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Report

LCA of Norwegian salmon production 2012

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Report

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ABSTRACT: LCA of Norwegian salmon production in 2012
This report presents an LCA of salmon produced with the average Norwegian feed of 2010 and 2012. The assessment cover the salmon production system from fishing of marine and growing og vegetable feed ingredients, up to the stage where the salmon is ready for slaughter, the salmon farm gate. The methodology is explained and the data that was used documented.
The results show that the carbon footprint of an average Norwegian salmon product increased from 2010 to 2012, despite an improvement in the economic feed conversion ratio for the same period. Climate impacts from land use change, associated with growing of soy, is identified as an especially important climate aspects for salmon aquaculture. A simplified screening also show that micro ingredients can be an important climate aspect.
The water footprint of the salmon showed that, compared to published data from other meat products, salmon is also an efficient food product with regards to fresh water use.

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Norwegian abstract / Norsk sammendrag

Denne rapporten presenterer en livsløpsanalyse (LCA) av lakseproduksjon med det gjennomsnittlige norske fôret brukt i 2010 og 2012. Dette miljøregnskapet dekket produksjonssystemet for oppdrettslaks fra dyrking og fiske av fôringredienser og frem til laksen er klar til slakting. Det vil si til der laksen er klar til å forlate oppdrettsanlegget.

Metodikken for regnskapet er forklart og de data som er benyttet blir presentert.

Resultatene viser at klimasporet til norsk oppdrettslaks økte far 2010 til 2012 til tross for en forbedring i den økonomiske fôreffektiviteten. Klimapåvirkning fra arealendringer knyttet til dyrking av soya er identifisert som et spesielt viktig klimaspekt for oppdrettslaks. En enkel screening viste også at microingredienser kan være et viktig klimaaspekt.

Laksens (fersk)vann fotavtrykk er også beregnet og viser at sammenlignet med publiserte data for andre kjøtt produkter, så er laksen også et effektivt matprodukt med hensyn til forbruk av ferskvann.

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1 Methodology

This environmental assessment is performed with Life Cycle Assessment (LCA)[1] methodology in accordance with the ISO standards for LCA in their ISO 14 000 family[2] on standards for environmental management [1, 2] . The article “drivers for environmental assessment in the seafood industry” by Hognes et al [3] points to different ways of using LCA in the seafood industry.

The chapter in this report follow the four iterative stages of an LCA illustrated in Figure 1-1. For a more detailed description of LCA methodology we recommend "General guide for Life Cycle Assessment – Detailed guidance" by the European Commission Joint Research Centre [4] and the book "The hitchhikers guide to LCA" [5]. The report "Carbon footprint and energy use of Norwegian seafood products" [6] gives a more thorough description of carbon footprint of seafood and references to articles.

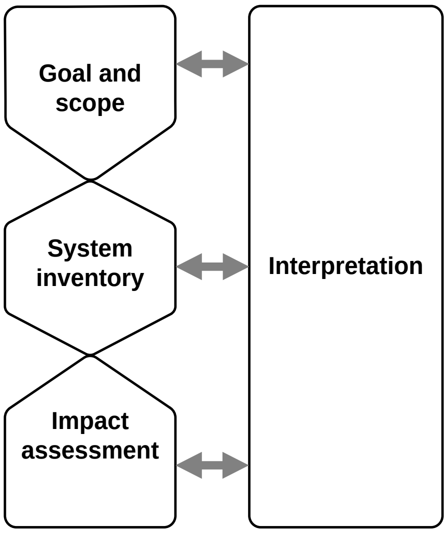

Figure 1-1 Iterative phases of LCA

1.1 Goal and scope

The goal of this study is to map the environmental hot spots in the production systems for Norwegian salmon production. The intended audience is feed producers, salmon producers and other decision makers involved in the development of sustainable food production. The results of these assessments are not suitable for comparison with other LCAs/products unless the methodical choices and data is identical.

This LCA compares the average diet of 2012 with that of 2010 to illustrate how changes in the feed diet can lead to changes in the environmental performance of the salmon production and to point out methodical challenges. The 2010 diet was also assessed in 2011 in the project “Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010”[3] [7, 8]. The results presented in this report and in 2011 can not be directly compared as the current assessment is performed using other goal and scope and other data are used (more details on this in chapter 3 and the following).

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[1] Link to more info on the LCA method from the EC Joint Research Centre: http://eplca.jrc.ec.europa.eu/
[2] Link to the ISO web page for their 14 000 standards: www.iso.org/iso/home/standards/management-standards/iso14000.htm
[3] Link to report: http://www.nofima.no/publikasjon/8DA9C7ED7BDDC2E0C12579910036F28E and http://www.fhf.no/prosjektdetaljer/?projectNumber=900912

The functional unit. The functional unit defines exactly for what product or functionality the assessment is performed. A clear understanding of this unit is important for the correct understanding of the results, especially if LCA results are compared between different products. In this assessment, the functional unit is 1 kilo edible salmon product at the point where the salmon is ready for slaughter, - at salmon farm gate. Also results per kilo of salmon feed is presented.

Scope and system boundaries. The assessment includes the salmon production system from growing of crops and fishing of marine species to produce feed and up to the point where the salmon is ready for slaughter. Production of smolt and the fish farming activities are included. Figure 1-2 illustrates the system boundaries. The system boundaries in this assessment is expanded from previous assessment [7], most important by including the production of the microingredients.

Impact assessment is the phase of an LCA where the in- and outflows that are identified and quantified in the life cycle inventory phase, are assigned into different impact categories and calculated into impact category reference substances.

The following impact categories was covered:

- Global warming potential. Emission of green house gases and other impact with a global warming potential are calculated into CO_2 equivalents according to the ReCiPe method [9] that follows the guidelines provided buy the IPPC [10].
- Fresh water footprint. The water used by the salmon production system is calculated according to method promoted by the Water Footprint Network and demonstrated by Mekonnen et. al. in their assessments of the water footprint of crops and animal products [27, 28]
- Phosporus use. The sum of inputs of raw phosphorus from ground is calculated.

Allocation is done when processes have several outputs and the environmental impact from that process and previous processes need to be shared among these outputs. In these analyses allocation is done based on the mass of the outputs, this is called "mass allocation". For seafood production systems based on feed allocation is especially important when by-products are used as input in the feed. Mass allocation means that no differentiation is done between of what might be considered as the by-product and the main product. Examples: per unit of mass guts and cut offs from demersal fisheries will carry the same environmental impacts as e.g a fillet. Per unit of mass soy protein will carry the same environmental impacts as soy oil. Further out in the seafood value chain mass allocation will have a positive effect as guts, blood and other cut offs that are somehow utilized will reduce the environmental impacts attributed to the finale seafood product.

Allocation is a methodical choice that can have considerable impact on the final results. For a thorough discussion on different allocation procedures we point to Appendix B in the report "Carbon footprint and energy use of Norwegian seafood products" [6]. The article "An Ecological Economic Critique of the Use of Market Information in Life Cycle Assessment Research" also give a good insight into economic vs. mass allocation [11]. Allocation methods and their effects are also studied in the article "Effect of different allocation methods on LCA results of products from wild-caught fish and on the use of such results" [12]. Torrisen et. Al. argue for economic allocation in their article "Atlantic Salmon (Salmo salar): The “Super-Chicken” of the Sea?"

Cut offs. As in all LCAs some processes and inputs can not be included due to restraints on data and/or the resources available to do the LCA. In this project some important cut offs are:

- Capital investments are in general not included in the modelling of the foreground processes, e.g. fishing vessels and farming buildings.
- Waste treatment is not completely covered throughout the whole system.

1.2 Data sources

Data for the assessments are collected from feed producers, reports, journal articles and life cycle inventory databases. More details are found in the inventory chapter.

The cultivation and processing of the vegetable ingredients are mainly modelled with data from the Agri-footprint database [13]. Important data are controlled with comparable data from databases built by SIK[14].

Data on energy production, production of materials and transport processes are mainly derived from the Ecoinvent V3 database [15] and the Agri-footprint database[13].

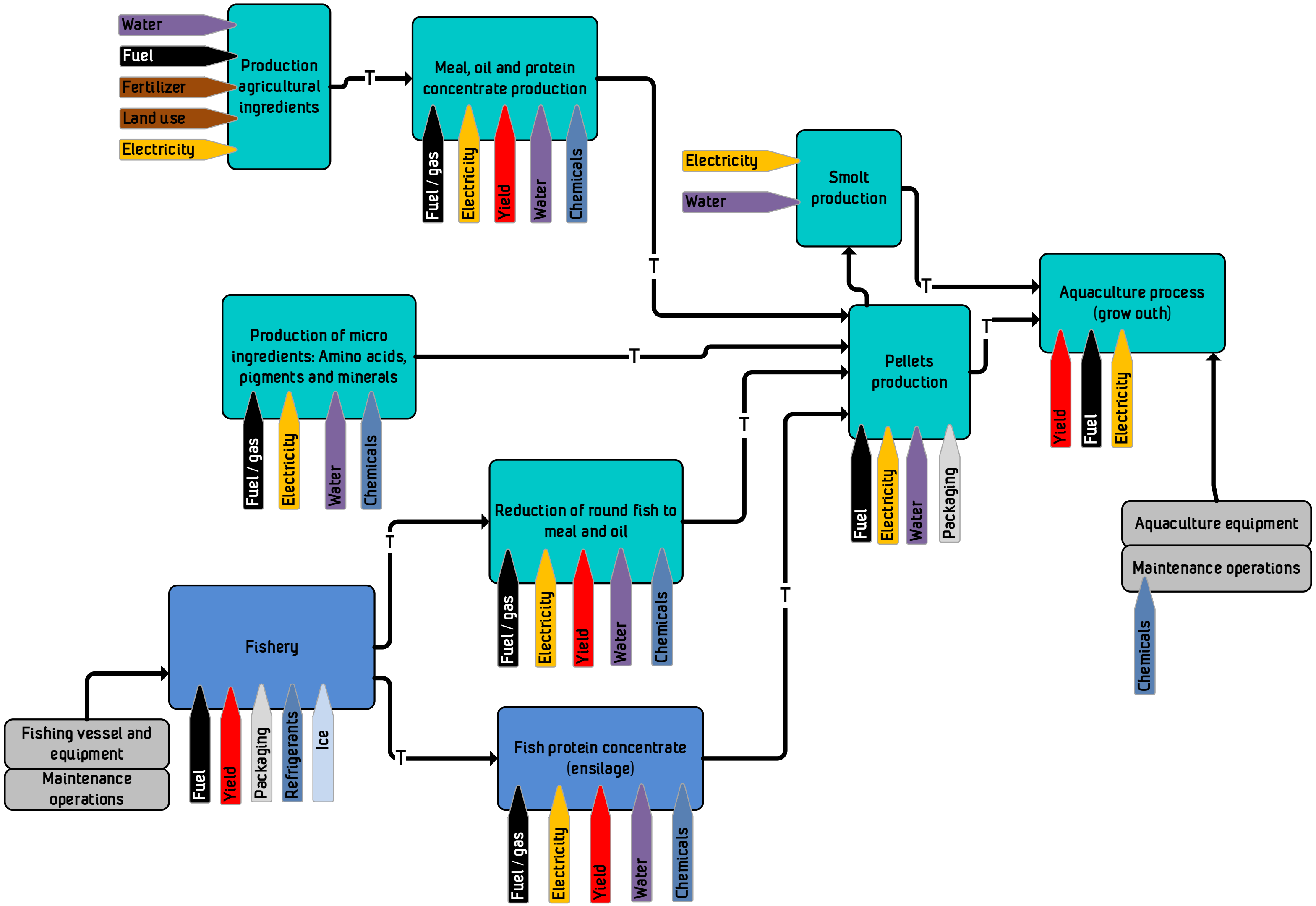

Figure 1-2 System boundaries for the impact assessment

2 Inventory

2.1 Feed composition 2010 and 2012

The composition of the average Norwegian salmon feed in 2012 is based on data from the three biggest Norwegian feed producers: Skretting, Biomar and Ewos. The mass is given in the state in which it is added to the pellets production, thus it is a mix of wet and dry weight. The composition is presented in more detail in Table 2-1 and Figure 2-1.

