LCI dataset all operational data is scaled accordingly.

[5] http://www.fodixgroup.com/

Smokehouse Land Use

Land use for the operation of the smokehouse was estimated and modelled equal to the land use and occupation of the aquaculture salmon farm, see Table 3-21.

Table 3-21 Land use for the operation of the smokehouse

	Amount	Unit	Remarks
Total land area covered by the production site (excluding buildings)	1,500	m^2	Estimated to be the same land use as for the aquaculture farm facilities
Area covered by factory halls	2,000	m^2	

Smokehouse inputs

Electricity use is provided for the smoking oven, ventilated cooling chamber and other electricity use (Table 3-22). Operation of the smoking oven is the most electricity intensive part of the smokehouse operation, with 85% of all electricity use. The use of electricity in the smokehouse in France is modelled using a dataset for the French electricity grid.

The smokehouse operates one light vehicle (diesel van) which is modelled with datasets for light vehicle (< 3,5 tonnes) and diesel oil. Machinery is maintained using lubricating oil.

Table 3-22 Use of energy for operation of the smokehouse in France

Annual energy use	Amount	Unit/year	Remark
Electricity used for the smoking oven	749,760	kWh	
Electricity used for the ventilated cooling chambers	88,207	kWh	
Electricity used for other purposes	40,103	kWh	
Total electricity used	***878,070***	***kWh***	
Diesel for operation of vehicles (please specify)	8,000	L	Light vehicle (< 3.5 tonne)
Machinery lubrication	100	L	

In total 11,900 m^3 of water was utilized at the smokehouse during the operation year (Table 3-23). Fresh cold water from tap is the dominant water use, or 97% of the total water consumption.

Table 3-23 Water use at the smokehouse in France

Water use	Amount	Unit/year
Fresh water (hot)	300	m^3
Fresh water (cold)	11,600	m^3
Total water use	***11,900***	m^3

Use of auxiliary materials can be seen in Table 3-24. Salt supplier is located in the South of France, and salt is transported by truck to Boulogne-sur-Mer (950 km). Detergents are modelled using a general dataset for soap.

Refrigerant used in cooling chamber is R-404a which is a mix of R 143a (52 wt.%), R 125 (44 wt.%) and R 134a (4 wt%) (DuPont, 2012). The total load of the refrigerant in the cooling system is 200 kg, and an annual leakage of 2% is assumed, therefore 4 kg are added during the year, i.e. 4 kg are lost to air during the operational year. Beech wood chips (hardwood) are used in the smoking process.

Table 3-24 Auxiliary substances used for the smokehouse operation

	Amount	Unit/year	Remark
Salt	223,000	kg	Salt is transported from the South of France
Spices	3,200	kg	
Detergents/soap	8,800	kg	
Refrigerants	4	kg	R404A
Wood chips	134	m^3	Beech wood chips for smoking oven

Use of packaging materials at the smokehouse for one operational year can be seen in Table 3-25. Packaging consists of a plastic polyethylene film (Pa/PE film), suitable for modified atmosphere packaging and carton. The carton is covered with aluminium foil; a datasheet for liquid packaging board containers is used as an estimate. The producer of packaging is located 1 km from the processing site. Furthermore 10,000 kg of cardboard boxes are utilized. Photograph showing the packaging of smoked salmon at Fodix can be seen in Figure 3-6.

Figure 3-6: Packaging of smoked and sliced salmon fillets at Fodix in France.

Table 3-25 Packaging for smoked salmon leaving the smokehouse

Packaging	Amount	Unit/year	Remark
Plastic film	27,960	kg	Plastic is Pa/PE film
Carton	65,240	kg	Carton is from recycled carton and it is covered with aluminium foil
Cardboard boxes	10,000	kg	

Smokehouse outputs

The smokehouse production volumes as well as the products' shares in the annual turnover and share by weight are presented in Table 3-26. During the one year period (30/11/2011 - 30/11/2012) the smokehouse produced 913 tonnes of smoked salmon products, and 3.4 tonnes of other products. The share of salmon products was 99.6 wt% and 99.7% of turnover. The environmental burden of herring and haddock products (0.4 wt% and 0.3% of turnover) are allocated to the salmon products in the study due to their low share.

Table 3-26 Production volumes of the smokehouse in tonnes per year and products' shares in the annual turnover and by product weight

	Produced amount	Unit/year	Share of total production		Remarks
			% of turnover	% of weight	
Main products:					
Cold smoked sliced vacuum	860	tonnes	98.5%	93.8%	Skin off
Cold smoked whole vacuum	26	tonnes	0.3%	2.9%	
Hot smokes salmon portion with spices	12	tonnes	0.3%	1.3%	
Co-product	15	tonnes	0.6%	1.6%	
Total salmon products	***913***	***tonnes***	***99.7%***	***99.6%***	
Other products:					
Herring filets cold smoked vacuum	0.4	tonnes	0.0%	0.0%	
Haddock	3	tonnes	0.3%	0.4%	
Total other products	***3.4***	***tonnes***	***0.3%***	***0.4%***	
Total products:	**917**	**tonnes**	**100.0%**	**100.0%**	

The salmon is headed, filleted and trimmed before processing (smoking) takes place. Because the by-products are not processed further at the smokehouse all energy use and use of materials in the smokehouse are allocated to the salmon products. The amount of by-products can be seen in Table 3-27.

Table 3-27 By-products from the smokehouse

	Amount	Unit/year
Heads and skin	411	tonnes
Trimmings	18	tonnes
Total	**429**	**tonnes**

In Table 3-28 the amount of waste generated in the smokehouse is given. Production losses (bones) are sent to landfill with methane recovery. The unsorted waste is mainly cardboard and some EPS boxes which are sent to landfill. The sorted fraction of the waste is polystyrene which is sent to incineration with energy recovery and hazardous waste is sent to hazardous waste incineration facility.

Table 3-28 Waste from the smokehouse operation

	Amount	Unit/year	Remarks
Product loss	1.1	tonnes	Recycling for methanisation (bones)
Unsorted waste	24,264	kg	Used boxes (cardboard boxes)
Polystyrene	9,360	kg	Used EPS boxes
Hazardous waste	50	kg	

In Table 3-29 the total wastewater discharges from the smokehouse can be seen. Small fraction (3%) of the total wastewater is discharged into the municipal sewer system, while most of the wastewater (97%) is discharged into the smokehouse waste water treatment plant (WWTP). Waste water quality parameters for the WWTP are given. The wastewater discharged directly to the municipal sewer system is mostly from office activities and canteen. Wastewater from the processing hall is directed to WWTP on site, where the recipient is seawater.

Table 3-29 Wastewater quality from pre-treatment from the smokehouse operation

	Amount	Unit/year	Remark
Discharge to sewage system	360	m^3	Recipient: sea
Pre-treatment in own wastewater treatment plant (WWTP)	11,540	m^3	
Biochemical oxygen demand (BOD)	800	mg/l	
Chemical oxygen demand (COD)	2,000	mg/l	
Nitrogen (total)	150	mg/l	
Ammonium	150	mg/l	
Sodium ions	400	mg/l	
TSS	500	mg/l	

Data Cut offs

The production of spices was not included in the study because of lack of data on environmental impacts. This ingredient is used in small quantities and is therefore not considered to make large contributions to the environmental impact.

3.2.8 Transportation to retailer

In Table 3-30 the transportation modes and distances from smokehouse to retailer can be seen.

Table 3-30 Transportation modes and distances from smokehouse to retailer

Transport	Distance	Unit	Transportation mode
Average distance **smoked** salmon products are transported from processing to wholesaler	300	km	truck
Average distance **smoked** salmon is transported from wholesaler to retailer	20	km	truck

3.3 Life Cycle Impact Assessment for fresh salmon (HOG)

The results from the LCIA for functional unit 1, fresh salmon (HOG), are presented in this chapter. Two transportation scenarios from Iceland to Europe are assessed. Figure 3-7 and Figure 3-8 show the relative contribution of environmental impacts of the different life cycle stages for the two assessed scenarios. In scenario 1 the main contributor in all impact categories is the aquaculture farm life cycle stage where the production of salmon feed is dominant factor in most categories.

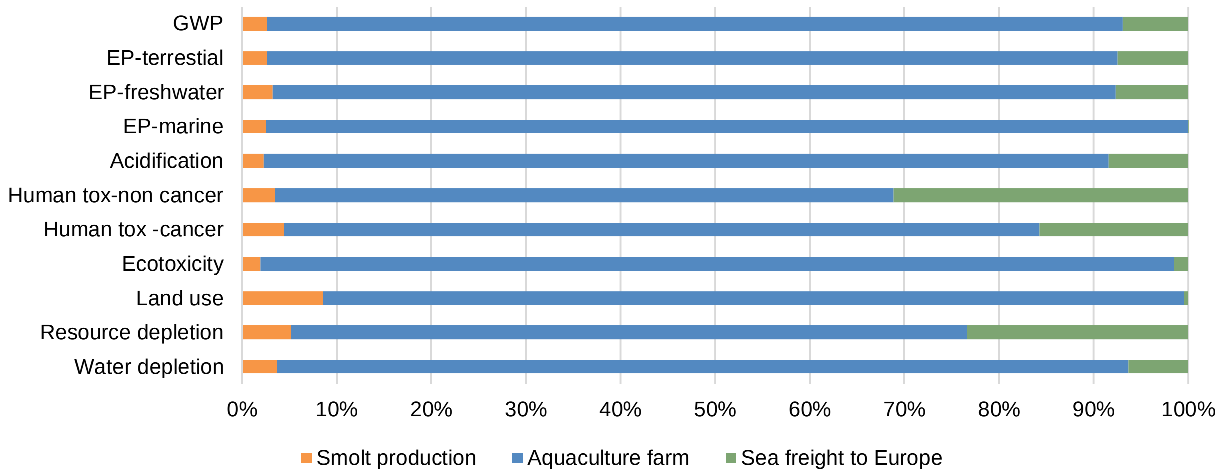

Figure 3-7 Relative contribution of environmental impacts for the different life cycle stages for fresh salmon (HOG), scenario 1

In scenario 2 the aquaculture farm is the main contributor to environmental impacts in seven of the 11 assessed impact categories, i.e. for terrestrial, freshwater and marine eutrophication, human toxicity (cancer effects), ecotoxicity, land use and water depletion. For the climate change impacts, acidification, human toxicity (non-cancer effects) and resource depletion the transportation phase is the main source of impact.

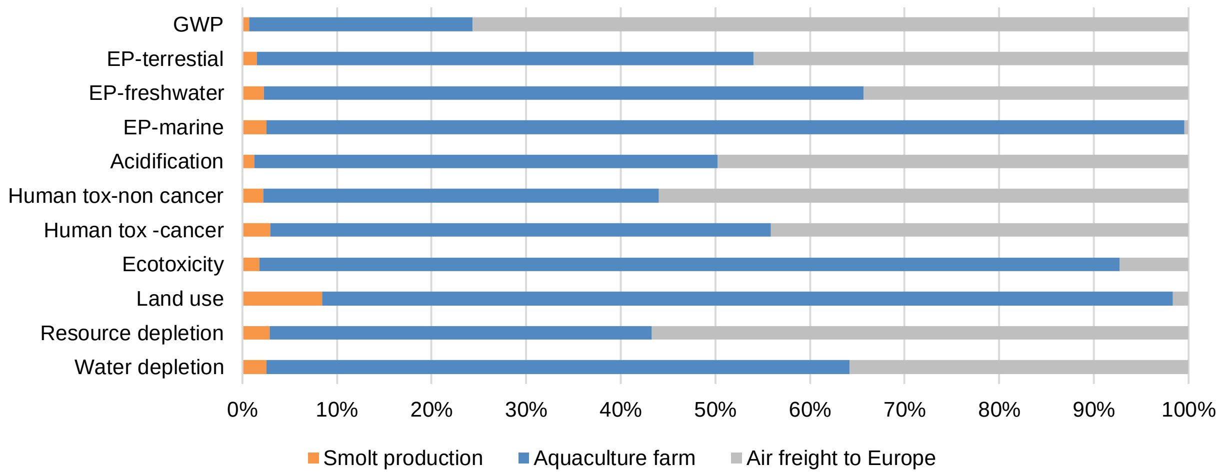

Figure 3-8 Relative contribution of environmental impacts for the different life cycle stages for fresh salmon (HOG), scenario 2

The LCIA results for each life cycle stage for both scenario1 and scenario 2 are shown in digits in Table 3-31 and Table 3-32 respectively.

Table 3-31 LCIA results for 1 kg fresh salmon (HOG) transported by sea freight to Europe and share of different life cycle steps in each impact category

Impact category	Unit	Smolt production		Aquaculture farm		Sea freight		Total
			%		%		%	
Climate Change	Kg CO_2 - eq	7,0,E-02	3	2,4,E+00	90	1,8,E-01	7	2,7,E+00
Eutrophication - terrestrial	mol_c N eq	2,0,E-03	3	6,8,E-02	90	5,6,E-03	7	7,5,E-02
Eutrophication - freshwater	kg P eq	7,6,E-06	3	2,1,E-04	89	1,8,E-05	8	2,3,E-04
Eutrophication - marine	kg N eq	4,2,E-03	3	1,6,E-01	97	6,3,E-05	0	1,6,E-01
Acidification	molc H^+ eq	3,2,E-04	2	1,3,E-02	89	1,2,E-03	8	1,4,E-02
Human toxicity - non cancer effects	CTU_h	6,5,E-09	3	1,2,E-07	65	5,8,E-08	31	1,9,E-07
Human toxicity - cancer effects	CTU_h	2,5,E-09	4	4,4,E-08	80	8,7,E-09	16	5,5,E-08
Ecotoxicity - freshwater	CTU_e	1,6,E-01	2	8,1,E+00	97	1,2,E-01	1	8,4,E+00
Land use	kg C deficit	8,6,E-03	9	9,2,E-02	91	4,3,E-04	0	1,0,E-01
Abiotic resource depletion	kg Sb eq	8,8,E-07	5	1,2,E-05	71	4,0,E-06	23	1,7,E-05
Water depletion	m^3 water eq	1,3,E-02	4	3,1,E-01	90	2,1,E-02	6	3,4,E-01

Table 3-32 LCIA results for 1 kg fresh salmon (HOG) transported by air freight to Europe and share of different life cycle steps in each impact category

Impact category	Unit	Smolt production		Aquaculture farm		Air freight		Total
			%		%		%	
Climate Change	Kg CO_2 - eq	7,0,E-02	1	2,4,E+00	24	7,6,E+00	76	1,0,E+01
Eutrophication - terrestrial	mol_c N eq	2,0,E-03	2	6,8,E-02	53	5,9,E-02	46	1,3,E-01
Eutrophication - freshwater	kg P eq	7,6,E-06	2	2,1,E-04	63	1,1,E-04	34	3,3,E-04
Eutrophication - marine	kg N eq	4,2,E-03	3	1,6,E-01	97	7,0,E-04	0	1,6,E-01
Acidification	molc H^+ eq	3,2,E-04	1	1,3,E-02	49	1,3,E-02	50	2,6,E-02
Human toxicity - non cancer effects	CTU_h	6,5,E-09	2	1,2,E-07	42	1,6,E-07	56	2,9,E-07
Human toxicity - cancer effects	CTU_h	2,5,E-09	3	4,4,E-08	53	3,7,E-08	44	8,4,E-08
Ecotoxicity - freshwater	CTU_e	1,6,E-01	2	8,1,E+00	91	6,4,E-01	7	8,9,E+00
Land use	kg C deficit	8,6,E-03	8	9,2,E-02	90	1,7,E-03	2	1,0,E-01
Abiotic resource depletion	kg Sb eq	8,8,E-07	3	1,2,E-05	40	1,7,E-05	57	3,0,E-05
Water depletion	m^3 water eq	1,3,E-02	3	3,1,E-01	62	1,8,E-01	36	5,0,E-01

3.3.1 Climate change

The global warming potential (GWP) related to the production of 1 kg of fresh salmon (HOG) is 2.7 kg CO_2 equivalent if transported by sea freight from Iceland to Europe, but 10.1 kg CO_2 equivalent when transported by air freight. A breakdown of the GWP by individual production stages is shown in Figure 3-9.

