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REPORT

Carbon footprint and energy use of Norwegian seafood products

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SINTEF Fisheries and Aquaculture

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ABSTRACT

Carbon footprint and energy use has been quantified for 22 Norwegian seafood products most of which currently constitute important components of Norwegian seafood export with regard to volume and value.

The conclusions from this work include that Norwegian seafood products are competitive from a carbon footprint and energy use perspective, both compared to other seafood products and compared to land-based production of meat products. Important focus areas for fisheries are improving the fuel efficiency further and replacing refrigerants with high global warming potential, used in onboard cooling systems, by climate neutral ones. For salmon farming, optimising feed use and feed composition is paramount with regard to reducing climate impact from salmon aquaculture products. For mussel farming increased edible yield from harvested mass, increasing by-product use and decreasing fuel use on vessels used for maintenance and harvest are areas to focus on.

General conclusions for all seafood products in this analysis are that increasing the proportion of frozen and super-cooled seafood to fresh, which in turn decreases the need for air freight and other resource-intensive means of transport, would lead to major improvement. Increasing the edible yield and use of by-products would likewise lead to lower emissions. Processing more seafood in Norway before export is also advantageous because of better possibilities to make use of by-products and decreased need for transportation when exporting products rather than whole fish.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Carbon footprint	Karbonavtrykk
GROUP 2		
SELECTED BY AUTHOR	Aquaculture	Havbruk
	Fisheries	Fiskeri
	Life Cycle Assessment (LCA)	Livsløpsanalyse

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Summary

Carbon footprint and energy use has been quantified for 22 Norwegian seafood products most of which currently constitute important components of Norwegian seafood export with regard to volume and value. A product currently representing a low volume was also included due to its potential for development and highly different production method, farmed blue mussels.

The products stem from capture fisheries for herring, mackerel, cod, saithe and haddock or from aquaculture of blue mussels and salmon. After landing or slaughter fish and mussels are processed into a variety of fresh, frozen, round, gutted or fillet products after which they are transported to the respective country and city where the wholesaler is located. The large number of chains assessed using the same methodology, ISO standardised Life Cycle Assessment methodology, following the supply chains from cradle-to-gate, allows for comparison between supply chains illustrating the effect single aspects such as species, transport mode and distance and product form.

In general, the products from pelagic fisheries were found to have the lowest carbon footprint while mussels, products from demersal fisheries and salmon were higher and in the same range (Figures 1 and 2). The range in carbon footprint was 1-14 kilos of carbon dioxide (CO_2) equivalents per kilo of edible product delivered to the wholesaler, the range in energy use was 16-210 megajoule (MJ) equivalents. The lowest value was achieved by round frozen herring and mackerel taken to Moscow by bulk shipping and train and the highest by gutted salmon taken to Tokyo by airfreight.

The two categories studied, energy use and carbon footprint, were highly correlated, indicating that the use of fossil fuels dominated the carbon footprint result. The use of the old generation of refrigerants, which were phased out in other applications decades ago, turned out to be the second largest contributor to the carbon footprint for almost all chains originating in demersal fisheries contributing to up to 30 % to the total carbon footprint. The exception to this was cod processed in China where transport was largest, diesel use in fishing second and refrigerants ranked third. Less surprising was that diesel use in fishing was the most important contributor in the other demersal chains, despite the fact that all fisheries were relatively fuel efficient compared to literature data. Pelagic fisheries are so efficient already that other activity such as packaging, processing and transportation become more important.

It was shown that processing in Norway is favourable compared to exporting whole fish for processing abroad, since by-products are used to a greater extent in Norway and part of the transport activity is avoided. Freezing or super-cooling of seafood requires some energy, but especially when long distance transportation is involved, the longer shelf-life of frozen or super-cooled fish makes it possible to transport it in a much more efficient manner which is more important for the overall result. Moreover, frozen and super-cooled fish does not require use of ice as does fresh fish which is positive both due to the electricity used for ice production, but more importantly due to the larger amount of fish that can be loaded per pallet, truck and container. While there is a clear effect of transport distance, the factors transport mode and transport time are equally important.