Around 66% of the feed origins from vegetable ingredients, the rest origins from the marine environment or they are micro ingredients. 23% of the marine oil and 32% of the marine protein (meal) come from by-products from the pelagic and demersal industry. The micro ingredients are mainly composed of phosphate substances such as mono-calcium-phosphate, vitamins, minerals, pigments and amino acids.

The total mass reported sum up to 1 577 233 tonn. In 2012 the Norwegian salmon aquaculture industry consumed 1.7 million tonn feed [16] and it is assumed that the feed composition calculated on the data reported to this project is representative of the average Norwegian salmon feed.

Table 2-1 Feed composition in 2010 and 2012

Component	**[tonn]**		**Comment**
	2010	**2012**	
Marine oils	217 156 (17%)	182 362 (12%)	More than 20% of this from by-products
Marine protein	323 551 (25%)	306 340 (19%)	More than 20% of this from by-products
Vegetable oil	164 712 (13%)	298 991 (19%)	Mainly rape seed oil
Vegetable protein	448 730 (34%)	617 032 (39%)	Around 60% of this soy protein concentrate
Vegetable starch	127 850 (10%)	122 158 (8%)	Mainly wheat starch
Micro ingredients	28 948 (2%)	50 349 (3%)	Mainly phosphate, vitamins, minerals and amino acids.
TOTAL	**1 310 947**	**1 577 233**	

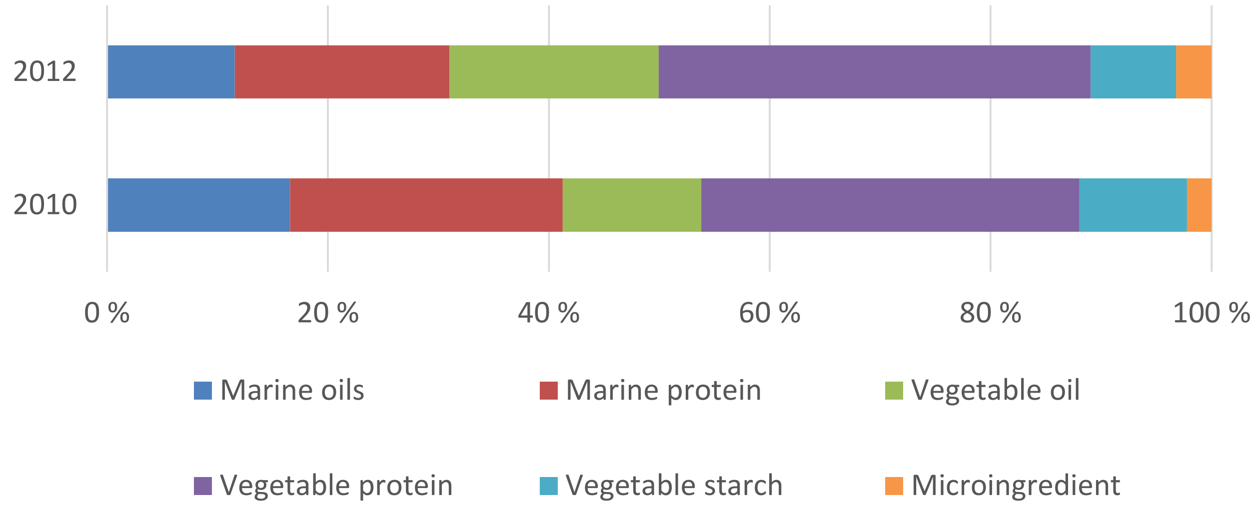

Figure 2-1 Feed composition in 2010 and 2012

2.1.1 Composition marine oil and protein

The companies report the data with different level of details, thus it was necessary to do some assumptions.

- Two producers did not specify what kind of herring that was used while one defined it into Norwegian spring-spawning, North Sea and Icelandic summer-spawning herring. Tt was assumed that the mass of undefined herring had the same origins as that used by the producer that gave most details. The same was done with capelin. Two producers reported just “Capelin”, this was distributed to Barents sea- and Icelandic capelin according to the third companies more detailed report

- Two producers reported a big part of their trimmings as “unknown from Atlantic and North Sea” this mass was assumed to be herring trimmings, based on inputs from the feed producers.

Table 2-2 presents the composition of the marine protein and oil in 2012. A few species dominates, Anchoveta, Capelin, Herring (in the form of trimmings), Sprat and Mackerel.

Table 2-2 Resources contributing with more than 1 % to the marine oil or protein. Percentages refer to average composition in 2012.

Species	Oil	Protein
Anchoveta	42.9 %	33.1 %
Blue Whitling	0.3 %	1.9 %
Herring	2.8 %	2.3 %
Sandeel	1.3 %	2.6 %
Sprat	8.7 %	7.4 %
Capelin	15.9 %	17.6 %
Menhaden	1.5 %	0.5 %
Mackerel	3.5 %	0.2 %
Boar fish	0.3 %	1.1 %
Krill		1.0 %
Trimmings Herring	18.1 %	21.2 %
Trimmings Capelin	0.5 %	3.6 %
Whitefish trimmings	1.6 %	1.6 %
Fish Protein Concentrate	2.1 %	4.9 %
SUM	**97.3 %**	**98.8 %**

2.1.2 Composition vegetable protein, oil and starch/carbohydrates

Table 2-3 presents details on the composition of the vegetable and microingredient component of the average Norwegian salmon feed in 2012.

Table 2-3 Detailed composition of vegetable and micro ingredients component in 2012 average Norwegian salmon feed diet

Component	Ingredient	Ton	% of feed	% of component
Vegetable protein	Soy Protein Concentrate	389 799	24.7 %	63.2 %
	Wheat gluten	84 616	5.4 %	13.7 %
	Corn gluten	12 509	0.8 %	2.0 %
	Sunflower meal	97 354	6.2 %	15.8 %
	Pea protein concentrate	12 936	0.8 %	2.1 %
	Horse/faba beans	19 819	1.3 %	3.2 %
Vegetable starch/carbohydrates	Wheat starch	102 296	6.5 %	83.7 %
	Pea starch	16 466	1.0 %	13.5 %
	Tapioka starch/karbs	3 396	0.2 %	2.8 %
Vegetable oil	Rape seed oil	298 991	19.0 %	100.0 %
	Palm oil		0.0 %	
Microingredients	Amino acids	6 542	0.4 %	13.0 %
	Pigments	654	0.04 %	1.3 %
	Vitamins and minerals	4 958	0.3 %	9.8 %
	MCP (monocalciumphosphate)	29 668	1.9 %	58.9 %
	MAP (Monoammoniumfosfat)	1 007	0.1 %	2.0 %
	Other additives	7 521	0.5 %	14.9 %

2.2 Vegetable ingrediens

Table 2-4 presents the carbon footprint associated with each of the vegetable feed ingredient used in this assessment. The details on these data are presented in the subsequent chapters. The values in this represents the sum of GHG emissions caused by growing of the crops, processing to concentrates/meal/starch/ and transports to pellets factory in Norway.

Table 2-4 Carbon footprint for vegetable ingredients at pellets factory gate

Origin	Ingredient	kg CO2e/kg ingredient @ pellets factory gate
Soy	Protein concentrate	5.69
Wheat	gluten	1.06
Wheat	starch	0.98
Sunflower	meal	3.10
Rape seed	oil	1.70
Pea	protein concentrate and starch	1.17
Fava beans	meal	1.33
Corn	gluten	0.90
Tapioka	starch	0.88

Soy Protein Concentrate (SPC)

The soy protein concentrate is a very important ingredient as it make a big share of the feed and growing of soy is associated with high environmental impacts such as climate impacts from land use change. The soy protein concentrate is modelled using the process "Soy protein concentrate, Brazil, at feed compound plant/BR Mass" found in the Agri-footprint database.

Soy protein concentrate is an important ingredient in salmon feed due to its high protein content and relatively low price. The main part of the global soy production comes from the US, Brazil and Argentina (35%, 27% and 19% respectively). Soy have a protein content of around 40 w% in dry mass. The dry mass of the bean is around 89 w%[4]. Soy meal can be categorized as high protein meal with 54 w% protein[5] and low-protein meal with 52 w% protein[6] (dry mass). Both these meals have a dry content of around 88 w%. The Brazilian producer IMCOPA, that is an important supplier to the Norwegian feed producers, have meals with 46 to 48% protein on a dry mass basis in meals with 12.5 w% moisture and soy protein concentrates with minimum 62 % crude protein and max 10% moisture. This SPC is produced with etanol extraction[7]. From these data the yield from round soy in wet weight to the soy protein concentrate will be around 0.57 kg SPC per kg soybeans ((0.4*0.89)/0.62 = 0.57). In the data from the Agri-footprint database the yield is 0.54 kg SPC per kg soy.

[4] Feedipedia webpage on soy beans: www.feedipedia.org/node/12627
[5] Feedipedia on high protein (dehulled) soybean meal http: www.feedipedia.org/node/11683
[6] Feedipedia on low protein (non dehulled) soybean meal: www.feedipedia.org/node/11682
[7] Link to IMCOPA web page with access to products specifications and data sheets http://www.imcopa.eu/products.php?page=13

The processing of soy to meal and protein concentrate also yields soy oil and residues. From 1 t of soy, 182 kg of soy oil (19%), 794 kg of soy meal and 18 kg of residues are obtained [17] Figure 2-2 presents an example of a soy-to-concentrate flow sheet.