For scenario 1 the operation of the aquaculture farm is the dominant life cycle stage in terms of GWP accounting for 90% of the total greenhouse gas (GHG) emissions, where the salmon feed is the greatest contributor of the total impact (65%) which is mainly connected to the fuel used for harvesting the marine ingredients. The transportation of fresh fish (HOG) by sea freight contributes approximately 7% to the total GHG emissions and the smolt production 3%. For scenario 2 the GWP is increased by a magnitude of four, where the transport by air freight is the dominant life cycle phase (76 %), mainly due to burning of fossil fuels. The transportation phase in scenario 2 has 42 times higher GWP than the transport phase in scenario 1.

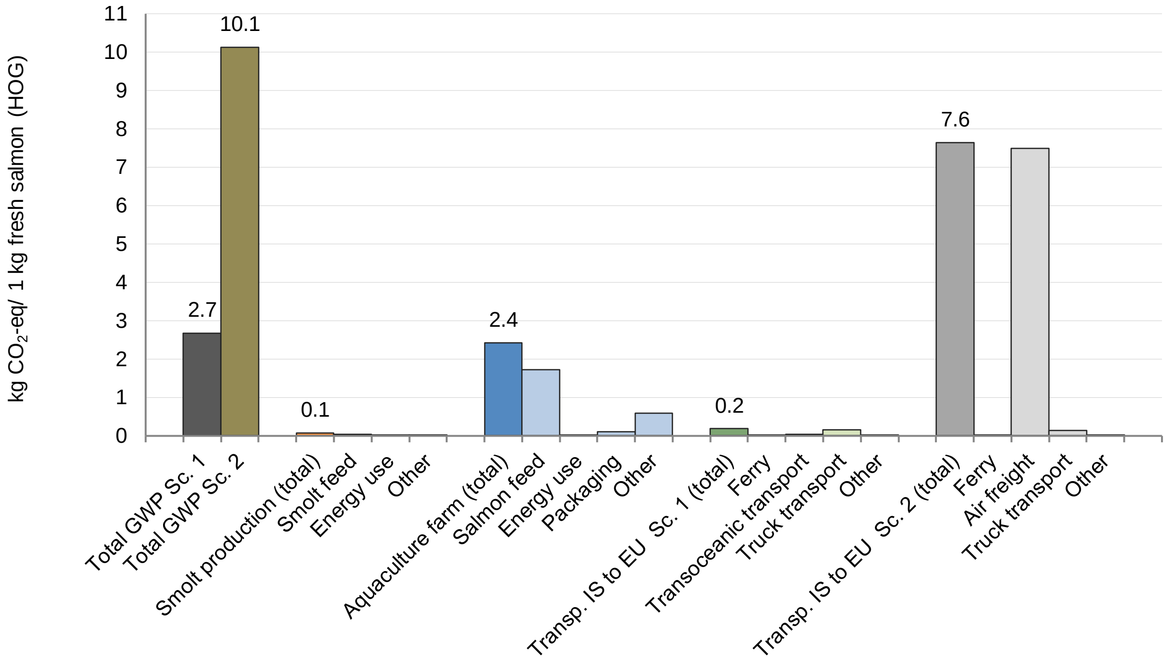

Figure 3-9 Global warming potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

Table 3-33 Legend explanation for Figures 3-9 to 3-19

	Legend	Included processes
Smolt production	Smolt feed	Cultivation of crop ingredients, harvesting of fish ingredients, transportation of ingredients to feed mill and energy use at feed mill
	Energy use	Electricity and diesel oil use
	Other	Land use and infrastructure, use of auxiliary substances, water use, transportation of salmon eggs, treatment of waste and disposal of wastewater
Aquaculture farm	Salmon feed	Cultivation of crop ingredients, harvesting of fish ingredients, transportation of ingredients to feed mill and energy use at feed mill
	Energy use	Electricity, diesel oil and petrol use
	Packaging	Production of packaging material
	Other	Land use and infrastructure, use of auxiliary substances, water use, transportation of smolt to farm, treatment of waste and disposal of wastewater
Transport	Ferry	Transportation of fresh salmon (HOG) by ferry in Iceland
	Transoceanic transport/ air freight	Transportation of fresh salmon (HOG) by ship or airplane from Iceland to Europe
	Truck transport	Transportation in trucks
	Other	Emissions from refrigerants and operation of refrigerated containers/trucks

3.3.2 Eutrophication

Terrestrial Eutrophication

The terrestrial eutrophication potential (EP) related to the production of 1 kg of fresh salmon (HOG) amounts to 0.076 mol_c N equivalents for scenario 1 and 0,13 mol_c N equivalents for scenario 2 (Figure 3-10).

For scenario 1 the life cycle stage at the aquaculture farm is responsible for 90% of the total terrestrial EP of which 71% of the total is related to the production of the salmon feed. Other life cycle stages, i.e. the transportation by sea freight and the smolt production contribute 7% and 3% respectively to the total impact.

For scenario 2 the total impacts are increased by 71% because of the increased impacts from the air freight. The air freight transportation phase contributes 46% to the total impact due to the fossil fuels and is 11 times larger than the impact from the transportation phase in scenario 1.

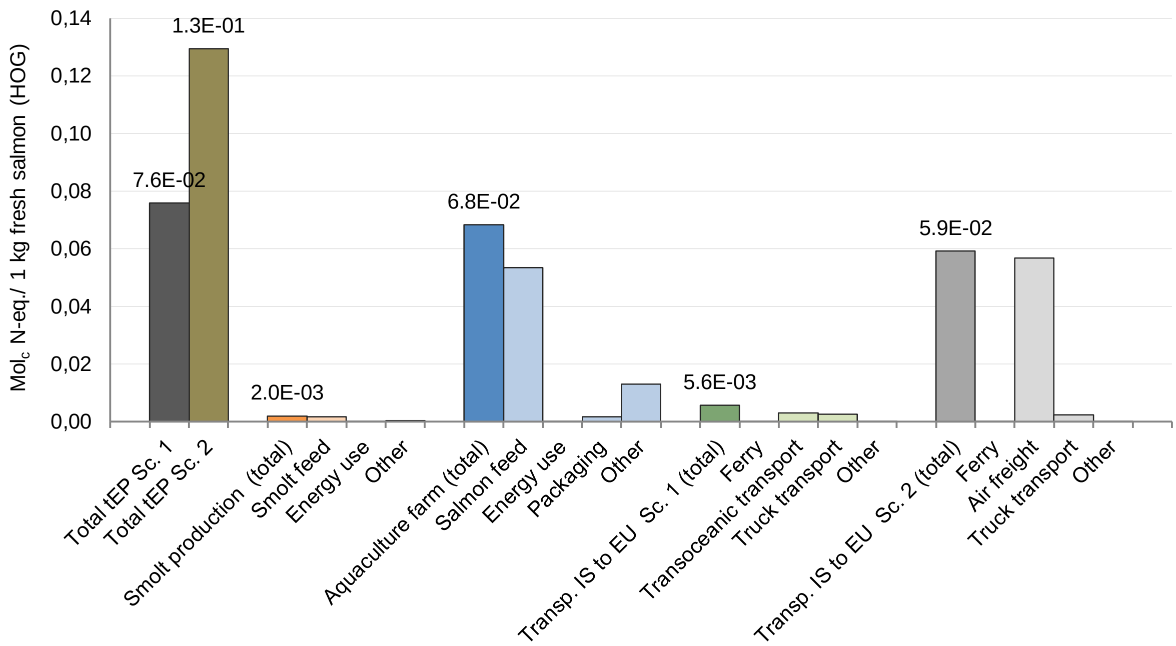

Figure 3-10 Terrestrial eutrophication potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

Freshwater Eutrophication

Total freshwater EP from the production of 1 kg of fresh salmon (HOG) is $2.4 \cdot 10^{-4}$ kg P equivalents for scenario 1 and $3.3 \cdot 10^{-4}$ kg P equivalents for scenario 2.

In scenario 1 the aquaculture farm life cycle stage is the greatest contributor to the freshwater EP with 89% of total impacts (Figure 3-11) from which feed ingredients are the largest contributor with 59% of total impacts. Other life cycle stages contribute in total to 11% of the total freshwater EP, the sea freight transportation from Iceland to Europe with 8% and the production of smolt 3%.

For scenario 2 the air freight contributes 34% to the total impacts and has 6 times greater impact than the transportation phase from scenario 1.

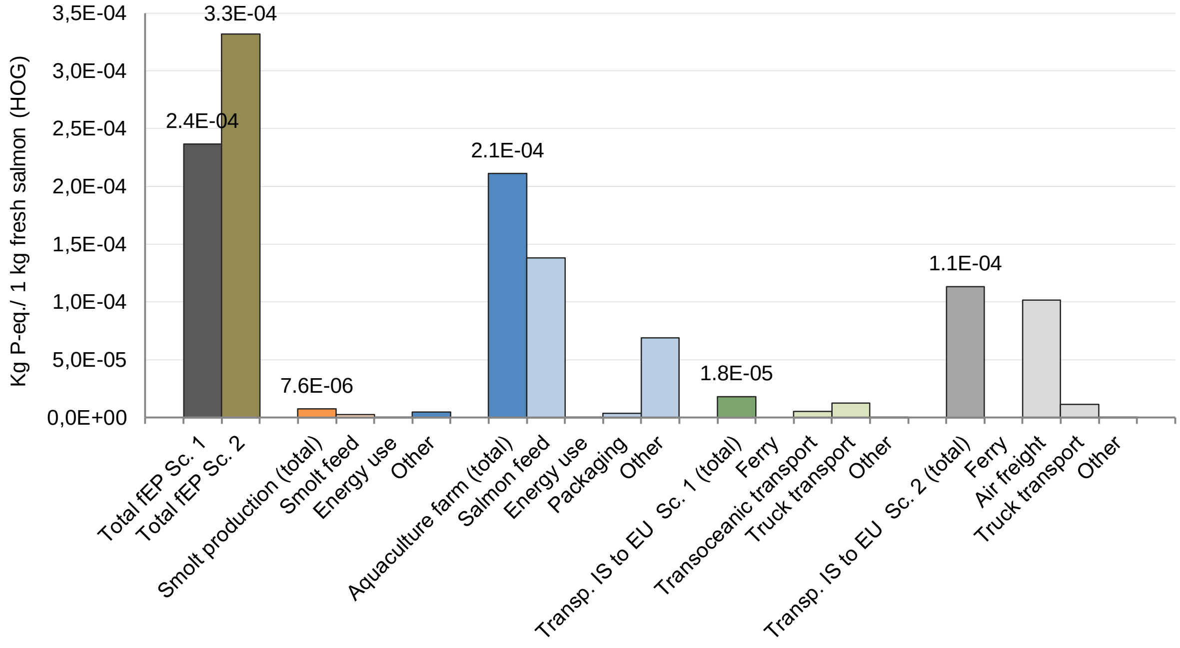

Figure 3-11 Freshwater eutrophication potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

Marine Eutrophication

Marine EP for the production of 1 kg of fresh salmon (HOG) is found to be 0.16 kg N equivalents for both scenarios (Figure 3-12). The main contributor is the aquaculture farming life cycle stage (97%) due to organic matter emitted to sea (faeces, feed and dead fish). The hatchery contributes 3% to the total impacts, predominantly due to emissions of organic matter to sea.

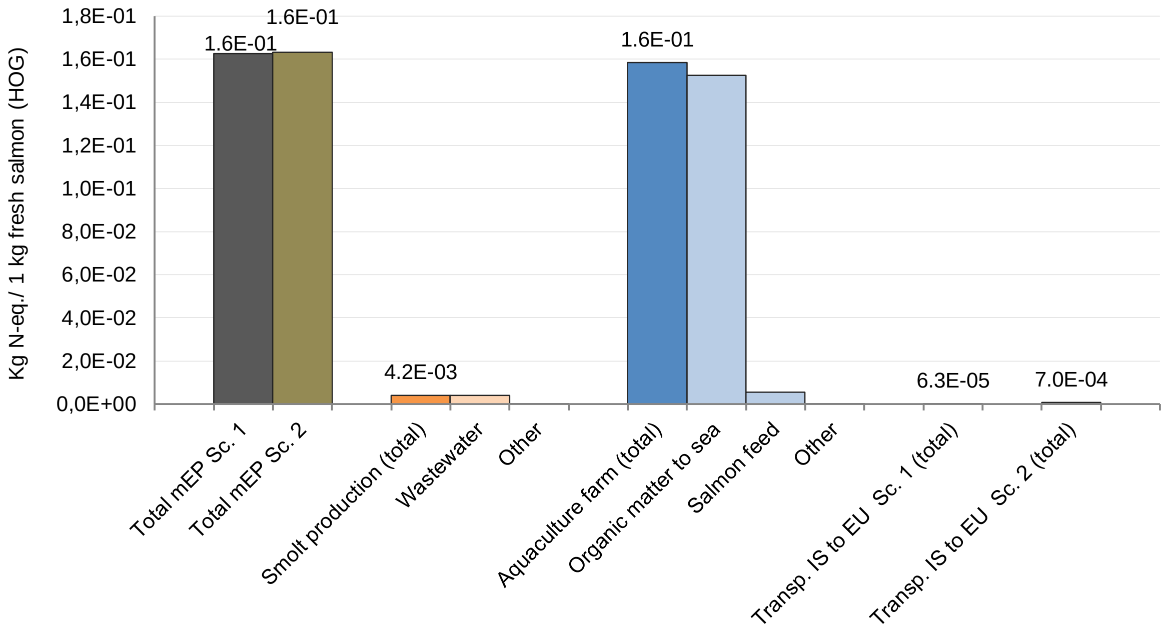

Figure 3-12 Marine eutrophication potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

3.3.3 Acidification

Acidification potential (AP) for the production of 1 kg fresh salmon (HOG) is $1.4{\cdot}10^{-2}$ mol_c H^+ equivalents for scenario 1 and $2.6{\cdot}10^{-2}$ mol_c H^+ equivalents for scenario 2 (Figure 3-13).

For scenario 1 the operation of the aquaculture farm is the main cause of impact (89%) where the marine feed ingredients (catching of fish) is the main contributor. The sea freight transportation phase contributes 9% to the total impacts and the smolt production 2%.

For scenario 2 the aquaculture farm stage contributes 49% to total impact and the air freight transportation stage 50%. Processes contributing the most to the total impacts are the burning of fossil fuels during the air freight and the harvesting of marine feed ingredients. The transportation by air has 11 times greater impact than the transportation phase in scenario 1.

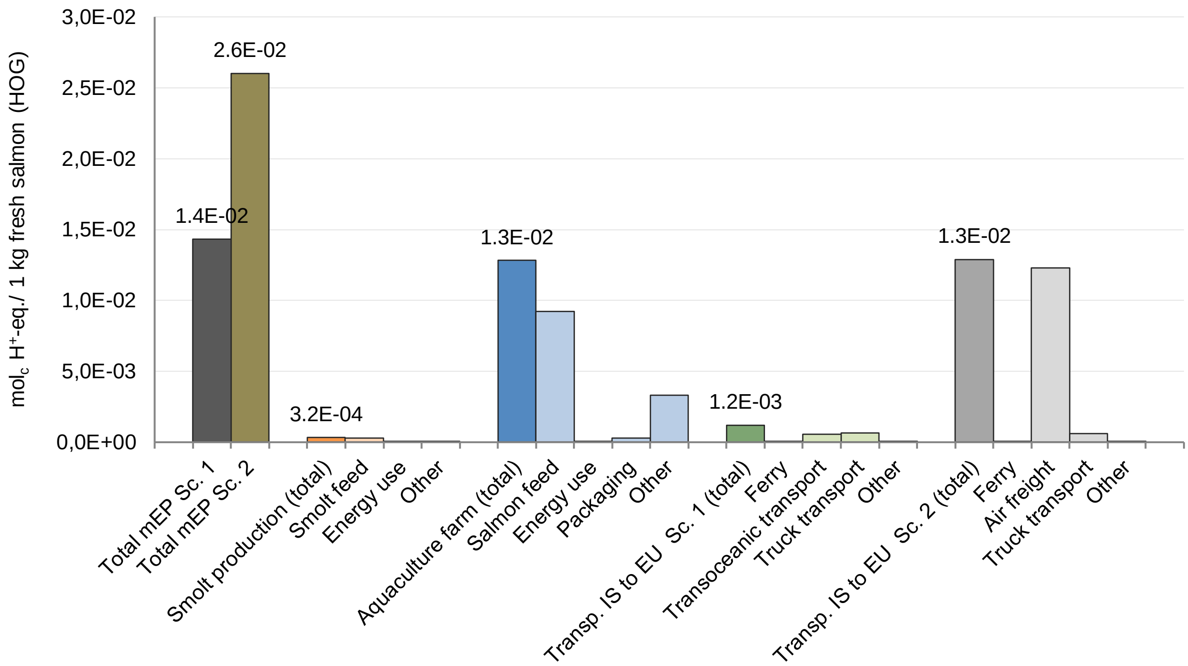

Figure 3-13 Acidification potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

3.3.4 Human Toxicity

Human toxicity, non-cancer effects

The total human toxicity potential (HTP), non-cancer effects is found to be $1.9 \cdot 10^{-7}$ CTU_h[6] for scenario 1 and $2.9 \cdot 10^{-7}$ CTU_h for scenario 2 (Figure 3-14).