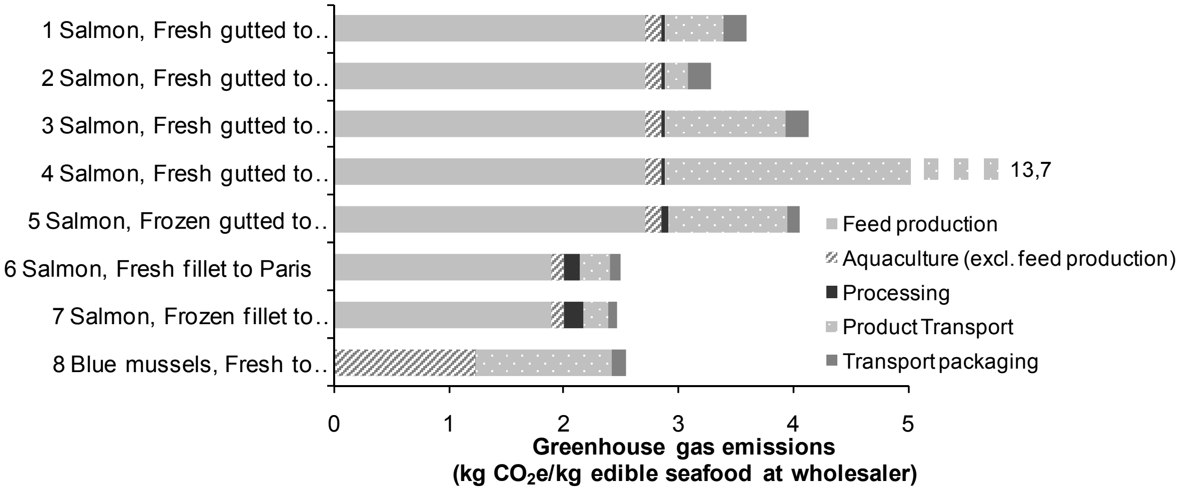

Figure 1 Overall carbon footprint results for products from aquaculture

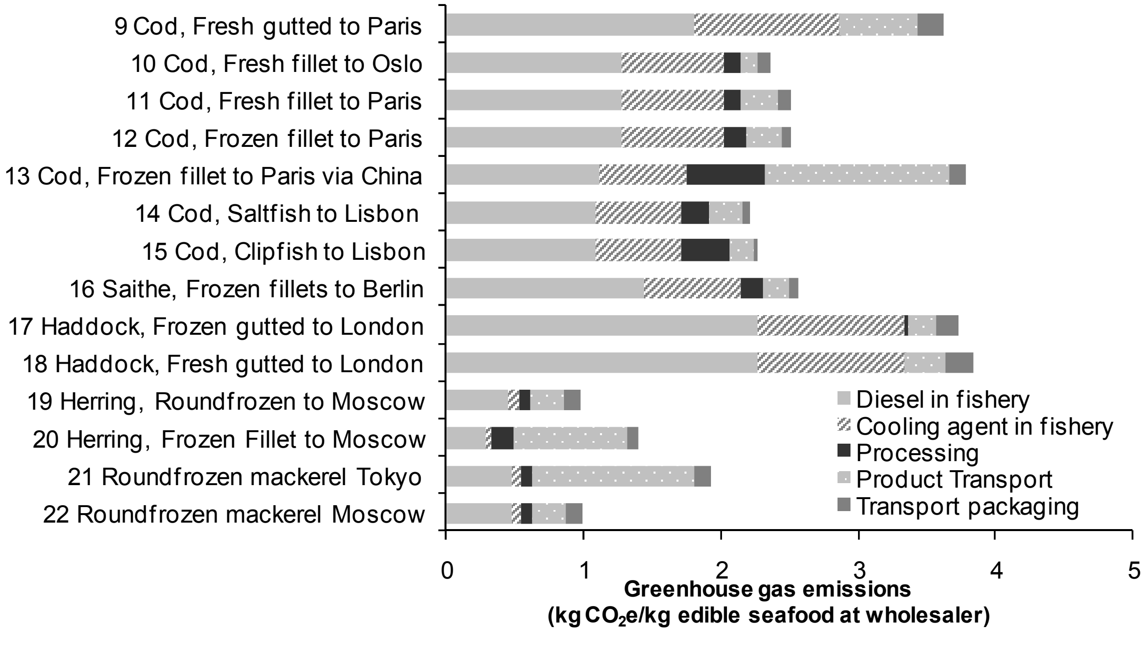

Figure 2 Overall carbon footprint results for products from capture fisheries

In comparison with land-based meat production systems for chicken, pig and beef, the seafood production systems studied had a carbon footprint in the range of chicken or lower and an energy use in the range of pork or lower.

A number of aspects are treated in the sensitivity analysis to test the robustness of the results. Improvement options for fisheries include the rapid replacement of freons by climate and ozone neutral refrigerants on both pelagic and demersal vessels and decreasing the fuel use in fishing further. To achieve this, more long-term changes are required with regard to the design of the fisheries management system and introduction of technological measures, taking into account the resulting carbon footprint of the seafood products produced. For blue mussels increased yield from harvest, lower fuel use on vessels and use of by-products represents a considerable improvement potential. For salmon, feed production dominates the results and therefore, decreased feed use and choosing the least resource-demanding feed ingredients that fulfil nutritional requirements of salmon represent the main improvement options. As already stated, general improvement options are to process more seafood in Norway before export and to export a larger proportion of frozen or super-cooled fish.