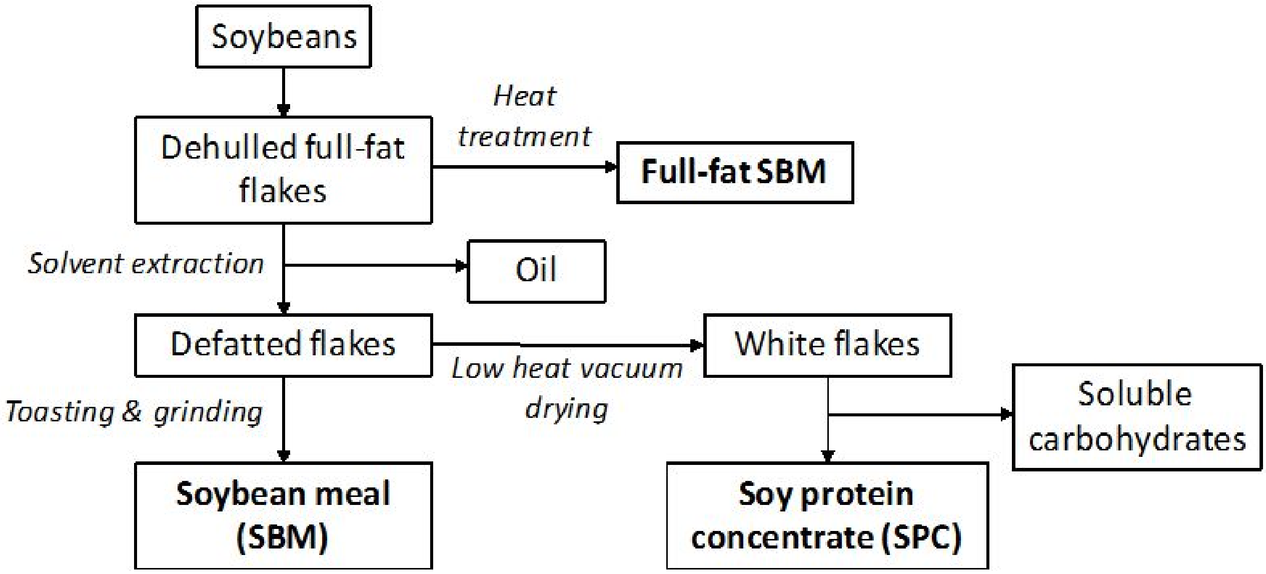

Figure 2-2 Production of Soy Protein Concentrate according to Pettersson & Pontoppidan 2013[8]

Pea Protein Concentrate (PPC) and pea starch

Pea Protein concentrate and pea starch only constitute a small part of the feed. It was not possible to find specific LCA data for these products and some assumptions was done.

According to the National Food Administration in Sweden the protein content of peas with a water content of 15 % is 21.5 % protein (National Food Administration, 2014). Then to yield 1 kg PPC with a 55 % protein content 2.56 kg of protein peas are need as input. The National Food Administration also informs that 49.2 % of the peas are carbohydrates. With the assumption that the starch is 100 % carbohydrates the input of 2.56 kg protein peas to the PPC production would also yield 1.26 kg pea starch. Al in all this results in the following mass balance for the pea protein and starch production:

- 2.56 kg protein peas -> 1 kg 55 % PPC + 1.26 kg Pea starch + 0.3 kg waste.

Since it was not found data on the processing from pea to concentrate and starch it was assumed that this process is comparable with that of production of wheat gluten and starch from wheat corns. The process “Wheat gluten feed, from wet milling, at plant/DE Mass” in the Agri-footprint database was modified by replacing the input of dried wheat grains with peas and replacing the outputs with pea protein concentrate, pea starch and “waste” according to the yields documented above.

[8] D. Pettersson and K. Pontoppidan (2013). Soybean Meal and The Potential for Upgrading Its Feeding Value by Enzyme Supplementation, Soybean - Bio-Active Compounds, Prof. Hany El-Shemy (Ed.), ISBN: 978-953-51-0977-8, InTech, DOI: 10.5772/52607. Available from: www.intechopen.com/books/soybean-bio-active-compounds/soybean-meal-and-the-potential-for-upgrading-its-feeding-value-by-enzyme-supplementation

Fava bean protein

It was not identified LCA data on fava bean meal or protein concentrate, thus the fava bean protein input was modelled with the same assumption as for the pea protein concentrate and starch: That the processing is comparable with that from wheat grains to gluten and starch.

The protein concentration of raw fava beans (broad beans) is 26 w% according to the USDA National Nutrient Database for Standard Reference [9]. The to produce a protein concentrate with 55 w% protein an input of 2.15 kg raw fava beans is needed. Growing of fava beans was modelled using the Ecoinvent v3 process "Fava bean, feed, Swiss integrated production GLO| market for | Alloc Def, U".

Sunflower meal

The sunflower meal used in the salmon feed mainly origins from Ukraine. In this assessment it is modelled with the process "Sunflower seed meal, from crushing (solvent), at plant/UA Mass" from the Agri-footprint database. The sunflower meal is a co-product in sunflower oil production, similar to the production process of rapeseed oil (Figure 2-4). The meal is produced from the press cake when sunflower seeds are pressed to produces crude sunflower oil.

Maize gluten meal

The maize gluten is modelled with the process "Maize gluten meal, from wet milling (gluten drying), at plant/US Mass" in the Agri-footprint database. Transport is with ship from America to Norway was added.

Maize gluten meal is produced together with starch, germ meal and corn oil in process like the one presented in Figure 2-3. Maize gluten meal is a high protein ingredient consisting of 60 % gluten protein with minimal quantities of starch and fibrous fraction[10].

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[9] Link to USDA National Nutrient Database for Standard Reference http://ndb.nal.usda.gov/ndb/foods/show/4774?fg=&man=&lfacet=&format=&count=&max=25&offset=&sort=&qlookup=fava+beans

[10] Corn refiners association. Corn wet milled feed products, 2006, www.corn.org/wp-content/uploads/2009/12/Feed2006.pdf

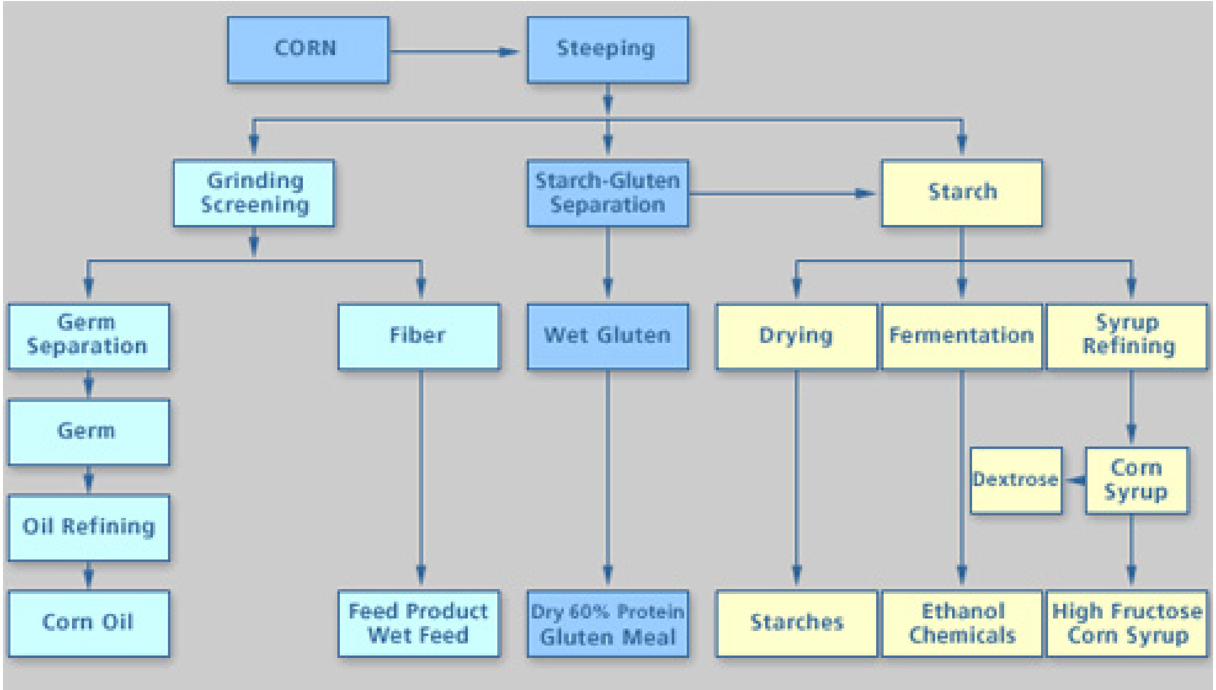


Figure 2-3 Wet mill process of corn[11]

Wheat gluten and wheat starch

Wheat is reported as a input to the protein in the form of wheat gluten, and as an input to the carbohydrate and fixing agent part. This latter input is in the form wheat starch, this is an co-product from the production of wheat gluten.

Wheat gluten and wheat starch are modelled using the processes "Wheat gluten meal, from wet milling, at plant/DE Mass" and "Wheat starch, from wet milling, at plant/DE Mass" in the Agri-footprint database. Thus the wheat inputs are included using German what growing and wet mill processing.

Tapioca starch

Tapioca, also called cassava, is a starch-rich root farmed in large quantities in Southeast Asia where Thailand is a large producer of the product Tapioca starch. Various LCA studies have been performed on the production of fuel ethanol from cassava, which per today is the main product extracted from the root. Tapioca starch is modelled with the process "Tapioca starch, from processing with use of co-products, at plant/TH Mass" in the Agri-footprint database. This tapioca starch is produced together with cassava pomac and peels.

Rapeseed oil and palm oil

The vegetable oil component of the feed is mainly rapeseed oil. Also palm oil is being used.

The rape seed is modelled with the process "Refined rapeseed oil, from crushing (solvent), at plant/DE Mass" in the Agri-footprint database. Transport from Germany to Norway was added to this process. Rapessed oil can also be produced just with pressing, but there it is assumed that a solvent is used.

[11] Link to source of figure: www.oilmillmachinery.net/corn-oil-production-process.html

The rapeseed oil used in the Norwegian salmon feed origins from five different countries Russia, Lithuania, UK, Germany and Denmark.
The most important parameter in rapeseed cultivation is the mineral fertilizer. Both the production and the use of mineral fertilizer cause climate impacts and eutrophication. Both direct and indirect emissions of N_2O are included.

Figure 2-4 and Figure 2-5 present a typical process flow from rape seeds to refined oil.