For scenario 1 the operation of the aquaculture farm is responsible for 65% of the total HTP, non-cancer impacts, mainly due to the salmon feed (23%). The sea freight transportation phase contributes 31% to the total impacts. The smolt production is responsible for 4% of the total impacts.

In scenario 2 the transportation phase dominates the total impacts (56%) due to fossil fuel use in air freight and truck. The impact from the air freight transportation phase in scenario 2 is approximately 3 times larger than from the transportation phase in scenario 1.

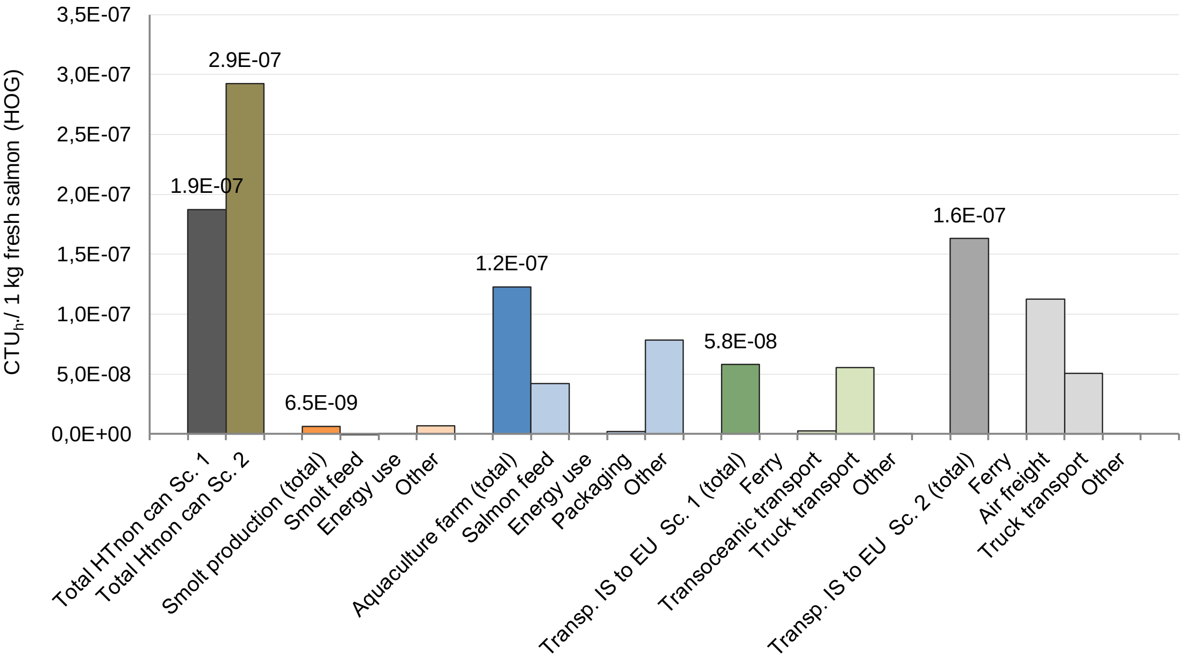

Figure 3-14 Human toxicity potential, non-cancer effects, for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

[6] Comparative Toxic Unit for Humans.

Human toxicity - cancer effects

The human toxicity potential, cancer effects, for production of 1 kg of fresh salmon (HOG) is $5.7 \cdot 10^{-8}$ CTU_h for scenario 1 and $8.5 \cdot 10^{-8}$ CTU_h for scenario 2 (Figure 3-15).

The aquaculture farm is responsible for 80% of the total impact in scenario 1 due to production and transportation of the salmon feed. Other life cycle phases contribute 20%, the transportation phase 16% and the smolt production 4%.

In scenario 2 the salmon feed for the aquaculture farm and the transportation phase contribute 53% and 44% respectively. The air freight transportation phase causes 4 times larger impact than the transportation phase in scenario 1.

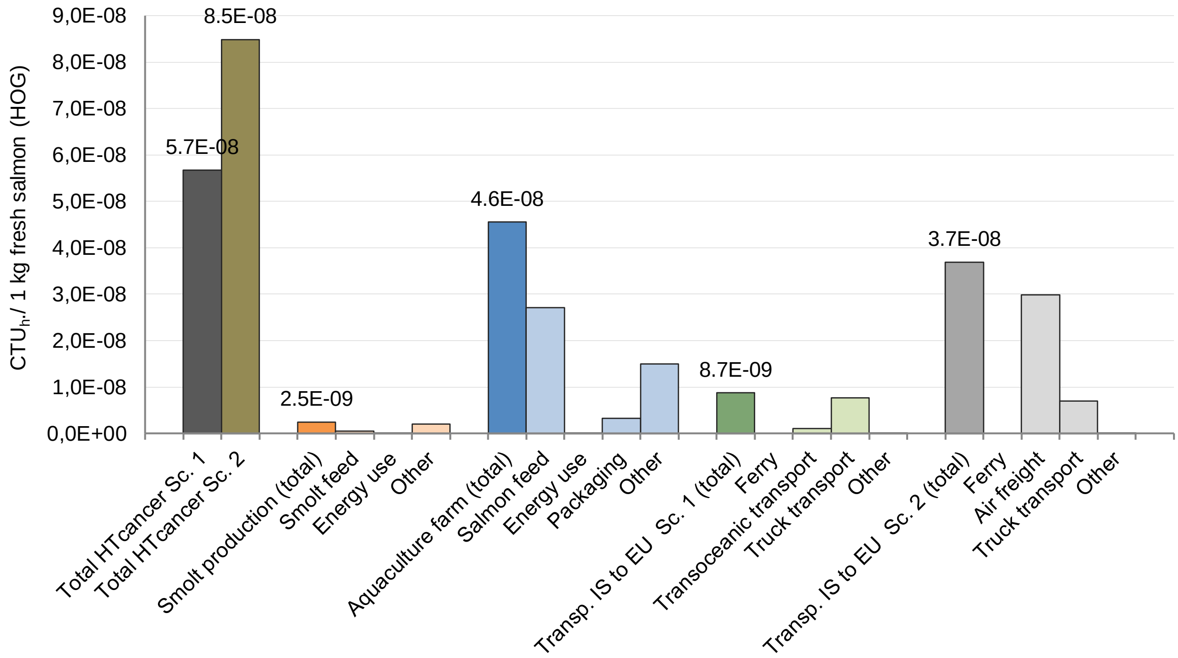

Figure 3-15 Human toxicity potential, cancer effects, for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

3.3.5 Ecotoxicity

Freshwater Ecotoxicity

Freshwater ecotoxicity potential is found to be 8.4 CTU_e[7] for scenario 1 and 8.9 CTU_e for scenario 2 (Figure 3-16). The main life cycle stage is the operation of the aquaculture farm, 97% in scenario 1 and 91% in scenario 2 due to feed. The transportation phases contribute 1% in scenario 1 and 7% in scenario 2. The air freight impact is more than five times greater than the sea freight.

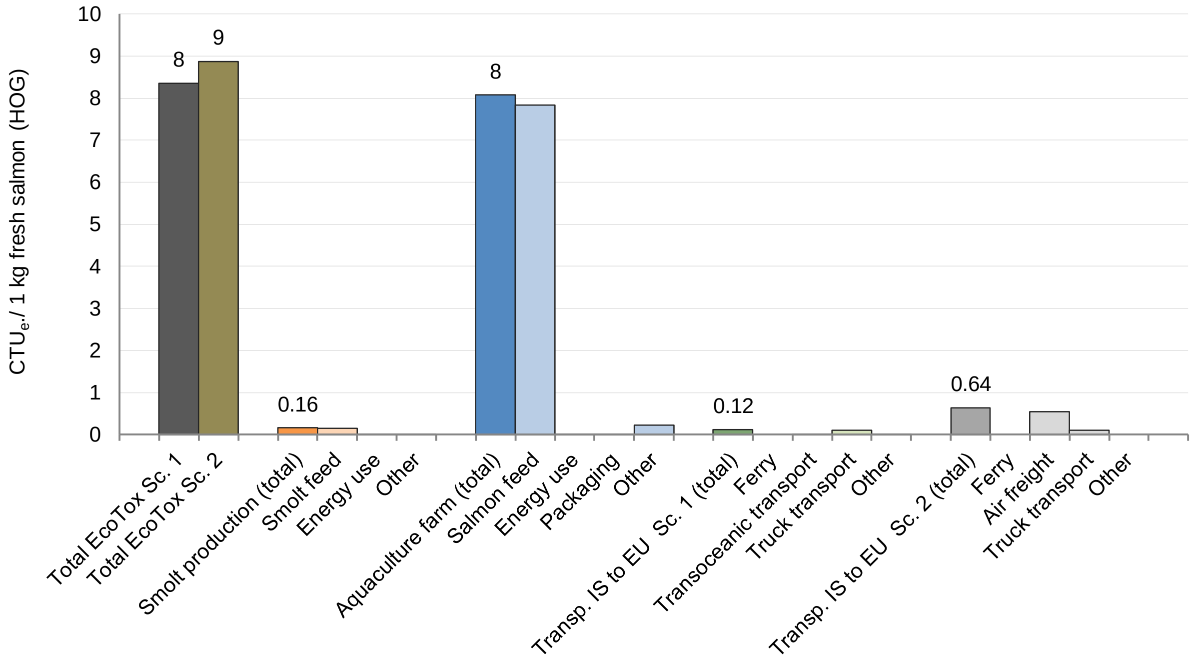

Figure 3-16 Freshwater ecotoxicity potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

Terrestrial and Marine Ecotoxicity

For terrestrial and marine ecotoxicity no method is currently recommended by the ILCD (JRC, 2011). Therefore these impacts are not assessed in this study. However, these impacts are relevant for aquaculture products as large part of feed ingredients are from marine sources which are caught using vessels.

[7] Comparative Toxic Unit for Ecosystems.

3.3.6 Land Use

The land use impact for both scenarios is 0.1 kg C deficit per kg fresh salmon (HOG) (Figure 3-18). The dominant cause of impact for both scenarios is the Aquaculture farm (approximately 90%) with the feed causing 85% of the total land use impacts. The transportation phase in scenario 2 is 4 times greater in terms of impact than the transportation phase in scenario 1.

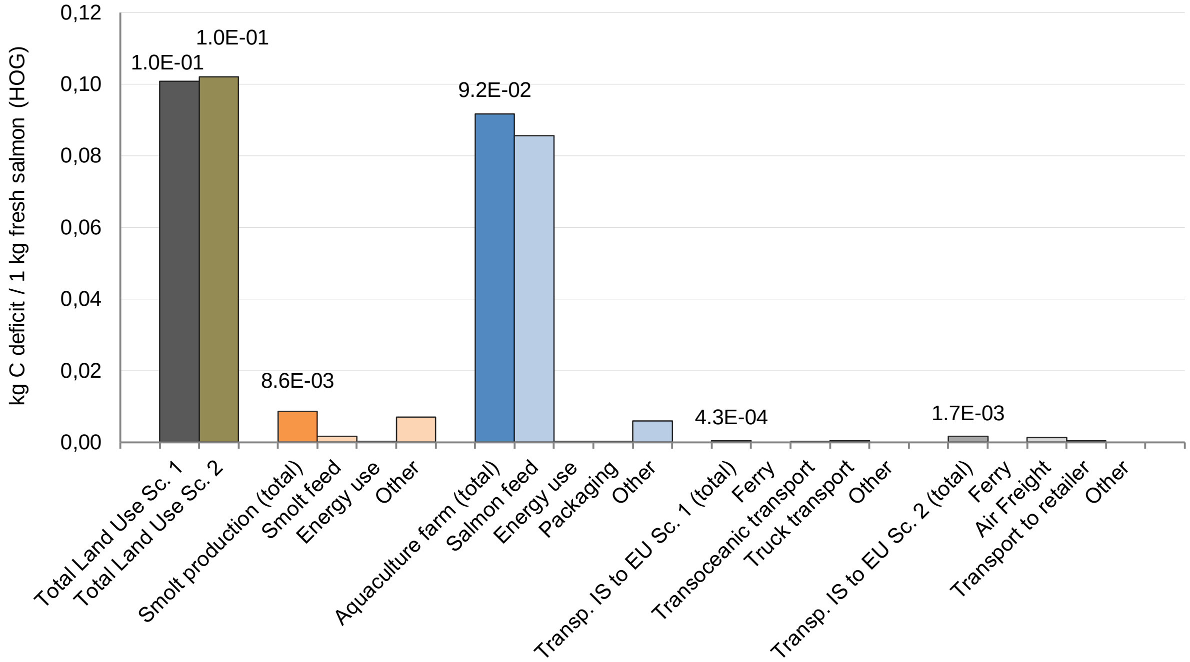

Figure 3-17 Land use impact for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

3.3.7 Abiotic Resource Depletion

The abiotic resource depletion (ARD) potential, i.e. the depletion of minerals, fossil energy and renewables, for the production of 1 kg of fresh salmon (HOG) is $1.7 \cdot 10^{-5}$ kg antimony (Sb) equivalents for scenario 1 and $3.0 \cdot 10^{-5}$ kg antimony (Sb) equivalents for scenario 2 (Figure 3-18).

The main life cycle stage contributing to the total emissions for scenario 1 is the operation of the aquaculture farm (72%) with the salmon feed contributing 53% to the total impacts. The transportation phase contributes 23% to the total impacts and the smolt production 5%. The main contributor to this impact is the use of fossil fuels.

For scenario 2 the air freight phase is dominant, contribution 57% to the total impacts and the aquaculture farm contributes 40% of the total impacts. The transportation phase in scenario 2 is 4 times greater in terms of impact than the transportation phase in scenario 1.

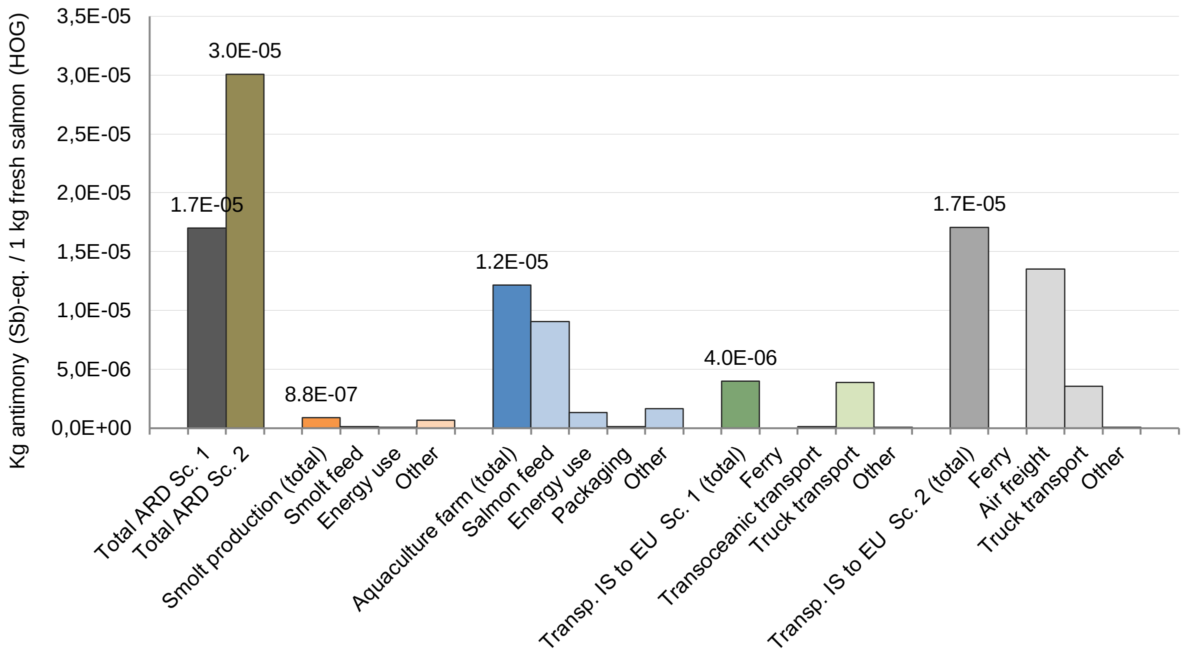

Figure 3-18 Abiotic resource depletion potential for production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

3.3.8 Water Depletion

From Figure 3-19 the water depletion potential for both scenarios can be seen. The water depletion potential for scenario 1 is $3.4 \cdot 10^{-4}$ m^3 equivalents and $5.0 \cdot 10^{-4}$ m^3 equivalents for scenario 2.