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1 Introduction

1.1 Seafood, environmental impact, carbon footprint and energy use

Traditionally, environmental concerns regarding seafood production have been focused on biological impact on target and by-catch stocks as well as ecosystem effects of certain types of fishing gear. Less attention has been paid to the fact that seafood production also contributes to many types of environmental effects above the ocean surface due to modern fishing and fish farming technology. The biological impacts on marine ecosystems have not become less important, quite the contrary. In recent years, however, resource use to produce supply materials and support the production chains of farmed and fished seafood products and resulting emissions to air, water and ground have received increased attention.

A method that has been used to quantify this resource use and emissions is Life Cycle Assessment (LCA) and the number of published seafood LCA studies has grown rapidly from zero during the last decade (e.g. Ellingsen & Aanondsen 2006, Ellingsen et al. 2009, Hospido & Tyedmers 2005, Pelletier et al. 2009, Thrane 2004a b, Ziegler et al. 2003, Ziegler & Valentinsson 2008, Ziegler et al. 2009). Actually, some authors have drawn the conclusion that there is a correlation between biological impact and high energy use due to the fact that when a stock is over-exploited, more energy is required to fish a certain amount of fish compared to the same stock sustainably fished with the same gear (Tyedmers 2001, 2004, Schau et al. 2009, Ziegler 2006), suggesting that energy use or global warming emissions could be a useful indicator of overall environmental impact of a fishery (Thrane 2006).

Some words about the terminology used in this report. Carbon footprint, global warming emissions, greenhouse gas emissions, climate impact and global warming potential are all used as synonyms. It means a weighted sum of emissions contributing to global warming according to the most recent IPCC guidelines (Intergovernmental Panel on Climate Change of the United Nations) using the 100 year perspective. It is measured in carbon dioxide equivalents (CO_2e), i.e. all global warming emissions are weighted compared to the global warming potential of carbon dioxide, which has the indicator 1 kg CO_2e/kg.

The carbon footprint of fishing systems is generally very dominated by the fuel (i.e. energy) use in the fishery, hence there is not much difference between global warming emissions and energy use. If we talk about farmed fish, however, the complex system of agricultural production of feed inputs plays a central role with its biogenic emissions of methane (CH_4) and dinitrous oxide (N_2O), two very potent climate gases with a global warming potential of 25 kg CO_2e/kg methane and 296 kg CO_2e/kg dinitrous oxide. Therefore, there is a larger difference between global warming potential and energy use of agricultural products (including farmed seafood that are fed such products) than of seafood products from capture fisheries.

1.2 Background and organisation of the project

The Norwegian Seafood Federation, FHL, in collaboration with The Norwegian Fishermen's Association initiated this work by performing a pilot study early 2008 where the possible methodologies to undertake an analysis of the carbon footprint and energy use of Norwegian seafood products are described. This work, which also contains a screening life cycle assessment of salmon farmed in Norway was carried out by SINTEF Fisheries and Aquaculture reporting the work in a project report (Olausson et al. 2008) and a scientific article (Ellingsen et al. 2008). The current project was formally started in early August 2008 when funding was granted by the Fishery and Aquaculture Industry Research Fund (FHF) and involves two project partners: SINTEF Fisheries and Aquaculture in Trondheim, Norway and SIK, The Swedish Institute for Food and Biotechnology in Gothenburg, Sweden. Representatives of FHL and The Norwegian Fishermen's Association act as a steering committee. In addition, a reference group consisting of representatives from fishermen's organisations, aqua feed producers, the salmon farming industry, seafood processing industry, NGOs and the steering committee has followed the project since it was started. An external reviewer has, in accordance with a requirement in the ISO standard for LCAs of public product comparisons, followed the project in an integrated way, i.e. he has provided valuable input on methodological choices and presentation of data and results from an early phase of the project. The final critical review is found as Appendix A. The supply chains included were chosen by the steering committee based mainly on volume of Norwegian export, but also in order to contrast chains that differ with regard to one or more respect and represent alternatives on the food and seafood market. A public meeting was held in Oslo in November 2008 where the project was presented to around 40 representatives from industry, governmental institutions and environmental groups. The participants provided comments that have been used to make various adjustments.

2 Goal and scope

2.1 Goal

The main goal of the present study is to quantify carbon footprint and energy use related to the chosen Norwegian seafood products. A goal is also to, based on the results, identify improvement options in the studied chains. The seafood products are also to be compared with agricultural food products that compete with Norwegian seafood products on the European market such as beef, pork and chicken meat, primarily of European origin. The commissioners are undertaking this work to learn more about carbon footprinting and energy analysis and how to identify climate and energy hot spots and improvement options for the different products included.

2.2 Modelling approach and system boundary

In this study, we take the attributional approach to Life Cycle Assessment, meaning that the aim is to find the average production in each case rather than the marginal production in case the production volume changes. We use ISO standardised LCA methodology (ISO 2006 a, b) to describe the climate impact and energy use of Norwegian seafood production today by analysing the most recent annual average data. Data collection started in 2008 and therefore in general we have used average data for 2007.