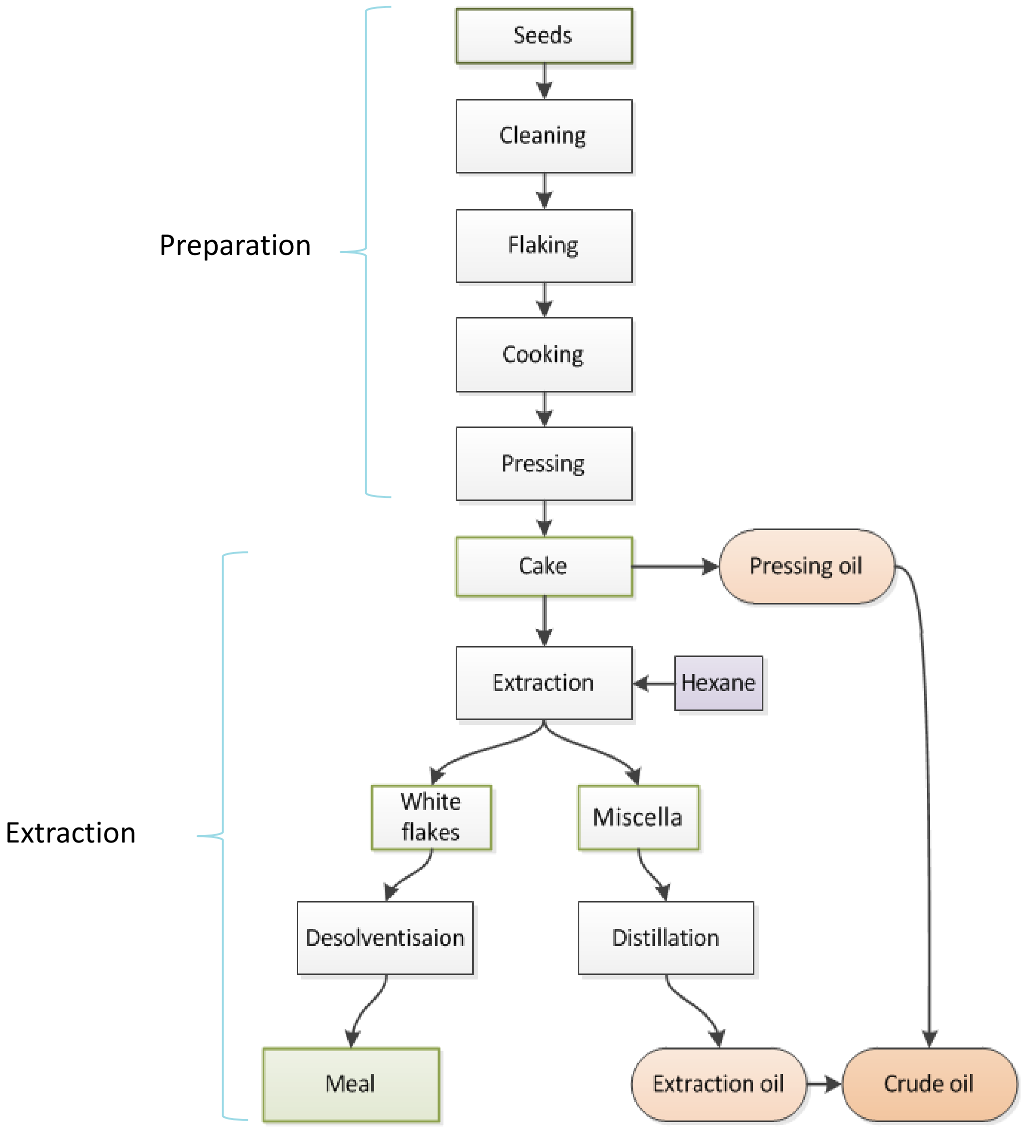


Figure 2-4 Flow chart from rape seeds to meal and crude oil

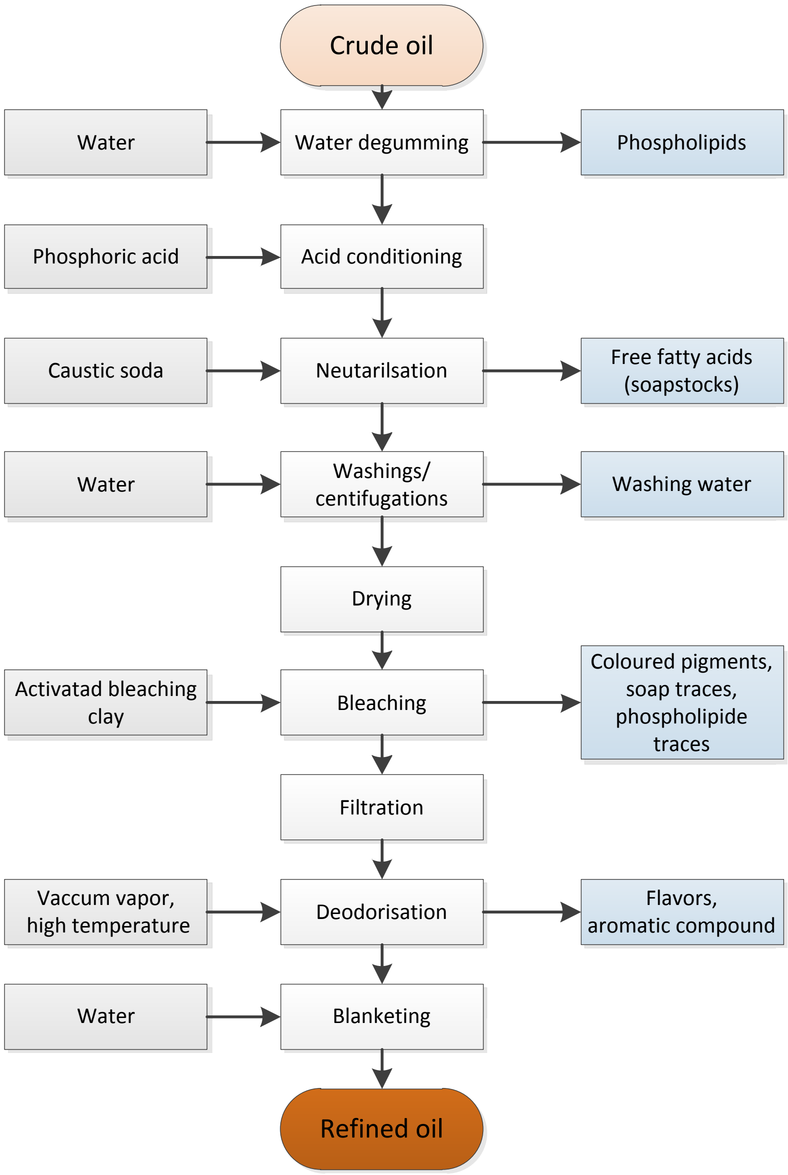


Figure 2-5 Flow chart from crude rape seed oil to refined rape seed oil

Palm oil is modelled with the process “Refined palm oil, at plant/NL Mass”. This process has an output of the refined palm oil and fatty acids distillates from refining of crude palm oil from Malaysia and Indonesia. The production of the crude oil also gives palm kernels. The documentation provided by the Agri-footprint database is not explicit on how environmental challenges from land use change associated with palm oil[12] is included in their data.

[12]More information on potential environmental challenges in palm oil production: http://wwf.panda.org/what_we_do/footprint/agriculture/palm_oil

2.3 Marine ingredients

The most important values for the assessment, for each species, the yield from round fish to meal and oil, the fuel consumption in fisheries and the carbon footprint of each ingredient at pellets factory gate, is presented in Table 2-7. The following paragraphs presents the background for these values.

Oil and meal processing and yield

The yield from round fish to meal/protein and oil/fat is a very important parameter for the overall results of LCAs of aquaculture products. Given the mathematically linearity of the assessment calculation a small change in this yield will increase or decrease the sum of environmental impacts associated with the specific meal and oil. Wet reduction of fish yields three products: fish meal, fish oil, and condensed fish solubles [18].

To be able to perform an assessment a value has to be set on these yields, but in real world they will vary a lot, this variation comes from factors such as

- Differences in the lipid content between the species. Only in the data mapped in this report we see reported lipid contents in the range of 1 % for Blue whiting to 34 % for Atlantic mackerel (see own chapter for references).
- Season, e.g in Norway the fat content of species is much higher during autumn, see Figure 2-6.
- Efficiency in the processing. The differences here has not been investigated, but given the close connection between the meal and oil producers profitability and yield one should assume that most big producers perform close to best practise.

Even though the yield from round fish to meal and oil can have a paramount impact on the final calculations, not only for LCA calculation, but also e.g. fish in/fish out calculations, there is still sometimes used one single average value. Hasan and Halwart present an average: 4–5 kg of wet fish will yield 1 kg of fishmeal and 100 g of fish oil [19]. This equals a yield of 22 % meal and 2 % oil from round fish. The fishmeal reduction yield that is accepted as an industry standard in South Africa is 23 % [19]. The Norwegian National Institute of Nutrition and Seafood Research (NIFES) presents a “fish-inn-fish-out” calculation where they spliot the oil yield in three categories: 3, 8 and 12 % oil yeild[13]

[13] NIFES web page “How much wild fish is there in fish farming feed?”: http://www2.nifes.no/sjomatdata/index.php?page_id=395

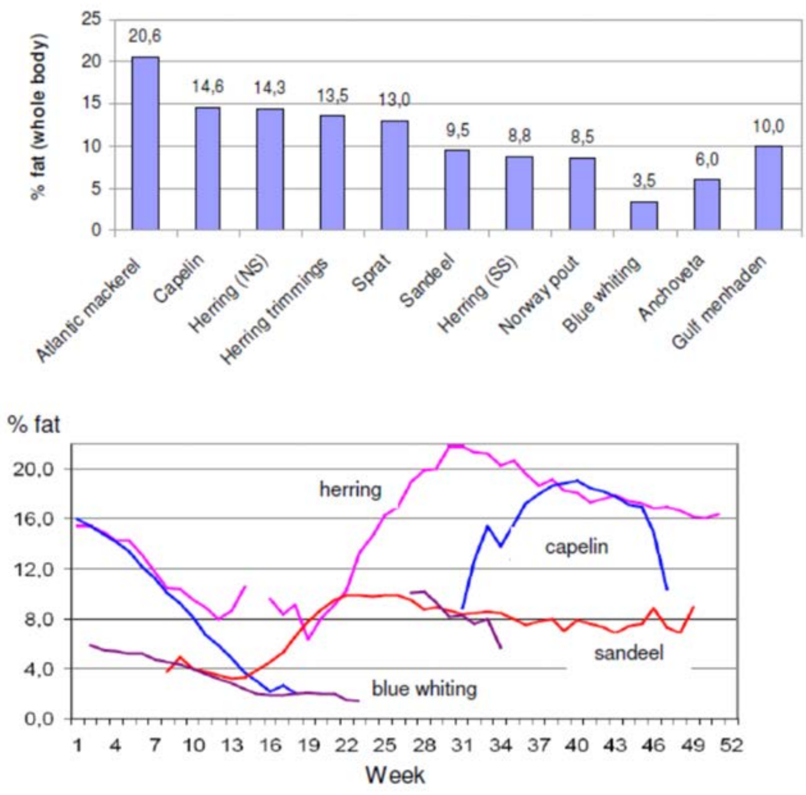


Figure 13 a) Variation in mean fat content (upper panel), and b) Seasonal variation in fat content in some species in some of the species used in fish meal and oil for production of Atlantic salmon in Norway in 2010 (lower panel). (Data taken from Fiskeriforskning-SSF, 2004)

Figure 2-6 figure from the report “Resource utilisation and eco-efficiency of Norwegian salmon farming in 2010” [8]

Fish meal and oil processing is thoroughly explained din the FAO Fisheries Technical Paper T142: "The production of fishmeal and oil"[14]. This paper presents a fuel oil consumption in the range of 30 – 55 kg fuel oil per tonn of raw material for drying of the fish meal. Henriksson et. Al. reports that natural gas is the main source of energy in the reduction of anchoveta in peru, 1 949 MJ to reduce one tonn of fish [20]. Using an energy density of 41 MJ/kg for light fuel oil we see that this sis the same ranger as the FAO paper (1 949 MJ/41MJ/kg = 47.5 kg).