For scenario 1 the aquaculture farm contributes 90% to the total impact, where the share of the production of packaging material is 34% and the production of concrete and glulam for the infrastructure in total contribute approximately 33% of the total water depletion. The salmon feed is responsible for 17% of the total impact. The transportation contributes 6% and the smolt production phase 4% of total impacts.

For scenario 2 the aquaculture farm is the main contributor (62%) whereas the transportation phase is responsible for 36% of the total impact. The air freight transportation phase is found to be eight times larger than the sea freight phase.

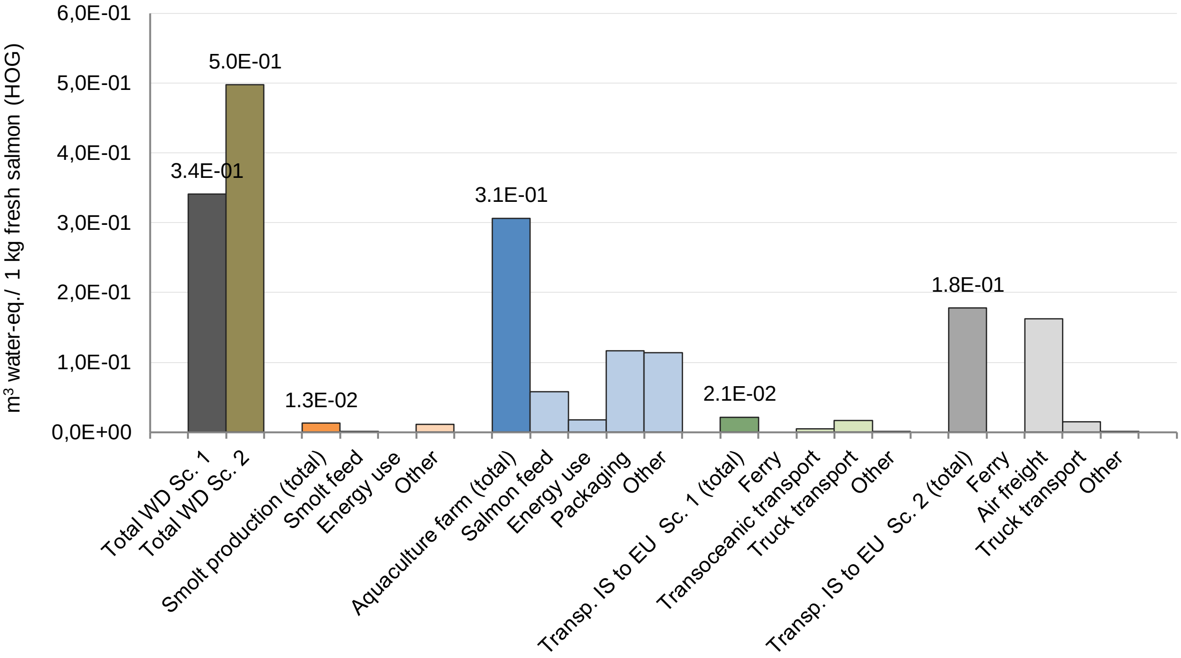

Figure 3-19 Water depletion from the production of 1 kg of fresh salmon (HOG). Two different transportation modes are presented (scenario 1 and scenario 2)

3.4 Life Cycle Impact Assessment for smoked salmon fillets

The results from the LCIA for the functional unit 2 (smoked salmon fillets) and transportation scenario 1 (sea freight) is presented in this chapter.

Figure 3-20 shows the relative contribution of environmental impacts of the different life cycle stages for the smoked salmon fillet. In nine of the 11 assessed impact categories the aquaculture farm life cycle stage is the main contributor of environmental impacts, mainly due to the feed. In two impact categories, human toxicity (non-cancer effect) and water depletion the operation of the smokehouse in France is the main source of impact. The LCIA results for each life cycle stage of the smoked salmon fillets are shown in digits in Table 3-34.

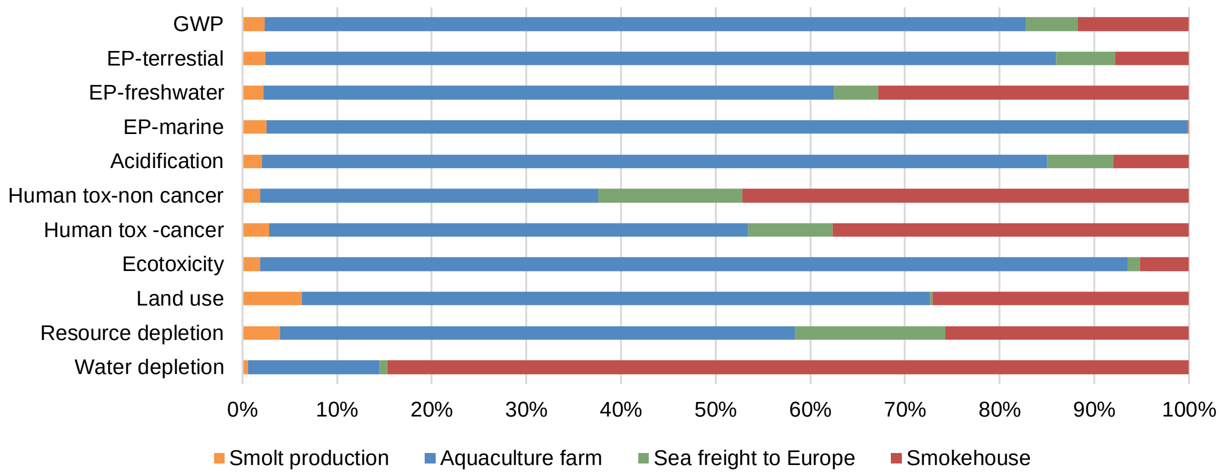

Figure 3-20 Relative contribution of environmental impacts for the different life cycle stages for smoked salmon fillet

Table 3-34 LCIA results for 1 kg smoked salmon fillet and share of different life cycle steps for each impact category

Impact category	Unit	Smolt production		Aquaculture farm		Sea freight		Smokehouse		Total
			%		%		%		%	
Climate Change	Kg CO_2 - eq	1,2,E-01	2	4,0,E+00	80	2,7,E-01	5	5,8,E-01	12	5,0,E+00
Eutrophication - terrestrial	mol_c N eq	3,3,E-03	2	1,1,E-01	84	8,4,E-03	6	1,1,E-02	8	1,4,E-01
Eutrophication - freshwater	kg P eq	1,3,E-05	2	3,5,E-04	60	2,7,E-05	5	1,9,E-04	33	5,8,E-04
Eutrophication - marine	kg N eq	6,9,E-03	3	2,6,E-01	97	9,4,E-05	0	2,9,E-04	0	2,7,E-01
Acidification	molc H^+ eq	5,4,E-04	2	2,1,E-02	83	1,8,E-03	7	2,1,E-03	8	2,6,E-02
Human toxicity - non cancer effects	CTU_h	1,1,E-08	2	2,0,E-07	36	8,7,E-08	15	2,7,E-07	47	5,7,E-07
Human toxicity - cancer effects	CTU_h	4,1,E-09	3	7,4,E-08	51	1,3,E-08	9	5,5,E-08	38	1,5,E-07
Ecotoxicity - freshwater	CTU_e	2,7,E-01	2	1,3,E+01	92	1,8,E-01	1	7,6,E-01	5	1,5,E+01
Land use	kg C deficit	1,4,E-02	6	1,5,E-01	66	6,4,E-04	0	6,3,E-02	27	2,3,E-01
Abiotic resource depletion	kg Sb eq	1,5,E-06	4	2,0,E-05	54	5,9,E-06	16	9,6,E-06	26	3,7,E-05
Water depletion	m^3 water eq	2,1,E-02	1	5,1,E-01	14	3,2,E-02	1	3,1,E+00	85	3,7,E+00

3.4.1 Climate change

The GWP related to the production of 1 kg of smoked salmon fillet is 5.0 kg CO_2 equivalent. A breakdown of the GWP by individual production stages is shown in Figure 3-21. Operation of the aquaculture farm is the dominant life cycle stage in terms of GWP accounting for 80% of the total GHG emissions, where the salmon feed, mainly harvesting of marine ingredients, contributes a significant 58%. Energy use at the aquaculture farm is responsible for 13% of the total GHG emissions. The second largest life cycle stage in terms of GWP is the operation at the smokehouse in France (12%), where energy use (4%) and production of packaging materials (4%) are the main contributors. Additionally, smolt production (2%) and transportation of fresh whole salmon (HOG) from Iceland to the smokehouse in France (5%) contribute considerably less to the overall GWP.

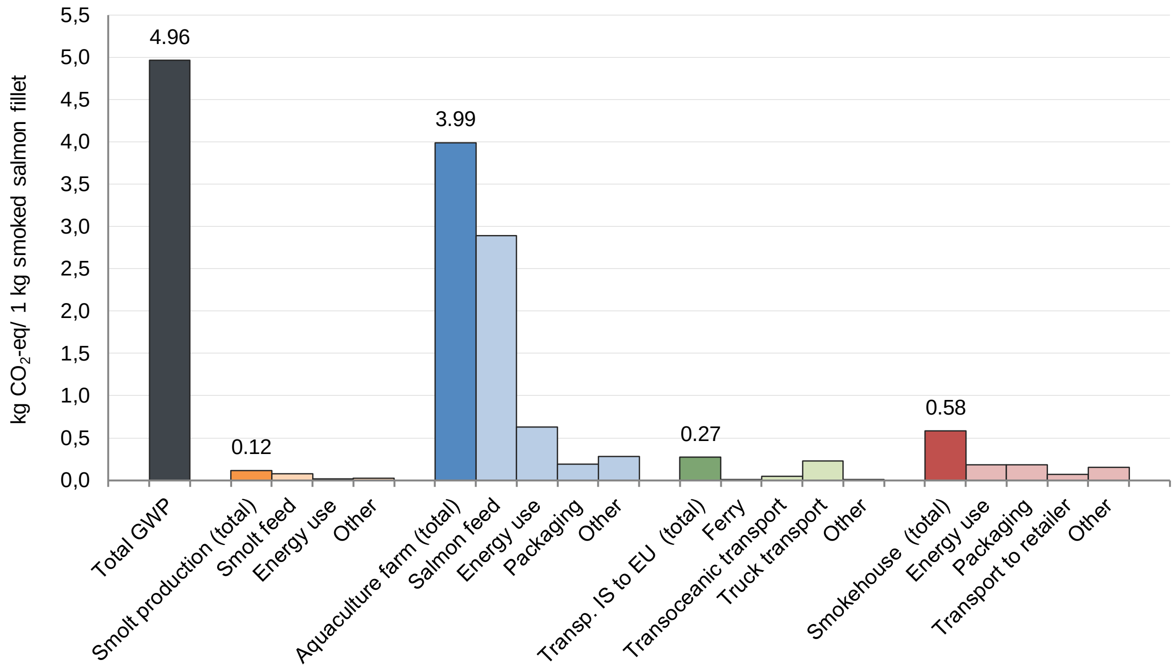

Figure 3-21 Global warming potential for production of 1 kg of smoked salmon fillet. The salmon feed is responsible for 58% of the global warming impacts

Table 3-35 Legend explanation for Figures 3-21 to 3-31

	Legend	Included processes
Smolt production	Smolt feed	Cultivation of crop ingredients, harvesting of fish ingredients, transportation of ingredients to feed mill and energy use at feed mill
	Energy use	Electricity and diesel oil use
	Other	Land use and infrastructure, use of auxiliary substances, water use, transportation of salmon eggs, treatment of waste and disposal of wastewater
Aquaculture farm	Salmon feed	Cultivation of crop ingredients, harvesting of fish ingredients, transportation of ingredients to feed mill and energy use at feed mill
	Energy use	Electricity, diesel oil and petrol use
	Packaging	Production of packaging material
	Other	Land use and infrastructure, use of auxiliary substances, water use, transportation of smolt to farm, treatment of waste and disposal of wastewater
Trans-port	Ferry	Transportation of fresh salmon (HOG) by ferry in Iceland
	Transoceanic transport	Transportation of fresh salmon (HOG) by ship from Iceland to Europe
	Truck transport	Transportation in trucks
	Other	Emissions from refrigerants and operation of refrigerated containers/trucks
Smoke-house	Energy use	Electricity and diesel oil use
	Packaging	Production of packaging material
	Transport to retailer	Truck transport from smokehouse to retailer
	Other	Land use and infrastructure, use of auxiliary substances and water, waste treatment and wastewater disposal

3.4.2 Eutrophication

Terrestrial Eutrophication

The terrestrial eutrophication potential (EP) related to the production of 1 kg of smoked salmon fillet amounts to 0.13 mol_c N equivalents (Figure 3-22). The life cycle stage at the aquaculture farm is responsible for 84% of the terrestrial EP of which 66% of the total terrestrial EP can be related to the salmon feed, mainly due to processing of fish ingredients. Terrestrial EP from energy use at the aquaculture farm is 12% of the total impact. Other life cycle stages contribute significantly less to the total terrestrial EP, with the smokehouse operation contributing 8%, transportation to Europe contributing 6% and the smolt production 2% of total impact.

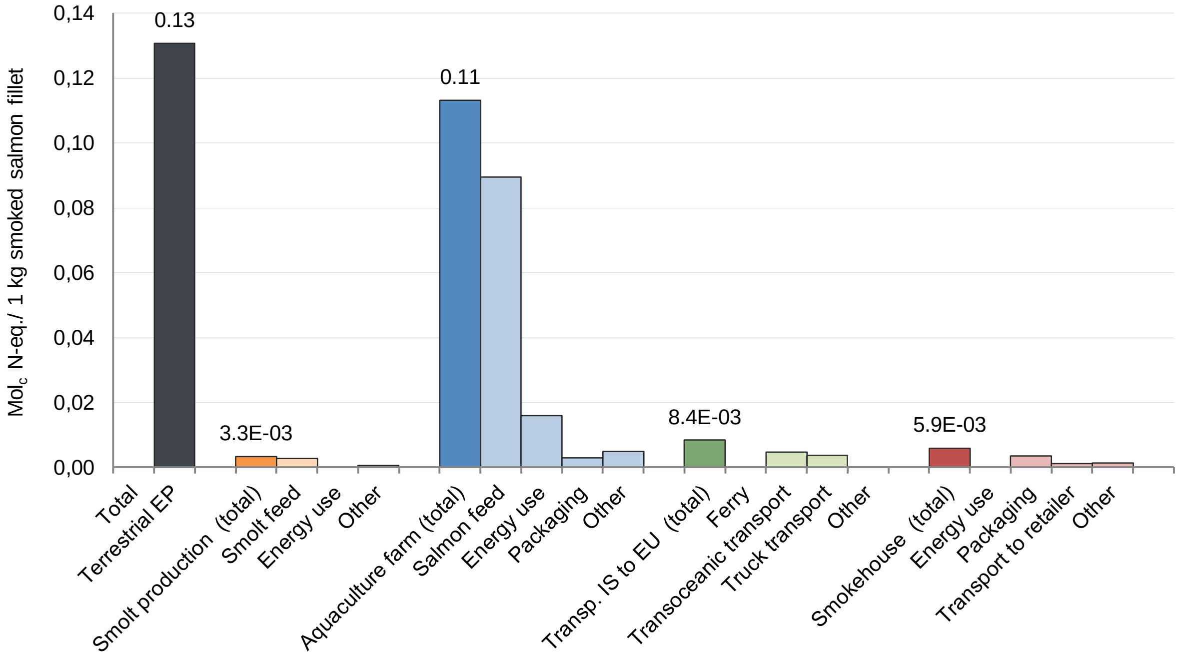

Figure 3-22 Terrestrial eutrophication potential for production of 1 kg of smoked salmon fillets. Production of salmon feed accounts for 66% of the total terrestrial eutrophication potential

Freshwater Eutrophication

Total freshwater EP from the production of 1 kg of smoked salmon fillet is $5.8{\cdot}10^{-4}$ kg P equivalents. The aquaculture farm life cycle stage is the greatest contributor to the freshwater EP with 60% of total impacts (Figure 3-23) from which crop ingredients is the largest contributor with 35% of total impacts (mainly soy bean products). Operation of the smokehouse is the second largest life cycle stage, responsible for 33% of total impacts. Impacts at the smokehouse are mainly divided between the energy use (18%) and the production of packaging materials (11%). Other life cycle stages contribute in total 7% of the total freshwater EP, the production of smolt 2% and the transportation to Europe from Iceland to the smokehouse with 5%.