For important inputs, attempts have been made to find the level of variance in relation to various variables such as time. The analysis of important uncertainties is found in section 6.4 in this report.

Production of supply materials used in fishing and farming operations represent the starting point of the chains studied. The products are then followed from fishing/farming to processing. Post-processing transport to the wholesaler represents the end point, see Fig. 2.1 for a generalised flow chart for the farmed and fished chains. Wholesaling, retailing and consumer phases were excluded, partly because of difficulties in obtaining data for the various locations included in the study and partly because there is less difference between preparation of a cod or a salmon fillet than in the early life cycle phases. The latter stages are discussed in section 6.2.

Perhaps the most important aspect of the post-processing part of seafood chains, product waste, was included in the sensitivity analysis (see 3.5). Some of the chains are consumer-packed within the studied system (fillets), some beyond the system boundary (round and gutted fish). To avoid misleading comparisons, we chose to exclude production of the consumer packaging and only included transport packaging in all cases, i.e. the cardboard and polystyrene boxes used during transportation.

Capital goods are generally left out in the foreground system[1], except in the case of farmed mussels, where farming equipment will be included as a presumed “worst case”. We expected that farm construction material in this case (in the absence of feed inputs and presumed relatively modest fuel use) would give the highest contribution to the total result of all chains. Capital goods were included in the background system, i.e. data used from LCA databases that were not specifically collected for this project e.g. for production of energy carriers and packaging materials and especially for transports, where capital goods are relatively important.

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[1] By foreground system we mean the life cycle activities for which specific data was collected, the background system is the part of the system where we rely on life cycle database data, see Figure 1 for more description.

2.3 Seafood products studied (brief system descriptions)

The products were chosen by the projects steering committee in discussion with the project group, taking into consideration input from the reference group and the initial public meeting. The choices are mainly based on major volumes of Norwegian seafood export. Seven production systems of which two farmed ones and five wild-caught ones were included. Cod, haddock, saithe, herring and mackerel are the capture fisheries included, salmon and blue mussels are the farmed ones. They end up in 22 seafood products, hence for some fisheries and farming systems more than one final product has been included. The full list is given in Table 2.1