FAO presents a water input in the range of 16 – 32 m^3 per tonn reduced. Parts of this can be covered with salt water, but for this assessment a water use factor of 30 m^3 of fresh water per tonn reduced was applied[15]

[14] Link to technical paper: www.fao.org/docrep/003/X6899E/X6899E00.HTM
[15] http://www.fao.org/docrep/003/X6899E/X6899E08.htm#7.3 Water Consumption

Trimmings and Fish Protein Concentrates

Trimming accounted for about 25 % of the marine oil and 13 % of the meal. By-products from fisheries enters oil/meal production as fresh or through an ensilage stage. In Norway in 2005 145 000 tonn of by-products yielded 29 000 tonn meal and 19 000 oil. This equal an meal yield of 20 % and oil yield of 13 % [21]. It is understood that ensilage can be added directly to the pellets production, but that option is not taken into account in this assessment.

Personal communication with Hordafor, a big producer of oil and FPC from pelagic and demersal by products, advised that a yield of 9% oil and 43% PPC should be used in the modelling of the process from ensilage to oil and FPC.

Pelagic trimmings arise from fileting of fresh and frozen fish. Around 50 % of the weight of the round fish will be by-products. In Norway these by-products are mainly used for meal and ensilage[16].

Figure 2-7 shows one pathway from trimmings to oil and Fish Protein Concentrate. After the oil has been separated the water phase that is left is dehydrated to a fish protein concentrate (FPC) to 40-50% dry content and 30-35 % protein [21].

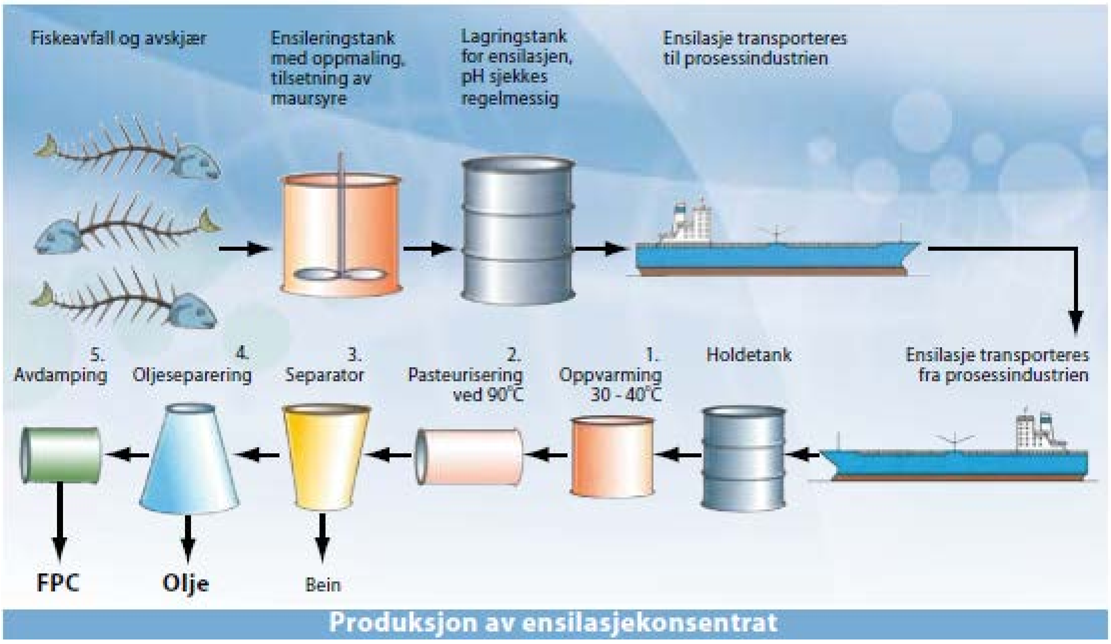


Figure 2-7 Flow sheet for trimmings-ensilage-oil/FPC production [21]

[16] RUBIN fact sheet from 2011: www.rubin.no/images/files/documents/varestrm_2011_nettversjon1.pdf

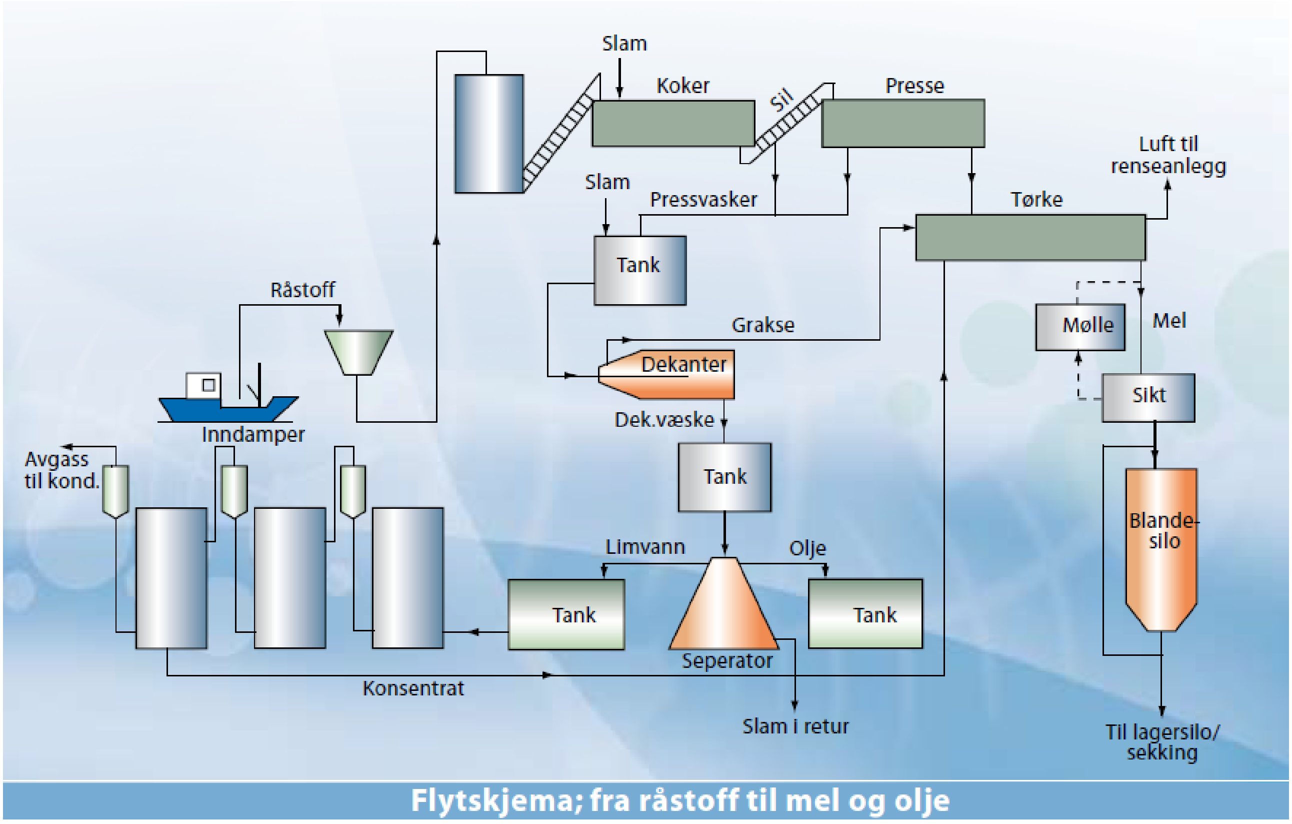
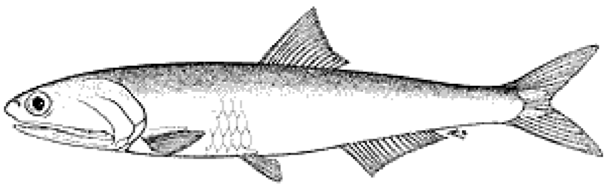


Figure 2-8 Process flow sheet from raw materials to meal and oil [21].

Peruvian anchovy



The Peruvian anchoveta fishery is performed by a large fleet (around 2800 vessels) with a wide range of vessel sizes and capacities. Fisheries used for feed (reduction fisheries) is mainly performed by the industrial fleet using purse seine in Peruvian and Chilean waters[17,18]. The Peruvian anchoveta (*Engraulis ringens*) fishery is the world's largest fishery, landing between 4 and 10 million tonn annually, depending upon climatic events [20]. The anchoveta is caught mainly with seine nets off the Peruvian coast. It is a very fuel efficient fishery, consuming only 16 kg diesel per tonn landed fish on average [22].

The yield from round anchoveta to oil is in the range of 2.0 – 6.1 % and to fishmeal 18.0 – 22.5 % [23]. These numbers are confirmed by looking at the IFFO data on landings of anchoveta and corresponding production of oil and meal (Table 2-5).

[17] FAO fact sheet on Peruvian anchovy: http://www.fao.org/fishery/species/2917/en
[18] IFFO data sheet on Peruvian anchovy: http://www.iffo.net/system/files/67_0.pdf

Table 2-5 Calculation example meal/oil yield anchoveta, based on IFFO data[19] and FAO data[20]

	Meal/oil production from IFFO data sheet[19]		Total catch from FAO[20]	Yield meal	Yield oil
Year	Meal	Oil			
	[tonn]		[tonn]	%	
2000	2 208 996	593 300	11 276 357	20	5
2001	1 884 079	332 509	7 213 077	26	5
2002	1 941 447	221 458	9 702 614	20	2
2003	1 250 793	206 817	6 203 751	20	3
2004	1 982 652	351 631	10 679 338	19	3
2005	2 019 858	286 407	10 244 166	20	3
2006	1 377 536	285 407	7 007 157	20	4
2007	1 407 000	337 000	7 611 858	18	4
2008	1 396 000	276 000	7 419 295	19	4

Capelin

The capelin is sourced from Icelandic capelin and Norwegian capelin (Barents sea).
Capelin is abundant in the Arctic parts of the North Atlantic. Most common fishing techniques are "small pelagic purse seining" and "Capelin purse seining". The total catch reported for this species to FAO for 1999 was 904 840 t. The countries with the largest catches were Iceland (703 694 t) and Norway (92 567 t).[21]

According to Nofima the yield from capelin to meal is around 17%. The yield for oil is dependent on the time of year: 2-7% from February to march, but only 3% during march where most of the Norwegian Capelin is caught. The main part of capelin that is landed by Norway is by purse sein and trawl[22]. According to NIFES the fat content of capelin from the Barents sea is in the range of 8.9 – 13.7% with an average of 10.8%[23].

[19] IFFO data sheet on Peruvian Anchovy www.iffo.net/system/files/67_0.pdf
[20] FAO web page with landing statistics: www.fao.org/fishery/statistics/global-production/en
[21] FAO fact sheet on Capelin: www.fao.org/fishery/species/2126/en
[22] The report "Markedsbasert høsting av lodde": www.nofima.no/filearchive/Rapport%2012-2011.pdf
[23] NIFES fact sheet on Capelin: www2.nifes.no/index.php?page_id=168

Sprat

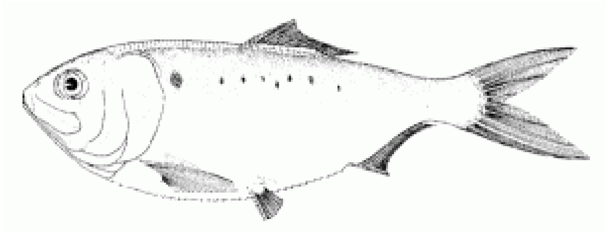
Main share of the Sprat is fished in North Sea, Baltic and off Norwegian coasts, Denmark and Norway are behind the main share of the landings. Caught in trawls or driftnets, or driven up Norwegian fjords by nets.[24]

Røjbek et al. Reported and average lipid content of sprat in the area of 3.6 to 17.5% of wet weight [24]

Gulf menhaden

Purse seining within the gulf of mexico is the dominating fishing technique and area and the fisheries are single-species reduction fishery for feed[25]. Menhaden meal is a valuable ingredient in animal feeds. It contains a minimum of 60% protein with a well-balanced amino acid profile. High levels of the essential sulfur amino acids, lysine, and methionine are present. Fish meal also contains desirable levels of important minerals such as calcium metaphosphate and natural selenium. [18].