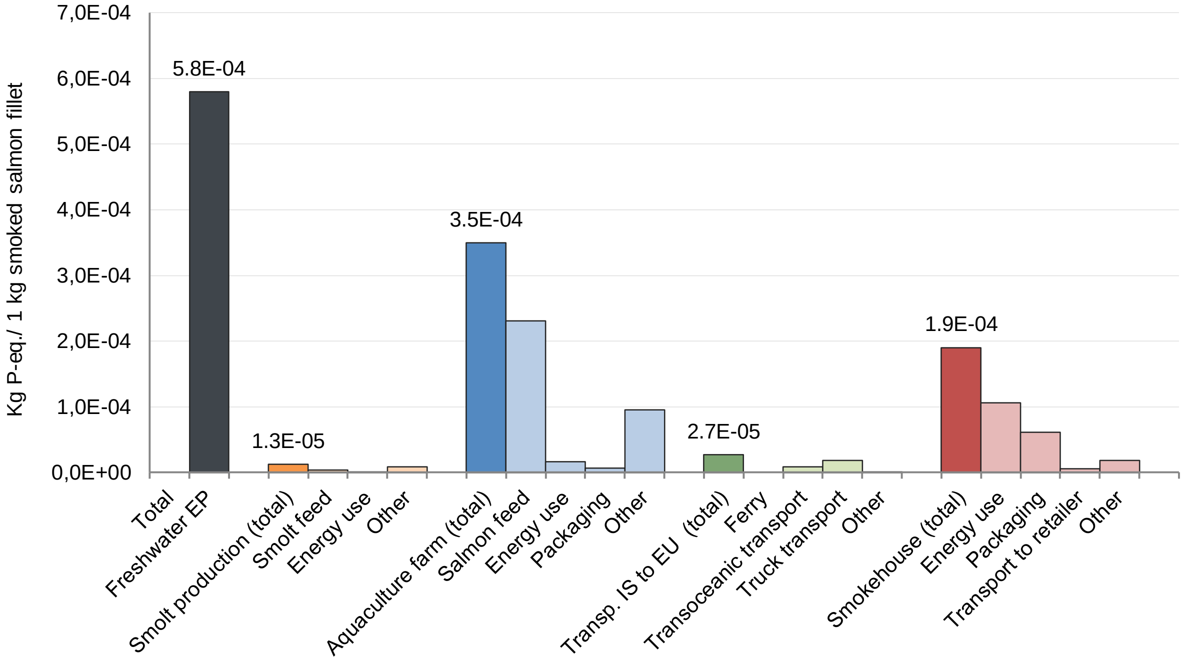

Figure 3-23 Freshwater eutrophication potential for production of 1 kg of smoked salmon fillets. Production of crop for the salmon feed accounts for 35% of the total freshwater eutrophication potential

Marine Eutrophication

Marine EP for the production of 1 kg of smoked salmon fillet is found to be 0.27 kg N equivalents. The main contributor is the aquaculture farming life cycle stage (97%) where emission of organic matter to sea (faeces, feed and dead fish) is the main cause of impact, 94% of total impact (Figure 3-24). The smolt production is the life cycle stage that comes second, with 3% of the total impacts, which are mainly from wastewater emissions to sea (organic matter).

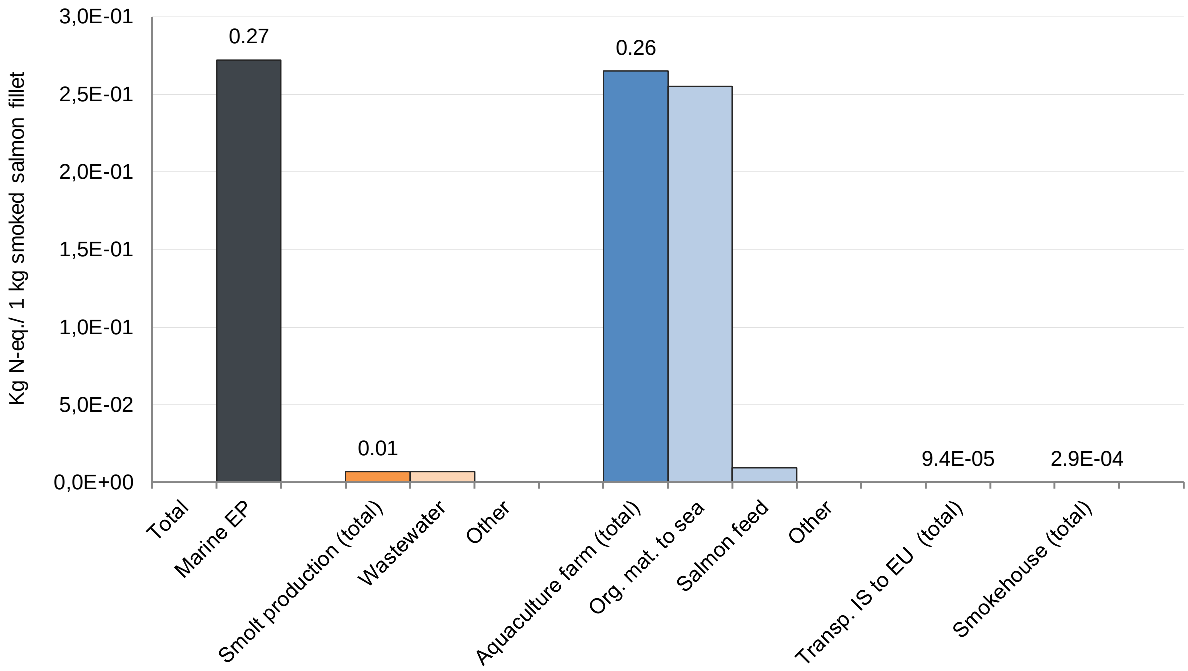

Figure 3-24 Marine eutrophication potential for production of 1 kg of smoked salmon fillets. Organic matter to sea accounts for 94% of the total marine eutrophication potential

3.4.3 Acidification

Acidification potential (AP) for the production of 1 kg smoked salmon fillet is $2.6{\cdot}10^{-2}$ mol_c H^+ equivalents (Figure 3-25). The main acidifying emissions occur during the aquaculture farm life cycle stage (83%), where 60% of the emissions are related to the production of the salmon feed. Energy use at the farm contributes 17% to the total AP emissions. Operation at the smokehouse contributes 7% to the total AP, where energy use (3%) and production of packaging (3%) are the main source of emissions from the smokehouse operation. Other life cycle stages, i.e. the transportation from Iceland to Europe (7%) and smolt production (2%) contribute 9% to the total impact.

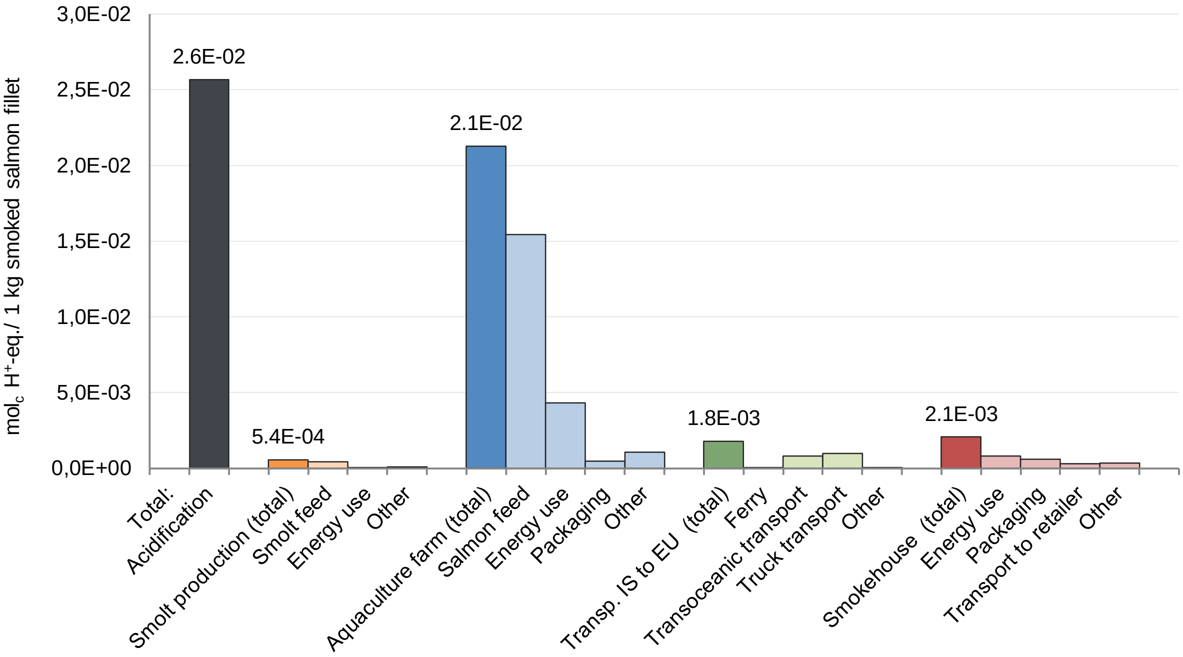

Figure 3-25 Acidification potential for production of 1 kg of smoked salmon fillets. Production of salmon feed accounts for 60% of the total AP

3.4.4 Human Toxicity

Human toxicity, non-cancer effects

The total human toxicity potential (HTP), non-cancer effects is found to be $5.7{\cdot}10^{-7}$ CTU_h[8] (Figure 3-26). Operation at the smokehouse in France is responsible for 47% of the total HTP, non-cancer impacts. The energy use at the smoke house contributes 27% to the total impacts of which majority is from the electricity use. Other significant impacts from the smokehouse operation are the production and transportation of packaging (9%) and the transport to retailer (4%). The aquaculture farm life cycle stage contributes to 36% of the total impacts. Transportation from Iceland to Europe contributes 15% which is mainly due to truck transport in Iceland and in Europe. The smolt production phase is the least significant life cycle stage in terms of HTP, non-cancer effects, contributing 2% to the total impacts.

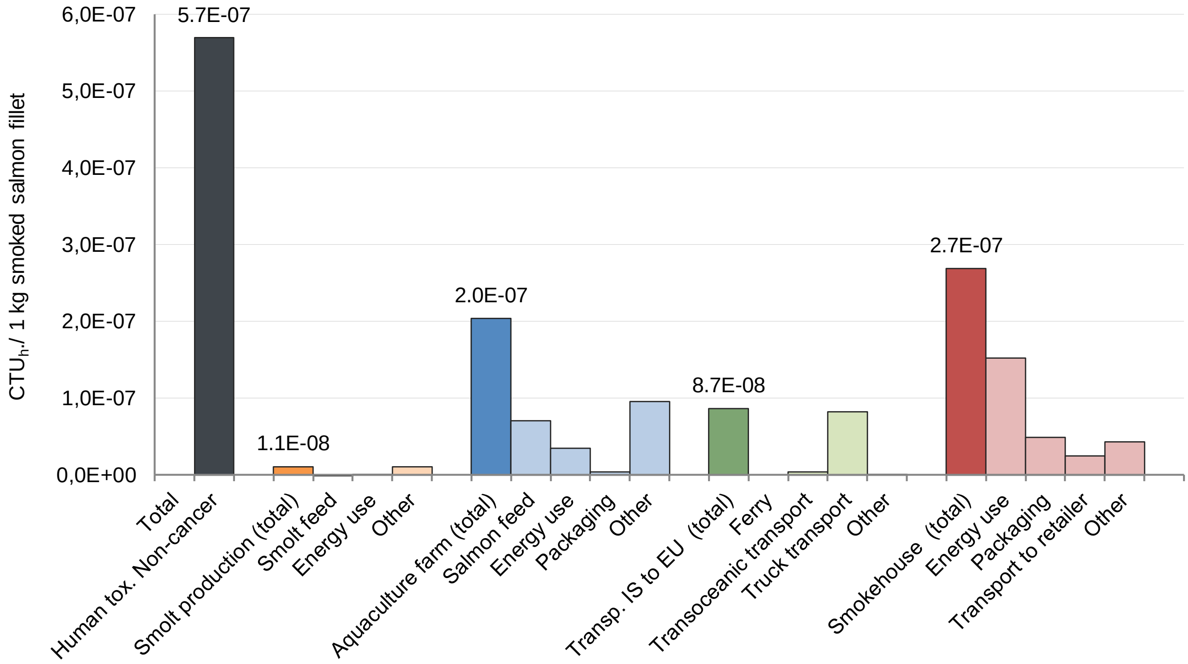

Figure 3-26 Human toxicity potential, non-cancer effects, for production of 1 kg of smoked salmon fillets. Operation at the smokehouse accounts for 47% of the total impacts

[8] Comparative Toxic unit for humans.

Human toxicity - cancer effects

The human toxicity potential, cancer effects, for production of 1 kg of smoked salmon fillet is $1.5{\cdot}10^{-7}$ CTU_h (Figure 3-27). The aquaculture farm is responsible for 51% of the total impact, where the salmon feed is dominant (31%). Of the total impacts 38% are related to the operation at the smokehouse in France, where it is the energy use (17%) and the production and transportation of packaging (13%) are the main cause of impacts. Other life cycle stages, i.e. the transport of fish from Iceland to France and the smolt production contribute 9% and 3% respectively to the total impacts.

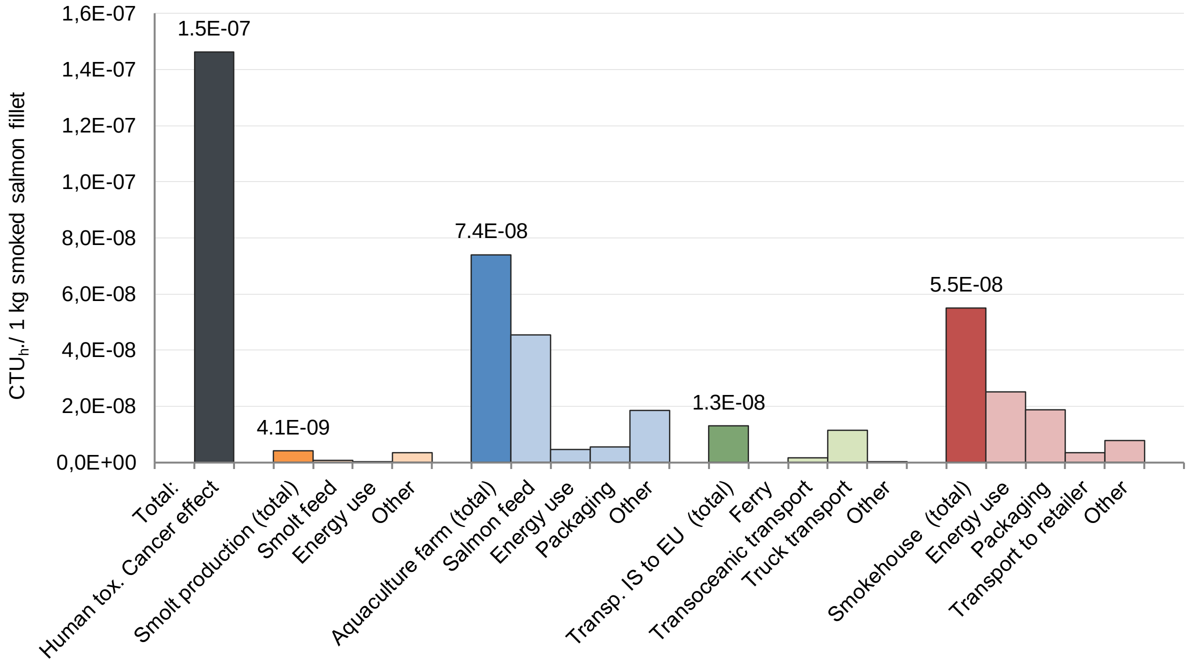

Figure 3-27 Human toxicity potential, cancer effects, for production of 1 kg of smoked salmon fillets. Operation at the aquaculture farm accounts for 51% of the total impacts

3.4.5 Ecotoxicity

Freshwater Ecotoxicity

Freshwater ecotoxicity potential is found to be 15 CTU_e[9] (Figure 3-28). The dominant life cycle stage is the aquaculture farm (92%), with the salmon feed as the dominant process (90%). Other life cycle stages contribute in total to 8% of the total impacts, i.e. the smokehouse operation (5%), smolt production (2%) and the transportation to Europe (1%).