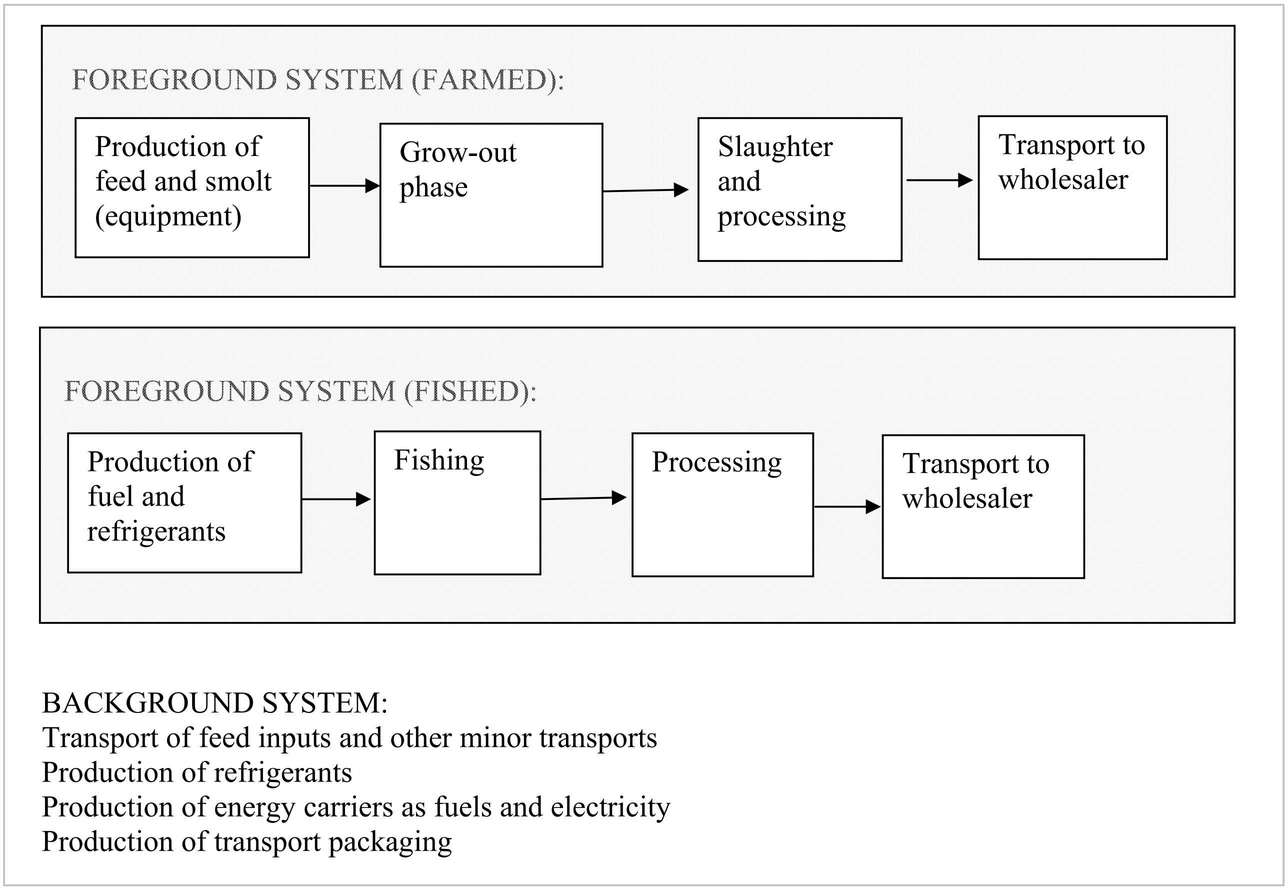

Figure 2.1 General flow chart showing system boundaries, foreground system and background system for seafood products from fisheries and aquaculture, respectively.

Table 2.1 Supply chains included in the study

Origin	Species	Product	Delivered to	Transport mode
Aquaculture				
1	Salmon	Fresh, gutted head-on	Paris	Truck
2			Oslo	Truck
3			Moscow	Truck
4			Tokyo	Air
5		Frozen, gutted head-on	Shanghai	Container freighter
6		Fresh fillet	Paris	Truck
7		Frozen fillet	Paris	Truck
8	Blue mussels	Living, fresh sorted	Paris	Truck
Capture fisheries				
9	Cod	Fresh, gutted head-on	Paris	Truck
10		Fresh fillet	Oslo	Truck
11			Paris	Truck
12		Frozen fillet	Paris	Truck
13			Paris	Truck/ Container freighter, processed in China
14		Saltfish	Lisbon	Truck
15		Clipfish	Lisbon	Truck
16	Saithe	Frozen fillet	Berlin	Truck
17	Haddock	Fresh, gutted head-on	London	Truck/RoRo vessel
18		Frozen, gutted head-on	London	Truck/Bulk freight
19	Herring	Round frozen	Moscow	Bulk freight/ Train
20		Frozen deskinned fillet	Moscow	Truck
21	Mackerel	Frozen round	Tokyo	Container freighter
22			Moscow	Bulk boat/ Train

2.4 Functional unit

The functional unit chosen in this study is one kilogram of edible product transported to the wholesaler at locations defined in Table 2.1. This means that in cases when the product is round or gutted head-on fish or blue mussels in shell, the quantity transported to the wholesaler was increased accordingly to correspond to a kilogram of edible product.

2.5 Comparison with competing products

The meat products competing with Norwegian seafood products on the European market were identified as beef, pork and poultry meat produced in Europe. Results of a recently reported Swedish research project studying global warming emissions of various Swedish meat production systems (Cederberg et al. 2009) were used for this purpose, adjusting allocation methodology, system boundaries and the functional unit according to the choices made in the present study. Comparison was also done with a recent report on improvement potentials of European meat and dairy products (Weidema et al. 2008) in order to evaluate whether the choice of letting Swedish production represent European meat production was a conservative choice in the comparison with seafood products, i.e. if the carbon footprint of the meat products was likely to be over- or underestimated by this choice.

3 Methodology

3.1 Data inventory seafood chains

The following data hierarchy was chosen:

1. Official statistics
2. Average data representing fishing/farming/processing sector from/via FHL and The Norwegian Fishermen's Association
3. Literature data
4. Data from single companies
5. Unpublished data

This hierarchy is related to the goal of presenting results that are valid for average Norwegian production of the products. In the end, data from all five categories was used.

3.2 Impact Assessment

The study is limited to the two categories:

- Greenhouse Gas (GHG) emissions, using a modified[2] version of the IPCC 2007 indicators with a 100 year perspective, measured in kilos of CO_2 equivalents (IPCC 2007)
- Cumulative Energy Demand (CED), i.e. primary energy use meaning not only the direct energy used in the production chain is included but also the energy that was used to produce various supply materials, measured in MJ equivalents.

3.3 Allocation strategy

The problems of allocating the resource use of a process to several co-products arises mainly in three situations, namely in the

- Processing of feed inputs used in fish farming
- Landing several fish species simultaneously
- Fish processing where several edible products are produced as well as by-products that are used for feed or other purposes

The assessment of allocation strategy has been extensive and is summarized in a document which is found as Appendix B.