Ruttan and Tyedmers reported a fuel consumption in US menhaden fisheries in the range of 20,89 – 55,98 tonn of fish per 1000 liters of fuel used. The average of their data gave a fuel factor of 0,032 liter of fuel per kilo landed [25]



Parker and Tyedmers reported finding of yields from 18,9 – 23% for meal and 12 – 19% for oil. This range is confirmed by comparing the global production of meal and oil from gulf menhaden with landings of gulf menhaden. Table 2-6 presents these data and using them to calculate the yield gives a range of 22–30% for meal and 10–16% for oil.

Table 2-6 Menhaden yields calculated from total production of oil and meal and total landings of Gulf Menhaden.

Year	Meal/oil production from IFFO data sheet[20].		Total catch from FAO[26]	Yield meal	Yield oil
	Meal	Oil			
	[tonn]		[tonn]	%	
2000	132 000	57 803	591 506	22	10
2001	117 000	94 895	528 506	22	18
2002	132 000	72 941	582 497	23	13
2003	117 000	53 405	522 195	22	10
2004	134 000	55 557	464 148	29	12
2005	111 000	60 491	369 906	30	16
2006	118 000	46 528	408 875	29	11

[24] http://www.fao.org/fishery/species/2102/en
[25] IFFO data sheet on Gulf menhaden: www.iffo.net/system/files/63.pdf
[26] FAO page on Gulf Menhaden: www.fao.org/fishery/species/2899/en

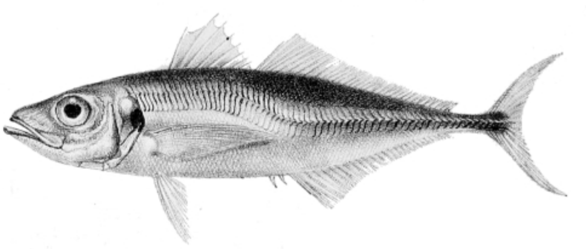
Herring - Atlantic NVG, ISS and North sea

Parker and Tyedmer present a range in yield from 18-22 % for meal and 9-13% for oil [23]. These ranges are confirmed by what NIFES[27] reports on the lipid content of Atlantic Norwegian Spring Spawning Herring (Clupea harengus):

- 4.1 – 10.4 % in the Norwegian Sea, with an average of 6.9%
- 13.4 – 17.9% in the North Sea, with an average of 15.7%

Fuel consumption and refrigerants emissions in the herring fisheries are assumed to be equal to Norwegian Pelagic fisheries

Mackerel - Atlantic, Atlantic Horse and Chilean Jack



According to NIFES the Horse Mackerel (Trachurus trachurus) has an fat content in the range of 9,9 – 23,6 w% and the Atlantic mackerel (Scomber scombrus) in the North Sea a fat content of 30 – 34 w%.

Hasan and Halwart report a yield from jack mackerel of about 23 % meal and 5–7 % oil [19].
Fuel consumption and refrigerants emissions in the Atlantic mackerel fisheries are assumed to be equal to Norwegian Pelagic fisheries.

Blue whiting

Blue whiting constitutes only a small share of the marine meal and oil in the 2012 diet. Acording to Norway Pelagic the fat content of Blue Whiting is in the range of 1-3 %[28]. Parker and Tyedmers presents a range in yields of 18 -21% for meal and 1-2,3% for oil [23]

Pilchard

The lipid content of Sardine (Sardina pilchardus) is reported to be in the range of 1.2 – 18.4 w% lipids (w/w) during one year. It is leanest in the spring and fattest in the autumn [26]

[27] NIFES statistic data: www.nifes.no/index.php?page_id=168
[28] http://www.norwaypelagic.no/index.asp?id=37540

Table 2-7 data used in the assessment of marine ingredients

	Mass of raw material	Yield % of meal or oil per mass of round fish in wet weight		Fuel consumption in fishery	Carbon footprint of ingredient from fishing, reduction to meal and oil and transport to pellets factory gate
Raw material	**kg/kg edible salmon**	**Oil**	**Meal**	**Liter fuel/kg landed**	**kg CO_2e/kg meal or oil**[29]
Anchoveta	0.505	5 (2-6)	23 (18-26)	0.019	1.30
Blue Whitling	0.024	2 (1-3)	20 (18-21)	0.095	2.86
Herring. NVG	0.009	12 (4-18)	21 (18-22)	0.095	1.95
Herring. ISS	0.006	12 (4-18)	21 (18-22)	0.095	1.91
Herring. North Sea	0.215	12 (4-18)	21 (18-22)	0.095	1.93
Sandeel	0.038	4.2	20	0.049	1.87
Norwau pout	0.003	20	12	0.095	2.04
Sprat	0.115	8 (<17)	19	0.095	2.30
Capelin	0.332	4 (2-7)	17	0.095	2.56
Menhaden	0.007	15 (10-19)	22 (19-30)	0.032	3.01
Mackerel. Atlantic	0.013	25 (<34)	19	0.095	1.12
Mackerel. Chilean Jack	0.001	7 (5-7)	23	0.019	1.48
Mackerel. Atlantic Horse	x	7 (< 24)	23	0.270	1.22
Pilchard	0.000	4 (1-18)	23	0.150	4.24
Boar fish	0.013	3.5	22	0.095	3.03
White fish	0.007	x	x	0.421	2.41
Pelagic by products	x	9	43	x	2.17
Whitefish by products	x	9	43	x	5.10

[29] The reason the carbon footprint is identical for oil and meal is the use of mass allocation

2.4 Micro ingredients

Micro ingredient was not included in the LCAs performed in 2011. To investigate the potential importance of this component. that in 2012 constituted up to 3.2% of the total feed, they were now included.

Only one feed company gave detailed data on the composition of their micro ingredients. The other two only gave the mass of micro ingredients and less detail on the composition. It was assumed that the composition of the micro ingredients was similar for all three companies and thus the detailed composition reported by the one company was used as a template for the two other companies. This approach lead to the average composition and tonnage of each ingredient presented in Table 2-8.

In the component, “other additives” there will be a share of palm oil. In 2010 this summed up to 0.2% of the total feed.

Table 2-8 Composition of microingredients in 2012

Component	Ton	Share of microingredient component
Amino acids	6 542	13.0 %
Pigments	654	1.3 %
Vitamins and minerals	4 958	9.8 %
MCP (monocalcium phosphate)	29 668	58.9 %
MAP (Monoammoniumfosfat)	1 007	2.0 %
Other additives	7 521	14.9 %

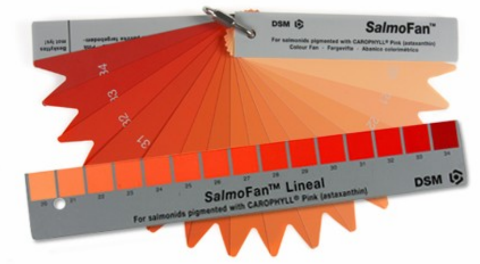
The following paragraphs presents how the different parts of the microingredients were modelled.

Pigments (Astaxanthin)

Astaxanthin is one of several pigments used in feeds. Data on production of pigments was not identified in any of the established LCA inventory databases, thus a literature was survey was performed.

Traditionally astaxanthin has been chemically synthesized, but today there is an increasing interest of producing it naturally by yeast (*Phaffia rhodozyma*) fermentation, or algal (*Haematococcus pluvialis*) induction. Synthetic astaxanthin still dominates the market and is the one use in fish feed, mainly because it is the low price alternative compared to the others. The article “Life cycle assessment of the production of the red antioxidant carotenoid astaxanthin by microalgae: from lab to pilot scale” by Paula Pérez-López et al. presents LCA results of astaxanthin with algae. After email correspondence with the Paula Pérez-López it was decided that the most representative data for industrial scale production of astaxanthin would be those presented in table 5 in the article.

In 2012 it was reported an input of around 654 tonn of pigments. It is assumed that this is not comparable to pure astaxanthin, but that it is only a share of this tonnage. Two commercial products with Astaxanthin was identified, "lucantin pink" from BASF and " CAROPHYLL® Stay-Pink" from DSM. Data sheets on these products show that they contain 10 - 11% pure astaxanthin[30] [31]. It was assumed that 10 % of the tonn reported as "pigments" are pure Astaxanthin. The feed producers report that they know of pigment mixtures with up to 20 % pure pigment.



BASF who is a big producer of astaxanthin have also performed environmental assessment of their production, but from the material that is identified through internet searches these data are impossible to use since BASF choose not to explain how the assessment is done and use impact categories and units outside of the established LCA methodology.

Amino acids

Fish cannot themselves synthesize a range of indispensable amino acids, so these amino acids must be supplied by the diet[32].

Also for production of amino acids it was difficult to find LCA data and results. One literature reference on environmental impact of amino acid production, by Blonk consultants, was found [27]. This study collected data from industry, consultancy, literature and internet. For impact assessment ReCiepe was used as characterization method. Their data on German Lysine production was used to model the input of amino acids. Table 2-9 presents the categorized results of their assessment.

Table 2-9. The impact per 1000 kg amino acid produced in three different countries [27]

		Methionine			Lysine			Threonine		
Impact categories (ReCiepe)	**Country Unit**	**DE**	**DK**	**FR**	**DE**	**DK**	**FR**	**DE**	**DK**	**FR**
climate change	kg CO_2 eq	5535	5408	5536	8914	8453	6746	19681	18211	13041
fossil fuel consumption	kg oil eq	3073	2983	3042	2809	2689	2187	7551	7143	5632
eutrophication	g P eq	1028	1025	1027	4062	1601	1122	10616	3078	1613
acidification	g SO2 eq	17068	16413	16763	28655	29756	26904	60906	63983	55406
photochemical smog formation	g NMVOC	10353	9717	10128	28043	27926	26201	46236	45589	40494
land use	m2a	69	69	69	5711	5767	5682	6467	6637	6378

[30] Link to BASF data sheet for "Lucantin pink CWD": http://www.bna-na.com/include/js/tiny-mce/plugins/kfm-1.4.5/get.php?id=26
[31] Link for report on CAROPHYLL http://www.efsa.europa.eu/en/efsajournal/doc/574.pdf
[32] FAO web page on nutritional requirements of atlantic salmon: http://www.fao.org/fishery/affris/species-profiles/atlantic-salmon/nutritional-requirements/en/

Vitamins and minerals

It was not found specific data for the production of vitamins and minerals, the only thing that was found was data on the chemical Dimethyl malonates. The input of vitamins and minerals was modelled with the process "Dimethyl malonate GLO| market for | Alloc Def, U " in the ecoinvent v3 database. According to the documentation on this process, as provided by the Ecoinvent database, this chemical is widely used for the production of vitamins, pharmaceuticals, agrochemicals, fragrances, and dyes.