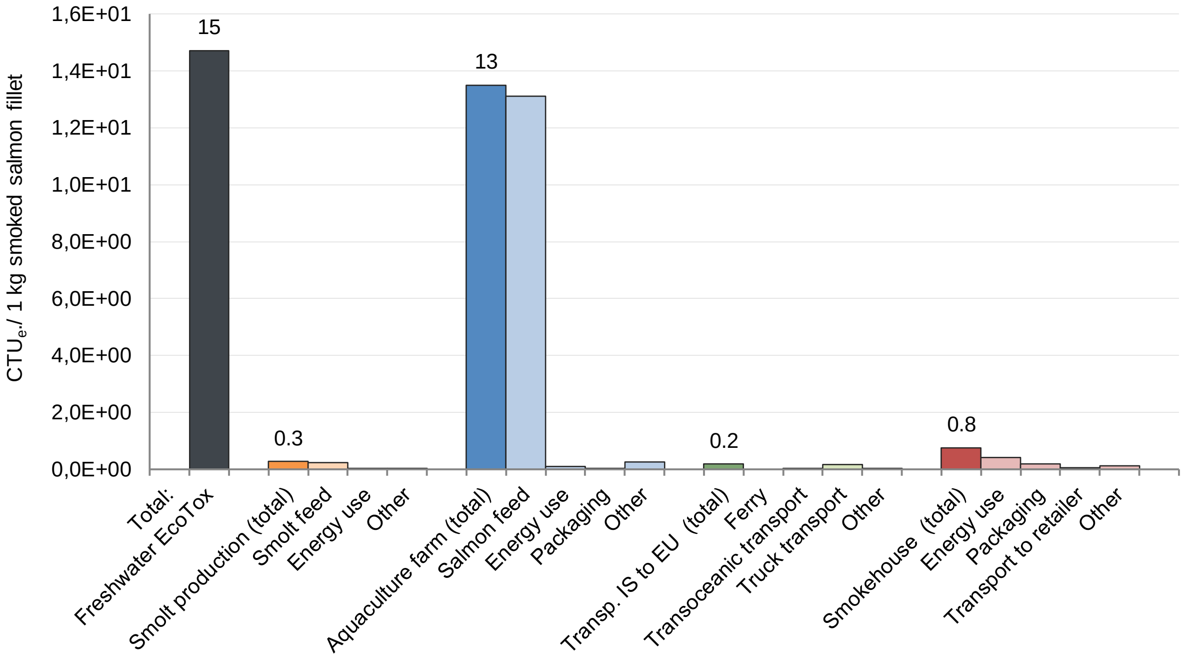

Figure 3-28 Freshwater ecotoxicity potential for production of 1 kg of smoked salmon fillets. Operation at the aquaculture farm accounts for 92% of the total impacts

[9] Comparative Toxic Unit for ecosystems.

3.4.6 Land Use

The land use impact from the production of 1 kg of smoked salmon fillet is 0.23 kg C deficit (Figure 3-29). The main life cycle stage contributing to the land use impact is the Aquaculture farm (66%) where 62% of the total impacts are due to the production of the salmon feed. The smokehouse operation is responsible for 27% of the total land use impacts mainly because of use of wood chips during the smoking process (19%). Other life cycle phases contribute significantly less, i.e. the smolt production (6%) and the transportation to Europe (<1%).

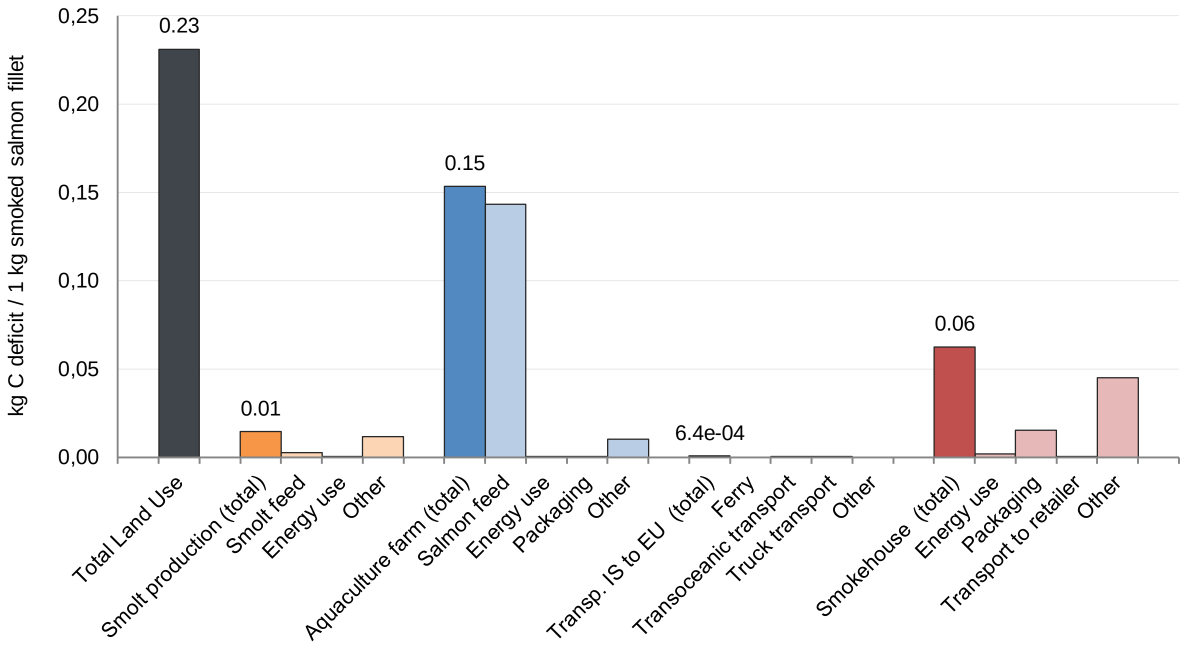

Figure 3-29 Land use impact for production of 1 kg of smoked salmon fillets. Operation of the aquaculture farm accounts for 66% of the total impacts

3.4.7 Abiotic Resource Depletion

The abiotic resource depletion (ARD) potential, i.e. the depletion of minerals, fossil energy and renewables, for the production of 1 kg of smoked salmon fillet is $3.7 \cdot 10^{-5}$ kg antimony (Sb) equivalents (Figure 3-30). The main life cycle stage is the operation of the aquaculture farm (54%) with the salmon feed contributing 41% to the total impacts due to fossil fuel usage. The life cycle stage at the smokehouse contributes 26% to the total impacts. For the transportation of fish from Iceland to France the dominant process is the truck transportation (16%). The smolt production contributes 4% to the total impacts, where the use of oxygen for water oxygenation in smolt tanks is dominant (2%).

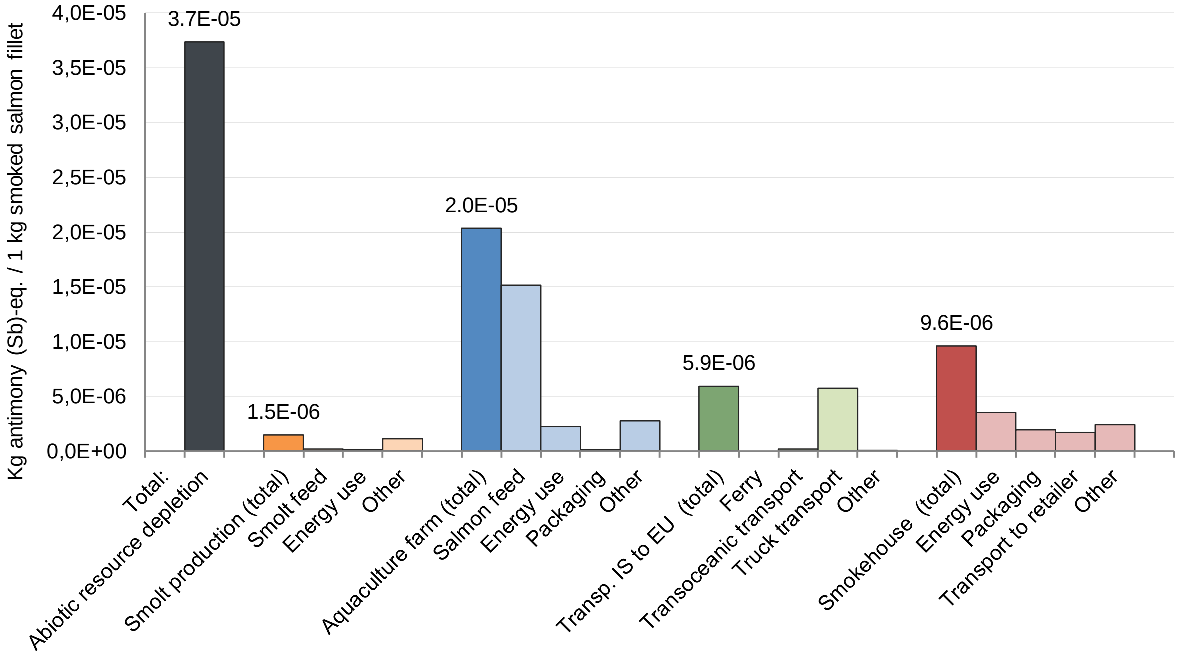

Figure 3-30 Abiotic resource depletion potential for production of 1 kg of smoked salmon fillets. Operation at the aquaculture farm accounts for 54% of the total impacts

3.4.8 Water Depletion

Water depletion for the production of 1 kg of smoked salmon fillet is $3.7 \cdot 10^{-3}$ m^3 water equivalents (Figure 3-31). Water depletion is mainly associated with the smokehouse operation in France (85%) where water scarcity in France is classified as being moderate. Despite the fact that the main water consumption in the life cycle of the smoked salmon occurs in Iceland, i.e. at the hatchery and aquaculture farm, these life cycle steps only contribute 1% and 14% respectively. Water scarcity in Iceland is classified as low (Frischknecht et al., 2009). The main source of water depletion during the aquaculture farm stage is from the production of packaging materials (plastic).

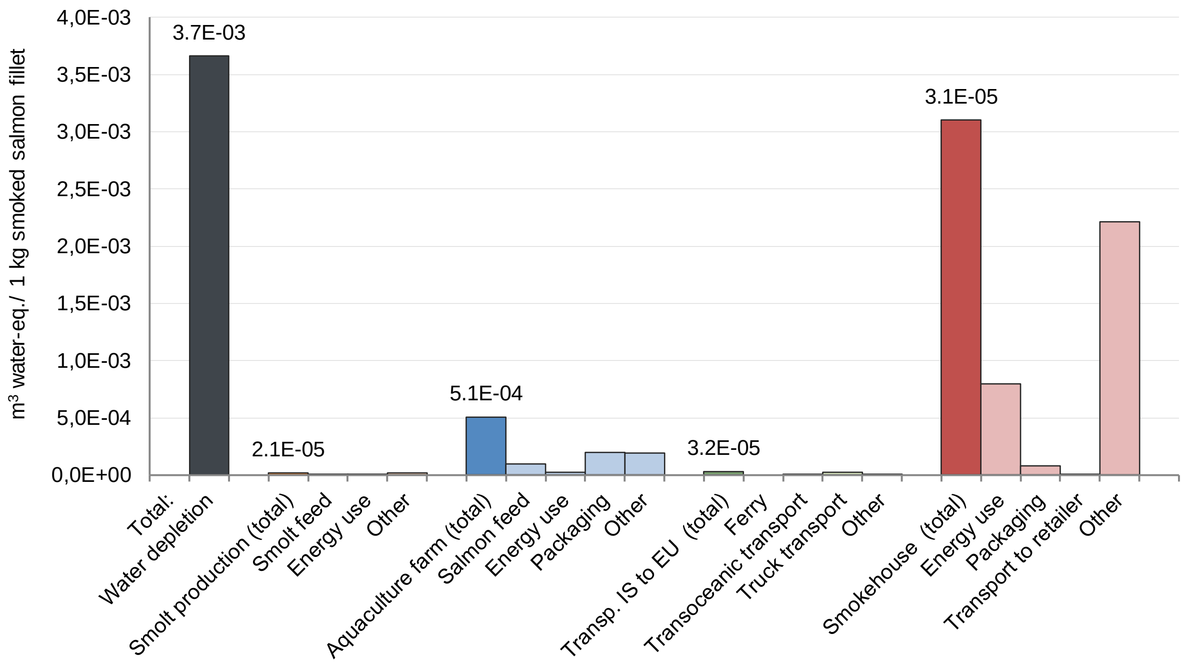

Figure 3-31 Water depletion from the production of 1 kg of smoked salmon fillets. The smokehouse operation contributes 85%to the total impact

3.5 Discussion

3.5.1 Most relevant stages

The main impact drivers and key substances for the assessed environmental impact categories for the aquaculture salmon are summarised in this chapter and can be seen in Table 3-36. In the life cycle of the aquaculture salmon the production of smolt at hatchery has a low contribution to the overall environmental impacts. It is mainly the feed for the smolt production that contributes to the environmental impact, related to fossil fuels, fertilizers and pesticides. It should be pointed out that while the impacts from the use of energy in the smolt production in Iceland are low, the impact of energy use has been identified as a dominating factor in recirculation systems (Aubin *et al*., 2009; Ayer and Tyedmers, 2009).

For aquaculture salmon the most significant life cycle stage in terms of environmental impacts is the operation at the aquaculture farm. The main contributor to most of the environmental impacts is the feed. This involves the harvesting of feed ingredients (marine and crop), processing of ingredients and its transportation. For the feed it is fossil fuels, fertilizers and pesticides that are the main cause of the environmental impacts. The different feed ingredients however have different impact potential and it is therefore important to know the ingredients composition of the feed.

Additionally, for marine eutrophication, organic matter emitted to sea at the aquaculture farm is the main contributor to that environmental impact category. Water use is an important indicator in aquaculture farms as well as hatcheries, however its impact depends on abundance of water in the operational area.

The results from this case study are in line with results from other LCA studies as summarised in the literature review in Deliverable 1.1 (Ólafsdóttir et al, 2013). Feed production has been identified as the main contributor to environmental impacts in conventional aquaculture systems (Aubin *et al.,* 2006; Ellingsen et al., 2009; Ellingsen and Aanondsen, 2006; Pelletier & Tyedmers, 2007; Winther *et al*., 2009: Ziegler *et al.,* 2012). Furthermore, the fish farm stage is a significant contributor to the eutrophication impact which has been shown to be highly dependent on the type of rearing systems, the type of feed and the feed conversion ratio (Ayer & Tyedmers, 2009; Aubin *et al.,* 2009; Boissy et al., 2011; Pelletier et al., 2009).

The main driver of environmental impacts in the transportation phase is fossil fuels. For the overall environmental impact of aquaculture salmon supply chain the selection of transportation mode is significant when transporting salmon products from Iceland to Europe. Similar results have been obtained for salmon aquaculture (Winther *et al*., 2009; Ziegler *et al.,* 2012; Ellingsen *et al*., 2009) and seafood products (Andersen, 2002; Freidberg, 2009; Ingólfsdóttir *et al*., 2010). For climate change impact the difference between the two transportation modes is mainly due to fossil fuels as more fuel is needed for transport per tonne of goods with air freight than with sea freight. Furthermore, carbon dioxide emissions from aircrafts have a higher contribution to climate change in the higher altitudes than carbon dioxide emissions occurring in the troposphere (Aronsson et al., 2013; Lee et al., 2009; Lee et al., 2010; Peters et al., 2011, Azar, 2012; Kollmuss & Crimmins, 2009; UBA, 2012). For the smoked salmon supply chain secondary processing stage is added to the aquaculture salmon life cycle. This step, i.e. the smokehouse, is important in terms of environmental impacts, especially regarding fossil fuels, electricity use and water use.