In short, system expansion was rejected due to resolution of the fuel data and difficulties in determining what sort of commodity actually was replaced by the by-product in question. Economic allocation was rejected due to the high variability in both fish and feed input prices in recent years. It was difficult to identify a way to do economic allocation that would be reasonably stable over time, moreover, we recognize that due to direct and indirect subsidies, first hand landing values do

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[2] The IPCC 2007 method was modified by setting the characterisation factor for uptake of carbon dioxide in air and emission of biogenic carbon dioxide to zero. These CO_2 in- and outputs are due to carbon assimilation by plants and in our opinion these should not be accounted for since they, in the long term, do not represent a net contribution to CO_2 in the atmosphere.

not reflect the true value and cost of fish, despite the fact that the value of the landings rather than its mass often is the driver of the fishing activity. Allocating based on gross energy content was rejected due to the counter-intuitive effect that appears for all whitefish species, that the by-products from processing are higher in energy content and consequently should carry more environmental burden than the main, edible, products. More advanced approaches that were discussed (see Appendix B) were dismissed due to lack of time and the risk of using a new previously untested methodology.

The conclusion is that we have used mass allocation, i.e. partitioned the environmental load between co-product streams based on their mass. Advantages of this approach include that mass reflects one important function of food, which it, according to the ISO standard should, that it encourages the food industry to make use of by-products (since it places high environmental burden on them). The main advantage, though is stability over time making it possible to follow up in a couple of years ensuring that differences detected will depend on actual changes in resource use and not changes in the distribution of the production value between co-products. It should be kept in mind throughout the reading of this report that this choice means that equal environmental load is put on all fish landed together, on fillets, mince and non-edible parts that are used in one way or another, in processing and on meals, oils and other outputs from feed processing. While this approach “encourages” seafood producers to increase the use of by-products, it also “encourages” the users of by-products from intensive production systems, such as demersal fishing or rearing of cattle, to switch to less intensive production systems that could be directed feed production, e.g. reduction fisheries. As this choice influences the results considerably, the sensitivity analysis comprises performing economic allocation for one farmed and one wild-caught product, frozen salmon and cod fillet delivered to Paris, respectively.

The only instance where another type of allocation has been done is in the beef system, between the co-products milk and meat, where a biological factor was used to calculate the proportion of nutrients used to produce the milk and the meat, respectively (resulting in a partition of 15 % to the meat and 85 % to the milk). For consistency, it is normally desirable to stick to one allocation method used in all instances where allocation is necessary, i.e. it is not an option to choose mass allocation in the fishing phase and economic allocation or system expansion in the processing phase. The choice of allocation method certainly represents one of the most controversial methodological choices in the performance of an LCA.

3.4 Strategy to handle things that were left out

The part of the product chains from wholesaler to consumer are described in section 6.2. Differences between frozen and fresh fish in this respect are described. Storage and product waste in retail and in the household are important activities that are highlighted as is preparation in the household. The most important transport has often been shown to be the transport between retail and household, which is likewise discussed in this section.

Capital goods were generally left out in the foreground system of the project in order to limit the data inventory, since it has been documented both for fishing systems and aquaculture that these inputs are minor compared to the direct fuel and material inputs (e.g. Tyedmers et al. 2007). The role of capital goods was evaluated in the case of mussel farming by including the farming equipment, as a kind of “worst case”.

3.5 Sensitivity analysis

The following aspects were chosen to be evaluated in the sensitivity analysis:

1. Replace Nordic electricity mix by Norwegian average grid

2. Product waste
   a) Product waste at processing plant 2 % (as opposed to no product waste)
   b) Product waste at processing plant 2 % and product waste at wholesaler 5 % (as opposed to no product waste neither at processing plant nor wholesaler)

3. Increase in edible yield when processing cod in Norway (from 62 % yield to 70 %)

4. Economic allocation (as opposed to mass allocation) in the case of
   a) Frozen cod fillets transported to Paris
   b) Frozen salmon fillets transported to Paris

5. Use of by-products from processing
   a) By-products of salmon and cod are used abroad to the same extent as in Norway
   b) By-products of salmon and cod are fully used both in Norway and abroad
   c) By-products of salmon and cod are not used at all

6. Feed Conversion Ratio in salmon farming and smolt production 1.0 (instead of 1.2)

7. Lower proportion of marine inputs in salmon feed (30 % instead of 60 %)

8. Only Anchoveta as marine input in salmon feed (as opposed to 28 % of marine inputs imported from South and North America)

9. Optimised mussel production (higher edible yield, less fuel used, use of by-products)

10. Replace all on-board refrigerants with carbon neutral ones

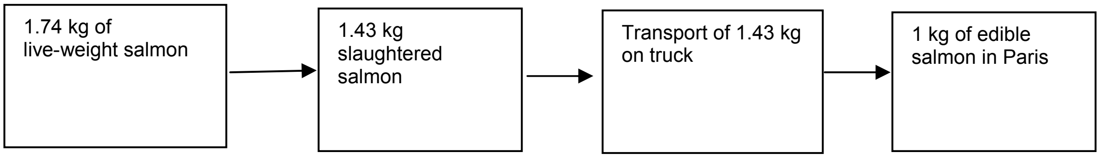
4 Inventory results

4.1 Brief supply chain descriptions

The intention of this section is to provide a brief description of each supply chain and to present the mass flows used in the analysis to arrive at one kilo of edible product at the wholesaler. The mass flows were obtained by a combination of official Norwegian conversion factors from fish to various product forms and through data from companies along the supply chain for whitefish, mussels and salmon. The chains are numbered as in Table 2.1.