2.5 Pellets production

Pellets production is modelled based on data found in the environmental reports from Skretting. In their Norway Annual sustainability report from 2013 they report that the production of 658 224 tonn of feed included the following in- and outputs:

- 2 336 tonn of waste (the report provides details)
- 22 775 tonn of CO_2e direct emissions (not including transport to farming cite)
- 5 90TJ of energy: NG/LNG (52 %), Diesel (1 %), Electricity (42 %) and Propane (5 %)

In addition to this some data from their 2010 sustainability report was kept: Input of packaging materials (plastic and euro pallets).

Figure 2-9 Example of ship used in feed transport to farmer[33]

2.6 Salmon aquaculture process, Feed Conversion Ratio (FCR) and product yield

The salmon farming, the grow out of the salmon, is modelled based on data from internal projects at SINTEF Fisheries and aquaculture. Energy use for feeding, maintenance of nets, handling of the salmon and transport of personnel is included. Also materials to construct the farming equipment is included.

[33] www.eidsvaag-rederi.no/baat/vis/12

The feed conversion ratio (FCR) that is used is the economic FCR (amount of feed used per kg of slaughtered fish) as they are presented in the environmental report from the Norwegian Fisheries and Aquaculture Association. In 2010 and 2012 the FCR was 1,3 and 1,2 [16, 28].

The marine area occupied by the aquaculture process is also derived from the FHL environmental report [28]: The area occupied by the Norwegian aquaculture industry in 2010 was 420 km^2 when restrictions of fishing and other activities and anchoring is included, at the same time they had an output of 991 000 tonn, this gives an "occupied area" factor of 0.424 m^2/kg salmon

In the calculation from living salmon to the functional unit; 1 kg edible part, it is assumed that 1.74 kg living salmon yield 1 kg edible fillet [6].

2.7 Smolt production

Smolt production is modelled based on data from an internal project at SINTEF Fisheries and aquaculture that compared a conceptual recycling aquaculture system (RAS) with a open net pen system. The most important input to this process except from feed is electricity, 18.5 MJ per kilo live weight of fish produced.

The water use in smolt production were investigated. In the book “vannkvalitet og smoltproduksjon” they report that, from 1999 to 2001, the average water use in Norwegian smolt production was 656 L/min in an tank with 38 000 individuals. At the same time the fish spent an average of 83 days to reach a weight of 80.7 gr at whish it is transferred to sea [29]. This gives a specific water use of 25.6 liter of water per kilo of smolt produced:

$$\frac{656\,{}^{L}/_{min} * 83 * 24 * 60\ \mathrm{min}}{38\,000 * 80{,}7\ gr} = 25.6\ \mathrm{l/kg}$$

This number was controlled with internal competence at SINTEF Fisheries and aquaculture, two examples of water use was presented:

1) In a flow through system with an annual 4 600 000 smolt per year and a water inflow of 18 m^3/min for 6 months and 18 m^3/min for 3 months. Assuming a weight of 100 gr/smolt this gives a water use factor of 27.4 m^3/kg smolt
2) In a recycling system, which is what all the new smolt production is based on, with a production of 14 000 000 smolt per year the inflow was 5 m^3/min. Again assuming a smolt weight of 100 gr/smolt this gives a water use factor of 1.9 m^3/kg smolt

In this assessment an average was used: (27.4+1.9)/2 = 14.7 liter of water added per kg smolt produced

3 Results

3.1 Carbon footprint of Norwegian salmon production

The carbon footprint is the sum of different forms of climate impacts caused by the functional unit. For this assessment that will be the sum of climate impacts caused by the production of one unit of salmon from fishing and growing of marine and vegetable feed ingredients up to the where the salmon is ready for slaughter, the salmon farm gate. This climate impact mainly arise in the form of greenhouse gas emissions from various activities in the value chain, but also from land use change, i.e. activities that change the carbon balance in terrestrial ecosystems.

3.1.1 Development in GWP from 2010 diet to 2012 diet

The carbon footprint per unit of edible salmon increased from 3.7 to 4,0 kg CO2e/kg edible salmon from 2010 to 2012. Despite an increase in feed efficiency, from 1.3 to 1.2, the changes in the composition of the feed made the final GWP increase. Figure 3-1 and Table 3-1 presents how the composition and economic FCR has developed from 2002 to 2012. The results of the carbon footprint is here referred to as the Global Warming potential (GWP), quantified in CO2 equivalents per unit of inn or output, of a defined product or process. A climate aspect is a process, activity or input that cause climate impacts.

The main climate aspects in feed production remain the same as those identified in 2011 [8], but with wider system boundaries, and better data, also new climate aspects are discovered, most important the use of micro ingredients. Figure 3 2 presents the GWP per kg edible salmon ready for slaughter for the 2010 and the 2012 diet.

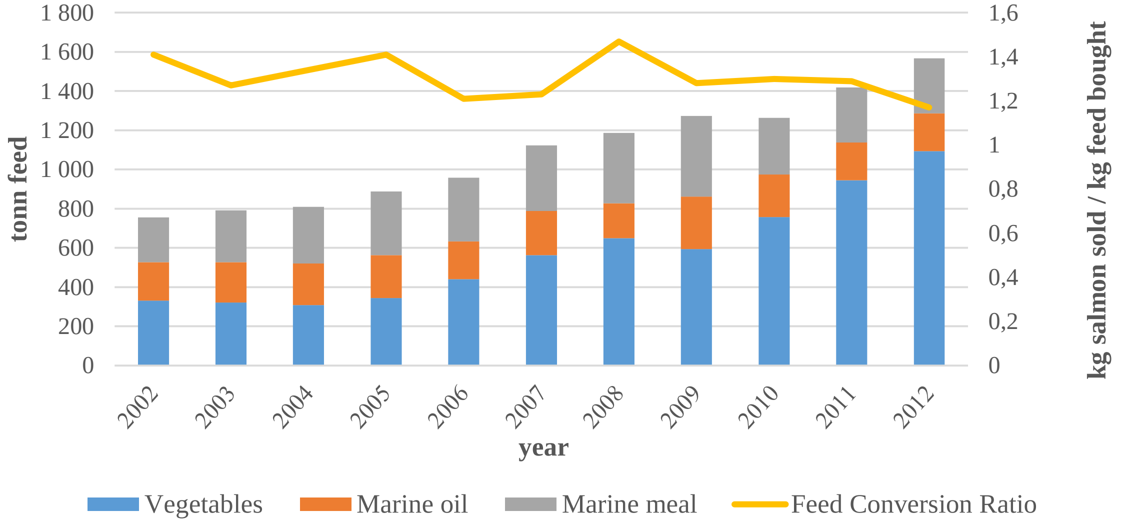


Figure 3-1 Development of feed composition and economic FCR for Norwegian salmon production from 2002 to 2012. Data from FHL.

The FCR is a dominating parameter for environmental assessment of salmon as it is the key to the overall efficiency of the production system. Feed represent around 95 % of the GWP per kg edible salmon at farm gate, thus a change of e.g. 10 % in the FCR will lead to a change of 9.5 % in the final GWP per kilo of edible salmon. The FCR of 1.2 for 2012 is the representative average for a big and diverse industry and many farmers can perform better than this while many also perform worse. The FCR is the result of the competence of the farmer, but equally important are external factors such as changes in the marine environment and most important diseases.

The main reason for the increase in GWP from 2010 to 2012 is the increased use of vegetable ingredients In general, The vegetable ingredients that replace the marine ingredients have a higher carbon footprint, especially that is true when growing of soy that are associated with land use change replace the most efficient pelagic fisheries. In 2010, the feed consisted of 19.6 % soy protein concentrate (SPC) while in 2012 the corresponding number was 24.7 %. The SPC in this assessment is attributed with a climate impact of 5.9 kg CO_2e/kg at factory gate. Land use change caused 84 % of this. As a comparison the biggest part of the marine protein, Peruvian Anchoveta, has a GWP of 1.1 kg CO_2e/kg meal at factory gate in Norway. This is not saying that SPC and anchoveta meal are directly comparable products, that one kilo can replace another. The GWP per kg feed at pellets factory with the 2012 diet was 3.1 kg CO_2e/kg feed while for the 2010 diet 2.9 kg CO_2e/kg feed.

The development from 2010 to 2012 is studied within the same assessment framework: Identical data for identical ingredients and identical system boundaries. E.g., there is no difference in the environmental impacts associated with the soy that was used in 2010 and 2012. Thus, this compares how changes in the diet influence the carbon footprint of the salmon, but does not include changes in how the ingredients are produced from one year to another.

3.1.2 Land use change and climate impacts from the use of soy

Soy protein concentrate is identified as an especially important climate aspect of salmon aquaculture products. Brazilian soybeans are associated with 4.9 kg CO_2e/kg soy at farm gate. 90 % of this climate impact comes from land use change. The rest comes from the use of fertilizers and burning of diesel in machinery.

The Agri-footprint database include climate impacts from land use change with the methodology presented by the GHG protocol and in appendix b in the "Product Life Cycle Accounting and Reporting Standard" [30]. Land-use change climate impacts include CO_2 emissions and removals due to carbon stock change occurring as a result of land conversion, and CO_2, N_2O, and CH_4 emissions resulting from the preparation of converted land, such as biomass burning or liming. To calculate the climate impacts from land use change it have to be defined what type of land use- and carbon stock change that the product has caused, and when these changes occurred. The calculation of climate change potential from land use is thus dependent on either very specific data on the exact location from where the soybeans are sourced or depending on assumptions.

In this assessment, it is assumed that all soy products are sourced as an average of the Brazilian soy production, as the Agri-footprint database present it. Thus the result of 4.0 kg CO2e/kg edible salmon does not consider that a major part of the soy used in the Norwegian salmon feed, according to the feed producers, are delivered by certified and old farms. Soy production for which it can be argued that the land use change happened so long ago, that it is not to be included anymore. The reason that we choose to present the results for the average Brazilian soy is to highlight how important it is to consider land use changes in the development of more sustainable feed. To show the effect of land use changes it was calculated a case where all of the soy was sourced from US soy production, which the Agri-footprint does not attribute with climate impacts from land use change (0.41 kg CO2e/kg soy). See Figure 3-1 and Table 3-1. This resulted in a GWP of 2.6 kg CO_2e per kilo edible salmon at salmon farm gate for the 2012 production. A reduction of more than 30%. Salmon producers should pay attention to how emerging rules for environmental assessment of food products treat climate impacts from land use change; it can dominate the outcome of the assessment.

The agrifood database also provide data from Argentina and the US. These data vary from 5.9 to 0.47 kg CO_2e per kg soy at farm gate. A difference of more than 1200%. In another recognized database for LCA data soy from Brazil and from "land recently transformed", carry a GWP of 8.0 kg CO_2e per kg soy at farm gate and US soy 0.41 kg CO_2e/kg soy.