Table 3-36: Impact drivers for the different environmental impacts for the aquaculture salmon case study

Impact Category	Impact Drivers	Key Substances
Climate change	Use of fossil fuels for harvesting and processing of marine and crop feed ingredients, air freight (use of fossil fuels)	Carbon dioxide, nitrous oxide, methane
Eutrophication, terrestrial	Harvesting and processing of marine feed ingredients, cultivation of crop feed ingredients, air freight	Nitrogen oxides, sulphur dioxide
Eutrophication, freshwater	Harvesting and processing of marine feed ingredients, cultivation of crop feed ingredients, salt mining, air freight	Phosphate, phosphorus
Eutrophication, marine	Feed sedimentation, product loss (dead fish), faeces	Nitrogen, phosphorus
Acidification	Harvesting of marine feed ingredients (fossil fuels), cultivation of crop feed ingredients (fertilizer)	Ammonia, nitrogen oxides, sulphur dioxide
Human Toxicity, non-cancer effects	Fossil fuel use, electricity use	Zinc, Mercury, Arsenic
Human Toxicity, cancer effects	Fossil fuel use, electricity use, cultivation of crop (pesticides, fertilizers)	Chromium
Ecotoxicity	Cultivation of crop (pesticide)	Diflubenzuron
Land use	Arable land	Land
Abiotic resource depletion	Fossil fuel use, electricity use	Coal, Crude oil, natural gas
Water depletion	Water use in water scarce areas	Water

3.5.2 Allocation rules

It is difficult to recommend what allocation method is most appropriate to apply in the SENSE tool. To date there is not a universally accepted method on allocation rules for fish products. In this study allocation is performed in accordance with ISO 14044: 2006 (step 3) and decision made by the SENSE Consortium to follow the recommendations of the ENVIFOOD protocol by using economic allocation. Although it may be controversial, economic allocation is used for products from the hatchery and the aquaculture farm. For the smokehouse no allocation is done in production of smoked fillets (heads and bones are discarded) as the economic share of smoked salmon products is more than 99.5% of sold products and turnover.

The use of economic allocation has been criticised as it does not reflect the biophysical properties of the production system and is sensitive to changes in market prices (Pelletier & Tyedmers, 2011; Ayer et al., 2007; Svanes et al., 2011; Ytrestøyl *et al*., 2011). Different allocation methods used in LCA studies for wild caught fish have been found to give very different results (Svanes et al., 2011; Henriksson et al., 2011). Svanes et al. (2011) concluded that different allocations methods might be appropriate depending on the intended audience and application. For example mass allocation might be appropriate for external communication to the market, but for internal improvement work economic allocation might be the best alternative. There may be a conflict of interest between producers and consumer of by-products regarding what allocation method is most beneficial for their product. Description of the advantages and shortcomings of different allocation methods and its impact on main and by-products can be found in Winther *et al.* (2009).

Mass allocation methods have been applied in studies on feed and aquaculture as well as fisheries (Boissy *et al*., 2011; Winther *et al*., 2009) while others have used gross nutritional energy (Pelletier et al., 2009) or economic allocation (Ellingsen et al., 2009; Ziegler, 2006; Ziegler et al., 2003). Winther *et al.* (2009) justified the use of mass allocation for salmon after evaluating both economic allocation and gross nutritional energy. They considered mass allocation to be favourable, since it would allow comparison of resource use over time. In mass allocation, the environmental cost associated with the by-products is the same as for the products for human consumption. Using mass allocation in LCA's is beneficial for producers of products for human consumption if they can recycle their by-products into other production systems. Therefore, mass allocation creates a positive incentive for full utilisation of by-products compared to economic allocation, where by-products of insignificant value otherwise carry a zero environmental burden. Many eco-labelling organisations are putting pressure on processors by using criteria for origin of marine inputs in feed from either fish processing by-products or from sustainably used stocks (Ziegler et al. 2011). However, the use of by-products from "environmentally costly productions" such as livestock production or demersal fish trimmings in salmon feed production contribute substantially to the outcome of an LCA analysis in terms of energy use and CO_2 emissions (see Table 3-37) (Pelletier et al., 2009; Ytrestøyl et al., 2011). Currently about a quarter of the fish meal produced comes from by-products from fish processing for human consumption (i.e., by-products from fish filleting plants). Even though the economic value of the by-products is much lower than the value of the fillets, the income generated by by-products does increase the overall profitability of the processing plant compared to a value of zero (Ziegler *et al.,* 2011).

To conclude, as the allocation method selected can significantly affect the reported results it is important that the applied allocation method in the SENSE tool will be reported and the limitations or benefits clearly stated.

3.5.3 Comparison with literature values

Direct comparison of the results with earlier studies are difficult since system boundaries, functional units and allocations methods vary as shown in Table 3-37. Additionally, different feed conversion ratio factors may have an impact on the results. Values in the range of 2.2 - 3.6 kg CO_2

eq. / kg edible fish for aquaculture salmon at the farm gate or at wholesaler have been reported for salmon fillet produced in Norway, depending on whether the feed is processed by the use of heavy oil, natural gas, and on the transportation distance (Ellingsen *et al*., 2009; Ytrestöyl et al., 2011; Winther et al., 2009). Studies on aquaculture farming have focused on the effect of different feed composition. Regional differences ranging from 1.78 kg CO_2 eq./kg (live weight) for Norwegian-produced salmon to 3.27 CO_2 eq./kg (live weight) for fish produced in the United Kingdom (Pelletier *et al*., 2009) were explained by the contribution of feed ingredients and higher use of marine by products for salmon produced in the UK.

Table 3-37 GWP as reported in different LCA studies on salmon in Norway, UK, Canada, and Chile (From Ytrestøyl et al. (2011), Winther et al. (2009), Pelletier et al., 2009) and compared to results from this study (Note the different functional units in the studies)

References		**GWP kg CO_2eq / kg edible salmon**	**GWP kg CO_2eq / FU**
This study: Salmon 2013			
Feed: 32% crops, 66% fish	Total HOG at farm gate	3,44	2,5
Country: Iceland	*Smolt production*	*0,03**	*0,02*
System boundary: Cradle to gate (wholesaler)	*Smolt feed production*	*0,07**	*0,05*
FU 1:1 kg HOG fresh salmon	*Aquaculture farm*	*0,96**	*0,70*
FU 2: 1 kg smoked fillet	*Aquaculture feed production*	*2,38**	*1,73*
	Total HOG at wholesaler/retail (sea freight)		2,7
Allocation: Economic allocation	*Transport IS - EU*		*0,18*
FCR: 1,2-1,3 kg feed/kg LW salmon	Total smoked fish fillet		4,96
	Smokehouse		*0,58*
Winther *et al. (*2009) (production stages and different transport)			
Feed: 40% crops, 60% fish	Total fresh gutted transported to Paris by truck	3,60	
Country: Norway	*Feed production*	*2,72*	
System boundary: Cradle to gate (wholesaler)	*Aquaculture*	*0,14*	
FU: 1 kg edible product at wholesaler	*Processing*	*0,03*	
Allocation: Mass allocation	*Product transport*	*0,51*	
FCR: 1.2 kg feed/kg LW salmon	*Transport packaging*	*0,20*	
Ytrestøyl, et al (2011) (different feed formulations)			
Feed Diet 2010 (56,4% crops, fish 41,4%)	2010 diet	2,60	
Country: Norway	Diet - High Marine Ingredient	2,40	
System boundary: From cradle to farm gate	2010 formulation - marine ingredients N-Atlantic	2,75	
FU: 1 kg edible salmon product at farm gate **FCR:** 1.3 kg feed/kg LW salmon	Diet - by-products from land animal products and fish oil from herring trimming	3,40	
Allocation: Mass allocation	Diet with high content of plant ingredients	2,47	
Pelletier *et al.* (2009) (different feed formulation)			
Countries: NO, UK, Canada, Chile	NO/Feed (40 % crops, 58,6 % fish)	3,11**	1.790
System boundaries: Farm to gate	UK /Feed (30 % crops, 66,6 % fish (use of trimmings))	5,69**	3.270
FU: 1 tonne live weight salmon **Allocation:** Gross nutritional energy	Canada /Feed (50% crops, 31,6 % fish, 19,9 % livestock)	4,12**	2.370
FCR: 1.1kg feed/kg LW salmon	Chile / Feed (40% crops, 42,2 % fish, 15% livestock)	4,00**	2.300

**calculated based on average 70% fillet yield from HOG (1kg fillet from 1,43 kg HOG) (Winther et al., 2009) and 96% economic share of fillets*

*** calculated assuming 57,5% yield (1kg fillet from 1,74 kg live weight) (Winther et al., 2009)*

When converting the results from this study to the same FU (1 kg edible fillets), using average yield values and economic shares, the result from this study are similar (3.44 kg CO_2 eq./kg edible salmon) to what has been reported in the Norwegian study, 3.6 CO_2 eq./kg edible salmon (Winther *et al*., 2011) as well as the converted values from the study of Pelletier *et al*. (2009), 3.11 kg CO_2 eq./kg edible salmon.

When these results are compared it must be noted that in this study economic allocation is used which gives a higher burden on the main product than if mass allocation would have been used as in two of the compared studies. At the aquaculture farm 10% of the biomass at the farm is guts which are given away for free. The by-product, guts, therefore has zero environmental load. If mass allocation would have been used the impacts of the salmon product would be reduced by 10%. Feed intake and feed efficiency may change during the lifetime of the salmon. In order to avoid this variation affecting the LCA results it may be more appropriate to use a three year average for the operation of the aquaculture salmon farm.

3.5.4 Key Environmental Performance Indicators (KEPI)

In this chapter a set of key environmental performance indicators (KEPIs) for the life cycle steps of aquaculture salmon products is suggested. The KEPIs are selected based on the impact drivers identified in the previous section. The KEPI's for the aquaculture salmon can be seen in Table 3-38. They have been separated into the five processing steps; feed, smolt production (hatchery), aquaculture farming, transportation and processing. Each KEPI is given a name and a unit and assigned to each relevant production step. On the left side, the impact categories are listed vertically. When the contribution of the KEPI to an impact category is relevant, the cell is coloured in red and examples of main pollutant emitted by the KEPI is listed on the right (e.g. carbon dioxide, heavy metals, ammonia, phosphate).

Table 3-38 KEPIs for aquaculture salmon supply chain

Impact category	Feed						Smolt Production (hatchery)					Aquaculture farming									Trans-portation		Processing						Main pollutants
Unit	kg/kg feed	kg/kg feed	l/ kg feed	l/ kg crop feed ingredient	kg/ kg crop feed ingredient	ha/ kg feed ingredient	kg smolt/year	%	kg/ kg smolt	kWh/ kg smolt	m^3/ kg smolt	kg live weight/year	kg product/year	%	kg feed / kg live weight	kg/ kg product	kWh/ kg product	l/ kg product	m^3/ kg product	kg/ kg product	sea-, air-, land freight	Tkm/ kg fish	kg fish/ year	kg final product/ year	%	kWh/ kg final product	kg/ kg final product	m^3/ l kg final product	
Key Environmental Performance Indicator (KEPI)	Marine ingredients composition	Crop ingredients composition	Fuel use	Pesticides	Fertilizer	Land use	Total production of smolt	Share of products in turnover	Use of feed	Electricity use	Water use	Total production of farmed fish (biomass)	Total production	Share of products in turnover	Feed efficiency (FCR)	Packaging material	Electricity use	Fuel use	Water use	Organic waste to sea	Transportation mode	Transportation	Raw material use	Total production	Share of products in turnover	Electricity use	Wood chips	Water use	
KEPI for all impact categories	x	x					x	x		x		x	x	x	x							x	x	x	x				
Climate change			x						x								x	x			x					x			CO2, NOx
Human toxicity			x	x	x				x								x	x								x			Heavy metals
Acidification			x		x				x									x			x								NOx, NH3, SO2
Eutrophication, terrestrial			x						x									x			x								NOx, SO2
Eutrophication, freshwater				x	x				x																	x			PO4
Eutrophication, marine																				x									N, P
Ecotoxicity, freshwater				x					x																				Diflubenzuron
Land use						x																					x		Land use
Abiotic resource depletion			x														x	x			x					x			Fossil resources
Water depletion											x					x			x									x	Water use

Feed

The feed used at the hatchery and aquaculture farm consists of marine and crop ingredients. It is vital to know the **composition of the feed** when determining the key environmental impacts of the feed as the impacts differ for the different ingredients. **Fossil fuels** are important for catching and processing of marine species as well as for the crop production and processing. The KEPI fossil fuels have a high contribution to climate change, acidification, human toxicity, terrestrial eutrophication and abiotic resource depletion. Furthermore, **land use**, **fertilizers** and **pesticides** used in crop cultivation are important contributors to the environmental impacts human toxicity, acidification, eutrophication (freshwater), ecotoxicity and land use.

There can be complications for smolt and aquaculture salmon producers to obtain information about the above mentioned information for feed composition. In order to simplify data collection it is recommended that the SENSE tool will provide background processes for the most commonly used feed and the most commonly used feed ingredients in the aquaculture sector.

Smolt Production

The KEPIs identified for the smolt production are **feed, water use** and **electricity**. The composition and amount of feed used are important in terms of climate change, human toxicity, acidification, eutrophication (terrestrial, freshwater) and ecotoxicity. Water use and electricity use are identified as KEPIs even though these indicators are not significant in the aquaculture supply chain analysed in this study. However, these KEPIs can be very important for other aquaculture systems and in other regions where renewable energy sources are not available and water is scarce. Information on the **total production at hatchery** and **share of products in turnover** are also identified as KEPIs for allocation purposes. Therefore, it is recommended that these KEPIs will be implemented in the SENSE tool and should easily available at the hatchery.

Aquaculture farm

For the aquaculture farm the **feed composition** and **amount**, **organic waste to sea**, **electricity use**, **fossil fuels**, **water use** and **packaging materials** are identified as KEPIs. For water use and packaging materials the environmental impact category of interest is the water depletion. The other KEPIs affect climate change, human toxicity, acidification, eutrophication as well as abiotic resource depletion. Information on the **total production at the farm** and **share of products in turnover** are also identified as KEPIs. The aquaculture farm should have information available from the operation of the farm to obtain these KEPIs.

The **feed efficiency** (FCR, feed conversion ratio), i.e. the weight of feed used (kg) compared to weight of fish produced (kg) is a key factor to assess environmental performance of the aquaculture farm. Furthermore, to assess the performance of aquaculture farms, the amount of marine resources that is consumed in the production of farmed fish, the FIFO ratio (fish in - fish out) is often used in the industry.

It is important to mention that the aquaculture farm in this study does not use anti fouling agents. Therefore it is possible that in the case where anti fouling agents are used that they can be of importance. Furthermore, land based aquaculture was not analysed in this study.

Transportation

For transportation the KEPI identified is **transportation mode** and **distance** travelled as can be seen from the different scenarios in this study. The fuel is important factor in terms of climate change, acidification, human toxicity, eutrophication (terrestrial) and abiotic depletion. The SENSE tool will need to take into account and provide background processes for different transportation types.

Processing

For the smokehouse the following KEPIs are identified: **electricity**, **fossil fuel** and **water use** as well as **raw material inputs** (salmon HOG), **total production** and **share of products turnovers**. The electricity and fuel have impact on climate change, human toxicity, eutrophication (terrestrial) and abiotic resource depletion. Water use has potential influence on water depletion; depending on the region the process takes place in. For land use impacts, the use of **wood chips** for the smoking process can also be of importance and are also identified here as a KEPI.

The head and bones from filleting process as well as cut offs and trimmings from finished products are discarded and do therefore not carry any environmental burden in this study. This may however be of interest if sold as added value by-products.

3.5.5 Regionalization

Regionalization is an important step towards improving the accuracy and precision of environmental impact assessment. It is therefore important to take into account where the emissions take place.