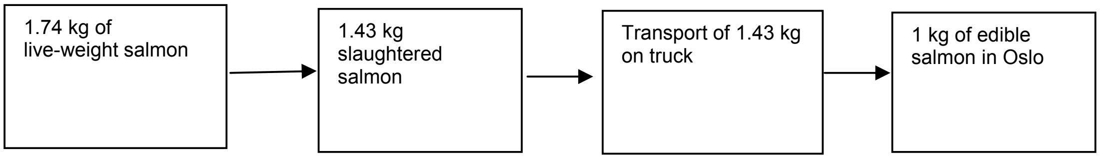
Chain 1: Fresh gutted salmon to Paris

Farmed salmon, slaughtered close to the farming site after transport by well-boat[3] and packed in EPS boxes on ice. Storage for five days before truck transport to Oslo. An average distance from the salmon slaughter plant to Oslo (842 km + 100 km positioning transport) was found by weighting distances according to each county's salmon production relative to total Norwegian production. From Oslo the salmon was transported on refrigerated trucks to Göteborg (300 km), via car ferry between Göteborg -Frederikshavn (95 km) and then Frederikshavn to Paris (1400 km).



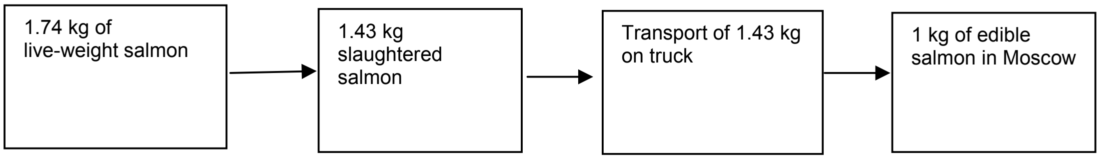
Chain 2: Fresh gutted salmon to Oslo

Identical to chain 1, except that it stops in Oslo.



Chain 3: Fresh gutted salmon to Moscow

Identical to chain 1 but truck transport from Oslo to Stockholm (530 km), car ferry Stockholm-Turkku (284 km) and truck from Turkku-Moscow (1281 km).



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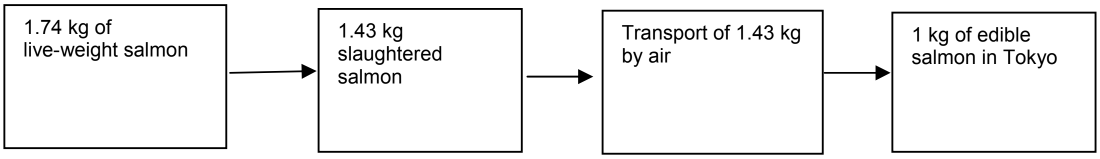
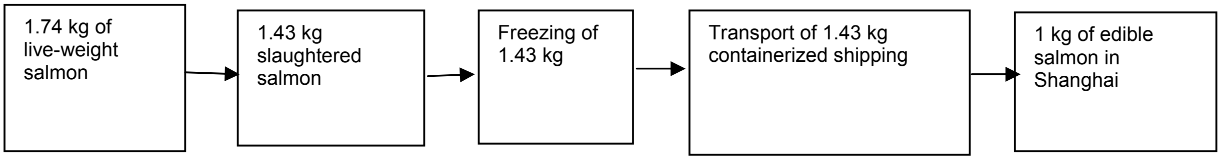
[3] No distance was specified, but the fuel used by well-boats was included in the fuel used on the salmon farm.

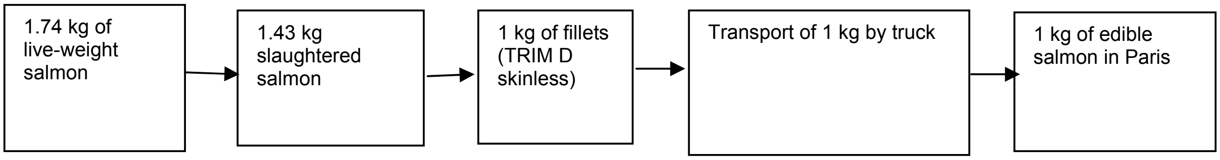
Chain 4: Fresh gutted salmon to Tokyo
Chain identical to Chain 2, but then air freighted from Oslo to Tokyo (8380 km).