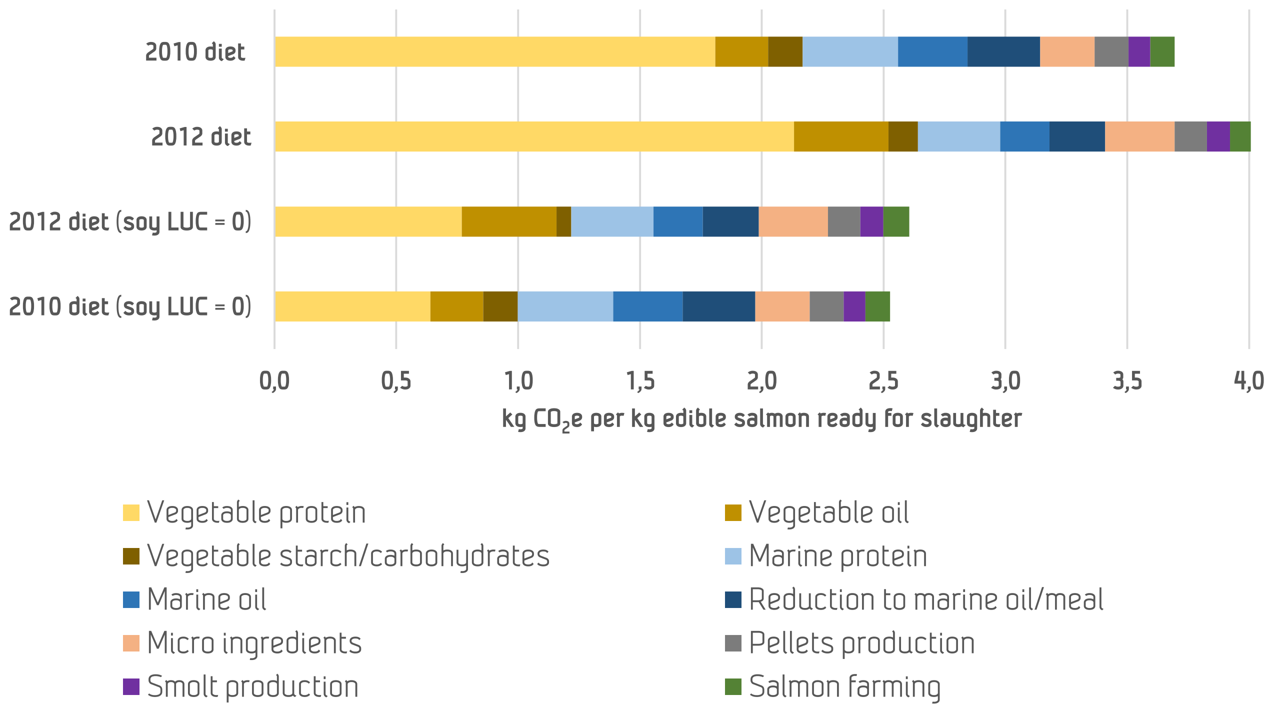


Figure 3-2 GWP results for 2010 and 2012 diet plus example where climate changes from land use in growing of soy is not included (see also Table 3-1 for explanations of categories)

Table 3-1 Results of carbon footprint

All values are kilo of CO_2 equivalents caused by the production of 1 kilo edible salmon at salmon farm gate	2012 diet no land use GWP from soy included	2012 diet	2010 diet	Comment
Vegetable protein.	0.77	2.13	1.81	Includes growing of crops. transport and processing
Vegetable oil	0.39	0.39	0.22	
Vegetable starch/carbohydrates	0.06	0.12	0.14	
Marine protein	0.34	0.34	0.39	Includes fishing and transports
Marine oil	0.20	0.20	0.29	
Reduction to marine oil/meal	0.23	0.23	0.30	only the processing from round fish to meal and oil
Micro ingredients	0.28	0.28	0.22	Production of the different micro ingredients
Pellets production	0.13	0.13	0.14	Includes compiling the different feed ingredients and transport from pellets factory to salmon farm
Smolt production	0.09	0.09	0.09	Includes energy to run smolt farm and feed used by the smolt
Salmon farming	0.11	0.11	0.10	Includes energy to operate the salmon farm and equipment used at the farm
SUM	**2.61**	**4.03**	**3.69**	

3.1.3 Development in assessment quality from 2011 to 2014.

Norwegian salmon production and feed production was also studied in 2011 [7, 8]. **The numbers from this report can not be directly compared to the numbers presented here in 2014 for numerous reasons**:

- During these years the data that are used has improved, e.g., Ecoinvent has been updated and the Agri-footprint database is published.
- The assessment represented here is more complete, e.g. micro ingredients are now included.

3.1.4 Microingredients

One of the goals of this assessment was to investigate if microingredients should be included in environmental assessments of salmon production. This group of ingredients only account for 2-3 % of the total mass of the feed. As described in the inventory chapter it was difficult to find precise and reliable data on the production of the microingredients. Several assumptions had to be done. With this in mind, it is still concluded that microingredients can be a very important environmental aspect in salmon production. The assessment of the 2012 diet indicate that microingredients caused more than 10 % of the GWP per edible salmon. Microingredients encompass a group of ingredients, in this assessment it includes amino acids, pigment, monocalciumphospate, vitamins and minerals. Among these components, production of the pigments and the amino acids were shown to be two especially important contributors to environmental impacts.

3.2 Input of phosphorus

The input of phosphorus to the salmon production system assessed here all comes from Phosphate[34] rock (P2O5). According to the Agri-footprint database, 1 kg of phosphate rock equals 14 gr of phosphorus. The sum of phosphorus that enters the system is 11 g P per kg edible salmon. 43 % of this is used in the micro ingredients by input of phosphoric acid to produce monocalciumphosphate. The rest is for fertilizers used in the production of rapeseed oil (14 %), sunflower meal, soy concentrate (41 %) and pea starch (2 %). Phosphorus that enters the system through the marine ingredients was not included in these 11 gr.

3.3 Salmon Fresh Water Footprint

Access to fresh water for aggregation and drinking is sailing up as the next big global environmental challenge; it is not only an environmental challenge, but a challenge for food supply and livelihood for many people. Global freshwater withdrawal has increased nearly sevenfold in the past century and expected to continue to increase in the coming decades [31].

Different methods have been developed to study the water footprint of products. This assessment follows the method promoted by the Water Footprint Network[35] and demonstrated by Mekonnen et al. in their assessments of the water footprint of crops and animal products [31, 32]. The water footprint of a product is the total volume of water that is used to produce, distribute, use and dispose of the product. Water use is often divided into three categories:

- **The blue water footprint** refers to consumption of blue water resources (water in freshwater lakes, rivers and aquifers) along the supply chain of a product. 'Consumption' refers to loss of water from the available ground-surface water body in a catchment area. Losses occur when water evaporates, returns to another catchment area or the sea or is incorporated into a product. Currently, the agricultural sector accounts for about 85% of global blue water consumption

- **The green water footprint** refers to the volume of rainwater consumed during the production process. This is particularly relevant for agricultural and forestry products (products based on crops or wood), where it refers to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop or wood. Green water is precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants.

[34] Phosphorous is #15 on the atomic chart of elements. Materials that contain phosphorous compounds create phosphates such as salts or esters of phosphoric acid.
[35] Link to water footprint web page: www.waterfootprint.org

Green water can be made productive for crop growth (although not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth) [36] .

- **The grey water footprint** refers to the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards.

Mekonnen concluded that on a global average the water footprint of meat increases from chicken meat (4 300 m^3/tonn), goat meat (5 500 m^3/tonn), pig meat (6 000 m^3/tonn), sheep meat (10 400 m^3/tonn) to beef (15 400 m^3/tonn). The differences are partly explained by the different feed conversion efficiencies of the animals and the feed composition used for each species. Particularly the fraction of concentrate feed in the total feed is important, because concentrate feed generally has a larger water footprint than roughages. Beef production, for example, requires 8 times more feed (in dry matter) per kilogram of meat compared to producing pig meat, and 11 times if compared to the case of chicken meat. Chickens are efficient from a total feed conversion efficiency point of view, but have a large fraction of concentrates in their feed. This fraction is 73% for broiler chickens (global average), whereas it is only 5% for beef cattle.

Around 98% of the total water footprint of animal production comes from the feed they consume. Drinking water, service water and feed-mixing water further account the only for up to 2 % of the total water footprint. In the feed production grazing accounts for the largest share (38%) of the water footprint, followed by maize (17%) and fodder crops (8%) [32]

Mekonnen et. al. only include the following components in their water footprint of animal products: the indirect water footprint of the feed and the direct water footprint related to the drinking water and service water consumed. Water that is used in the production of electricity, fuels, chemicals and other commodities that underpin the productions system is not included. Thus, when one consider the system from growing of crops to finished animal product as foreground system; they only include direct water use.

The salmon produced in 2012 was assessed with the following included:

- The water footprint of the vegetable ingredients were included according to the data provided by Mekonnen et al [31, 32].

- In addition to the growing of crops the following processes were included:
  - Pellets production with 0.65 m^3 of water used to produce 1 tonn of feed (see chapter 2.5). This input was categorized as blue water.
  - Reduction of round fish to meal and oil with 30 m^3 per tonn of fish reduced (see chapter 2.3). This input was categorized as blue water.
  - Smolt production with 14.6 m^3 per tonn of smolt produced (see 2.7). This input was categorized as blue water.

Water use that was not included

- Salt water that flows through the fish farm and thus is added substances such as nutrients from feces and feed that is not eaten, chemicals from medical treatment of the fish and net treatment. Cleaning of the nets will also release organic matter into the water body.

[36] Link to water footprint glossary: www.waterfootprint.org/?page=files/Glossary

- Water used in the processing of the salmon, e.g. for washing is not included, this is also outside of the system boundaries of the assessment, this assessment only include the salmon production system up to where it is ready for slaughter.

- In this assessment, water used to provide commodities such as electricity, that underpin the salmon production system, was not included. Neither was net maintenance operations or transports.

This assessment gave a water footprint of 1 950 m^3 water per tonn edible salmon. Around 98% of this originates from growing the vegetable ingredients. Reduction of fish to meal and oil contributed with the last 2% and pellets and smolt production with less than 0.05%.

Table 3-2 Data and results water footprint

			Water footprint of each inputt [m^3/tonn]			Result [m^3/tonn edible salmon]		
Input	**kg input /kg feed**	**kg input /kg salmon**	**Green**	**Blue**	**Grey**	**Green**	**Blue**	**Grey**
Soy	0.26	0.31	2037.00	70.00	37.00	623.32	21,42	11,32
Wheat grains	0.07	0.09	1278.00	342.00	208.00	110.22	29.50	17.94
Sunflower seed	0.09	0.11	3017.00	148.00	201.00	337.06	16.53	22.46
Rapeseed	0.22	0.26	1703.00	231.00	336.00	445.50	60.43	87.90
Pea	0.02	0.02	1453.00	33.00	493.00	31.91	0.72	10.83
Fava bean	0.01	0.01	3945.00	125.00	983.00	55.39	1.76	13.80
Maize		0.01	947.00	81.00	194.00	9.47	0.81	1.94
Smolt		0.02		14.60		0.00	0.29	0.00
Pellets production		1.22		0.65		0.00	0.79	0.00
Fish reduction to meal/oil		1.29		30.00			38.63	
SUM						**1613**	**171**	**166**
SUM TOTAL						**1950**		

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