For acidification regional characterisation factors for many countries in Europe are available (Posch et al., 2008). Acidification characterisation factors for sulphur dioxide, nitrogen oxides and ammonia are available for France and differ somewhat from the weighted average factors used in this case study. However, regional acidification characterisation factors are not available for Iceland. For terrestrial eutrophication, regionalised characterisation factors are also available for France but not for Iceland. The regionalised factors for France are found to be higher than the weighted average applied in this study. In the case of the operation of the smokehouse in France application of the regionalized characterisation factors would have had influenced the results in the smokehouse life cycle step to some extent.

Availability of water differs greatly between countries and regions. Regional characterisation factors are available for water scarcity (Frischknecht et al., 2009). In this case study regionalisation factors for water depletion were used. The smokehouse in France has considerably higher impact on water depletion than the hatchery and aquaculture farm in Iceland, although they use significantly higher amount of water. This is because water is defined as abundant in Iceland.

It is recommended that the SENSE tool will implement the regionalised characterisation factors for acidification, eutrophication (terrestrial) and water depletion. For other regional impact categories regionalised characterisation factors are not available yet.

Availability of energy resources vary between regions and countries and the share of renewable energy differs significantly between countries. It is therefore important that the SENSE tool will take into account these differences. Datasets on electricity mix are publicly available and shall be implemented in the tool as background data. Background LCI datasets need to be available on the nitrogen content in different aquaculture fish species to be able to assess the marine eutrophication potential from dead fish. Additionally, datasets should be available in the tool for N and P content from faeces and feed deposition for sea based aquaculture in different regions. These information are available e.g. for aquaculture farming in the Nordic countries (Solbakken et al., 2008). The same applies to the different feed for salmon aquaculture, but information on the feed ingredient composition is not publicly available. It is however important that these will be generated in order to provide a simplified tool that can be easily used by the SME´s, i.e. non LCA experts.

4 Copyright

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Annex A: Life Cycle Assessment (LCA) Methodology

The life cycle assessment (LCA) – sometimes also called ecobalance – is a method to assess the environmental impacts of a product[10] encompassing the whole life cycle (cradle to grave). Hence, the environmental impacts of a product are evaluated from resource extraction to material production, product manufacturing, use of the product up to the disposal of the product and also the production wastes.

The general procedure of conducting an LCA is standardised in ISO 14040 (International-Organization-for-Standardization-(ISO) 2006a) and ISO 14044 (International-Organization-for-Standardization-(ISO) 2006b).

An LCA consists of the following four phases (Figure 1):

1. Goal and Scope Definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

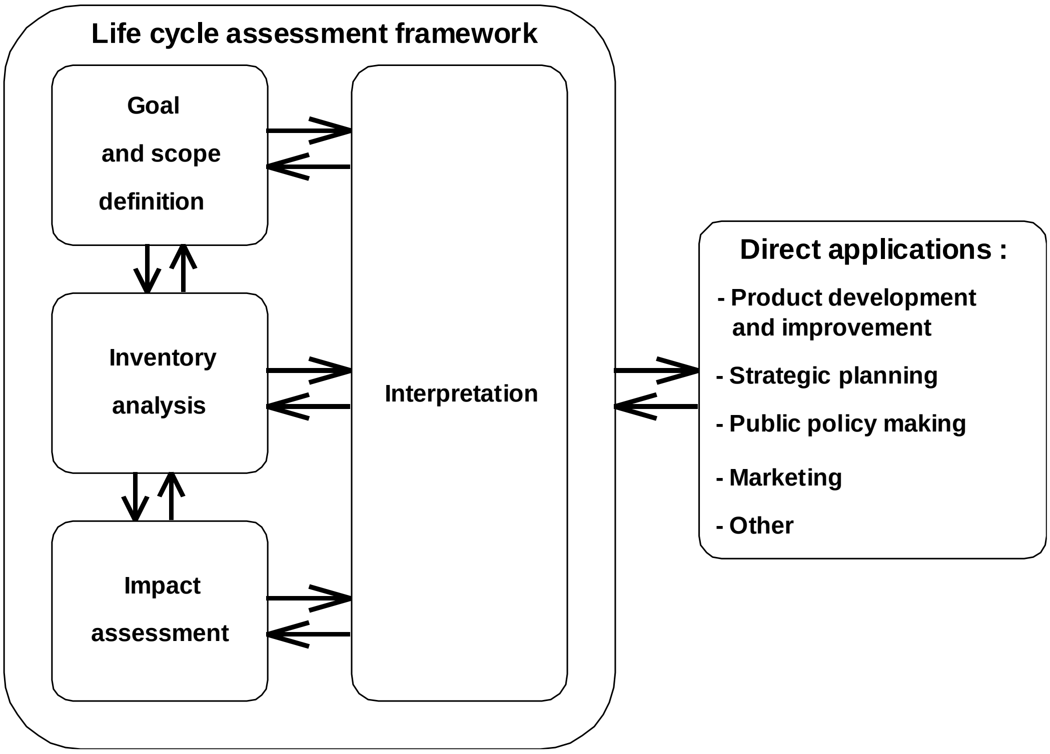

Figure A. 1 The four phases of the life cycle assessment (LCA) framework according to International Organization for Standardization

[10] The term product also encompasses services

The *Goal and Scope Definition* (phase 1) includes a description of the goal of the study and covers the description of the object of investigation. The intended audience is determined. The environmental aspects to be considered in the impact assessment and the interpretation and the functional unit, to which all emissions and resource uses are referred to and which determines the basis for the comparison, are defined.

The elementary flows[11] occuring in a process, the amount of semi-finished products, auxiliary materials and energy of the processes involved in the life cycle are determined and inventoried in the *Inventory Analysis* (phase 2). These data are set in relation to the object of investigation, expressed by the functional unit. The final outcome consists of the cumulative resource demands and the cumulative emissions of pollutants.

The Inventory Analysis provides the basis for the *Impact Assessment* (phase 3). Applying current impact assessment methods, such as climate change impact according to IPCC (2007), on the inventory results leads to impact indicator results that are used and referred to in the interpretation.

The results of the inventory analysis and the impact assessment are analysed and commented in the *Interpretation* (phase 4) according to the initially defined goal and scope of the LCA. Final conclusions are drawn and recommendations stated.

[11] Resource extraction and emission of pollutants

Annex B: Description of Life Cycle Steps

5.1.1 Smolt Production Process steps

Description of the process steps for the smolt production located in Iceland can be seen in the table below.

Table B. 1 Description of the process steps at the hatchery

	Description
Name of the product:	Smolt
Description of production site:	Land based salmon fingerling station. The station is located in South Iceland, close to sea and seawater is pumped from several boreholes. The station is also supplied with fresh groundwater and geothermal hot water.
Production step 1: Breeder, Juvenile production	Salmon eggs are purchased from an Icelandic breeding firm. The breeder produces salmon roe and delivers juvenile salmon to the fingerling/smolt station. The eggs are on the eyed stadium when they are delivered. The egg hatched under controlled temperature, oxygen and light conditions. The hatching take place after one month and first feeding starts soon after in small indoor tanks. The juvenile production takes place in indoor tanks, under controlled temperature, oxygen and light conditions. During smoltification the salmon is adapted to seawater in outdoor tanks. The production period of smolts in 14-20 months. Juvenile salmon producer uses feed water and oxygen under controlled temperature and light conditions.
Production step 2: Transport to salmon aquaculture farm	When the salmon smolt weights approximately 100 -200 g., it is transferred to the salmon aquaculture farm by ship in tanks.

5.1.2 Aquaculture Farm Process steps

Description of the process steps for the aquaculture farm at the producer located in Iceland can be seen in the table below.

Table B. 2 Description of the process steps at the aquaculture farm

	Description
Name of the product:	Arctic Salmon
Production step 1: Salmon farming	When the salmon weights approx. 100-300g., it is transferred with well boats to floating marine net-pens. The pen holds salmon but is open to the marine environment. Growth period in the net- pen ranges from 14 to 25 months before harvesting when the salmon has gained a weight of 2-5.5 kg. The net-pen structure usually consists of several cages located around 500 m off-shore in fjords for sheltering from storms.
Production step 2: Well boat and pumping	Well boats are used to transport salmon to the pens. The salmon is kept alive in sea water at shore in cages before it is slaughtered.
Production step 3: Slaughtering	The fish are hauled into the harvesting boat, where the salmon is stunned and bleed by the automatic slaughtering equipment. The fish swims through to the “killing” equipment which includes stunning and cutting the main artery and bleeding can takes place.
Production step 4: Cooling and transport	After slaughtering the fish is kept in 360 L plastic tanks for bleeding in ice water. It takes approximately 2-4 hours for the salmon to be cooled down to 0°C. The salmon is transferred by the harvesting boat to the harbour and transported by truck (30 km) to the factory for packaging.
Production step 5: Gutting	From the cooling tanks the salmon is transferred to gutting machine. After that it is cleaned and packed.
Production step 6: Packaging	After cleaning, the salmon is graded according to size and packed (i.e. < 4kg, 4-5 kg, > 5kg). After it has been packaged in EPS boxes (i.e. 25kg) with plastic ice mat. The package is weighted and labelled. Finally, the boxes are loaded on pallets (i.e. 27 boxes) according to requirements made by the buyer of the product
Production step 7: Storage – waiting for dispatch	The pallets are kept in cooling room at the factory until the pallets are loaded on a truck.
Production step 8: Transport to airport or export harbour.	The salmon is transported to the Keflavik airport or Reykjavik harbour by truck. The truck enters a ferry (55 km). The total driving distance is 260 km to Reykjavik Harbour and 310 to the Keflavik airport.
Additional information	The aquaculture farm has a Whole food market (WFM) certification and is applying for organic certification as well as Best Aquaculture Practice (BAP) Regarding escapes: Divers monitor 1-2x per month the state of the pens and there is constant monitoring with video cameras.

5.1.3 Smokehouse Process steps

Description of the process steps for the smokehouse located in France can be seen in the table below.

Table B. 3 Description of the process steps at the smokehouse

Reference	Description
Name of the product	Smoked salmon
Production step 1: Receiving – chilled storage	Reception of whole fish gutted with head on in EPS boxes (including ice mat). Re-icing may be required
Production step 2: Salting /Brining and Draining	Salting method: dry salting
Production step 3: Smoking.	Temperature and duration of smoking: 27°C during 8 hours
Production step 4 Cooling	Temperature and duration of chilling: From two hours to 24 hours
Production step 5: Slicing, packaging	The finished products are vacuum packed in plastic packaging material and cardboard
Production step 6: Chilled storage – waiting for dispatch	Maximum 9 days
Production step 7: Transport to wholesaler	Transportation is done by another company; the duration of transport is 24 hours

Annex C: Key Figures

Key figures for the different life cycle steps of the aquaculture salmon supply chain are presented in the tables below. The figures are presented on per annual basis and per kg output from each life cycle phase.

Table C. 1 Key figures for the hatchery presented on annual basis and per kg smolt produced

		per year	**per kg smolt**
Use of feed			
Smolt feed	kg	272,000	1.04
Energy use			
Total electricity used	kWh	1,960,000	7.5
Total amount of diesel oil used	L	5,700	22
Water use			
Freshwater use	m^3	720,450	2,750
Seawater	m^3	300,000	1,145
Auxiliary substances			
Oxygen	tonnes	211	0.81
Detergents/ Soap	kg	50	0.19
Formaldehyde (formalin)	kg	20	0.08
Vaccine	kg	2	0.01
Wastes			
Unsorted waste	kg	4,000	15
Biological waste / feed sediments	kg	500	1.91
Paper and plastics	kg	100	0.38
Water disposal			
Direct discharge to sea	m^3	1,000,000	3,817

Table C. 2 Key figures for the aquaculture farm presented on annual basis and per kg fresh salmon (HOG) produced

		per year	per kg fresh salmon (HOG)
Smolt input			
Smolt	kg	44,000	0.04
Use of feed			
Salmon feed	kg	1,675,000	1.49*
Energy use			
Total electricity used	kWh	332,970	0.30
Total amount of diesel oil used	L	116,723	0.10
Total amount of petrol used	L	8,094	0.01
Water use			
Fresh water use	m^3	262,542	0.23
Auxiliary substances			
Detergents (soap and disinfectants)	kg	1,200	1.1.E-03
Packaging			
EPS boxes	kg	35,038	0.03
Cooling mats	kg	44,920	0.04
By-products and waste			
Guts	kg	137,000	0.12
Blood	kg	41,000	0.04
Weight loss as a result of starvation before slaughter	kg	69,000	0.06
Product loss (e.g. due to natural cause, etc.)	kg	96,000	0.09
Biological waste / feed sediments	kg	68,000	0.06
Unsorted waste	kg	5,658	0.01
Sorted waste (other than hazardous)	kg	2,000	1.8.E-03
Hazardous waste	kg	380	3.4.E-04
Water disposal			
Direct discharge to sea	m^3	31,536	0.03

** FCR = 1.22 (kg feed / kg live weight) based on the inventory and calculated taking into account 5% extra weight before starvation and one operational year at the aquaculture farm.*

Table C. 3 Key figures for the smokehouse presented on annual basis and per kg smoked salmon (skin off) produced

		per year	per kg smoked salmon (skin off)
Energy use			
Total electricity used	kWh	878,070	0.96
Total amount of diesel oil used	L	8,000	0.01
Water use			
Fresh water use	m^3	11,900	0.01
Auxiliary substances			
Salt	kg	223,000	0.24
Spices	kg	3,200	0.00
Detergents/soap	kg	8,800	0.01
Refrigerants	kg	200	2.2.E-04
Wood chips	kg	91,328	0.10
Packaging			
Plastic film	kg	27,960	0.03
Carton	kg	65,240	0.07
Cardboard boxes	kg	10,000	0.01
Wastes			
Product loss	kg	1,100	1.2.E-03
Unsorted waste	kg	24,264	0.03
Polystyrene	kg	9,360	0.01
Hazardous waste	kg	*50*	5.5.E-05
Water disposal	Unit		
Discharge to sewage system	m^3	360	3.9.E-04
Pre-treatment in own wastewater treatment plant	m^3	11,540	0.01

Annex D: Marine Feed Ingredients

Data for the impact assessment on the marine feed ingredients was done using data from an LCA study on global salmon farming systems (Pelletier et al., 2009). Information on the environmental impacts for the marine ingredients: capelin meal, herring meal and capelin oil can be seen in the table below. Furthermore a table is provided for the material and energy inputs to salmon feed milling in Norway used in this study to represent the feed mill in Iceland.

Table D. 1 Environmental impacts for the marine feed ingredients (Pelletier et al., 2009)

	Cumulative Energy Use	Global Warming Potential	Acidification Potential	Eutrophication Potential	Biotic Resource Use
	MJ / tonne feed	*kg CO_2 eq. / tonne feed*	*kg SO_2 eq/ tonne feed*	*kg PO_4 eq/ tonne feed*	*tonnes C/ tonne feed*
Capelin Meal					
Production	5.9.E+00	4.4.E-01	5.2.E-03	1.1.E-03	0.112
Processing	2.4.E+01	1.4.E+00	1.7.E-03	7.6.E-03	
Transportation	1.2.E+00	7.5.E-02	1.2.E-03	1.2.E-04	
Herring Meal					
Production	1.2.E+02	8.8.E+00	1.0.E-01	2.1.E-02	0.487
Processing	7.6.E+01	4.3.E+00	5.1.E-03	2.4.E-02	
Transportation	5.2.E+00	3.1.E-01	5.2.E-03	5.2.E-04	
Herring By-product Meal					
Production	1.7.E+02	1.2.E+01	1.5.E-01	3.0.E-02	0.757
Processing	1.3.E+02	6.9.E+00	8.8.E-03	3.8.E-02	
Transportation	4.4.E+00	2.6.E-01	1.7.E-03	3.6.E-04	
Capelin Oil					
Production	3.2.E+00	2.3.E-01	2.8.E-03	5.6.E-04	0.060
Processing	1.3.E+01	7.2.E-01	9.3.E-04	4.0.E-03	
Transportation	3.5.E-01	2.1.E-02	3.5.E-04	3.4.E-05	

Table D. 2 Material and energy inputs to salmon feed milling in Norway used to represent the feed mill in Iceland (Pelletier et al., 2009)

INPUTS	**Unit / tonne feed**	**Amount**
Energy	MJ	902.6
Electricity	MJ	469.9
Natural gas	MJ	124.3
LPG	MJ	74.2
Light Fuel oil	MJ	52.8
Diesel	MJ	4.9
Steam	MJ	176.6
PET* Packaging (kg)	kg	2.6

** Polyethylene terephthalate*