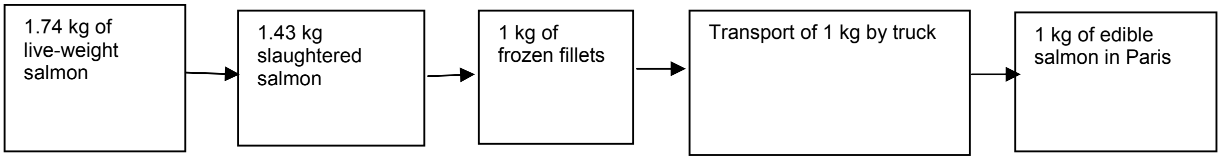
Chain 5: Frozen gutted salmon to Shanghai
Chain identical to Chain 1 up to slaughter. The salmon is then frozen in a processing plant in Norway, packed in cardboard boxes, stored for three months and then taken to Rotterdam (1350 km) and from Rotterdam to Shanghai (19500 km) by refrigerated container transport.



Chain 6: Fresh salmon fillets to Paris
Chain identical to Chain 1 up to slaughter. The salmon is then processed to fillets and packed in EPS boxes before export by truck. Transport similar to salmon transport in Chain 1, except that fillets are transported rather than whole fish. By-products from slaughter and processing are used for feed.

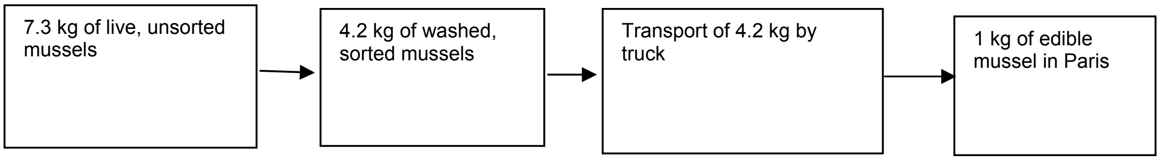


Chain 7: Frozen salmon fillets to Paris
Chain identical to Chain 1 up to slaughter. The salmon is then processed to fillets, frozen and packed in EPS boxes before export by truck after three months of storage. Transport similar to salmon transport in Chain 1, except that frozen fillets are transported instead of cooled gutted fish. This means similar use of energy and refrigerant, but no ice is needed , hence more fish can be loaded per pallet and truck. By-products from slaughter and processing are used for feed.



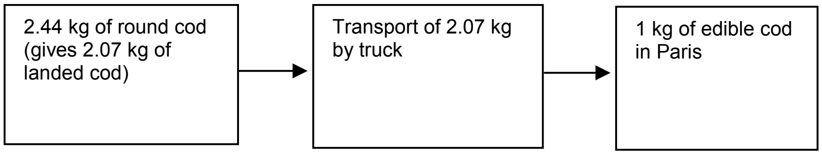
Chain 8: Blue mussels, fresh, sorted, to Paris

Blue mussels farmed in Norway and trucked to a processing plant on average 200 km away where mussels are washed, sorted and packed in nets. Transportation after five days of storage in EPS-boxes on ice to Paris on refrigerated trucks via the same route as salmon in Chain 1. By-products in processing in Norway are currently not used, nor are shells in Paris.



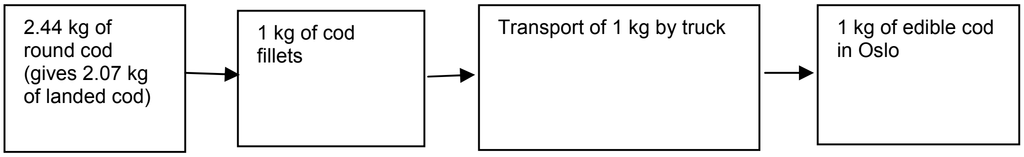
Chain 9: Fresh gutted cod to Paris

Cod caught in Norwegian fisheries by various different fishing gear (29 % bottom trawl, 17 % Danish seine, 31 % gillnets, 9 % auto-lines and 13 % other coastal fishing methods), gutted on-board with no use of by-products. Packed in EPS-boxes on ice and after five days of storage transported to Oslo from weighted average whitefish landing location, based on landings per county (1200 km + 100 km positioning transport). From Oslo to Paris cod transports are like salmon transports with regard to route and load (Chain 1).



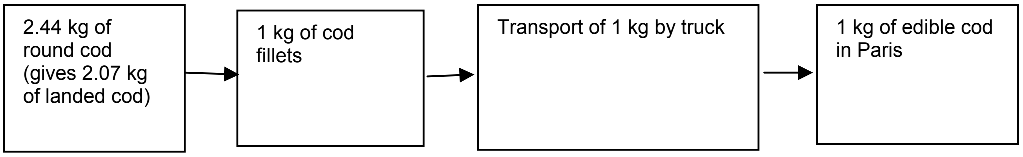
Chain 10: Fresh cod fillets to Oslo

Cod caught in Norwegian fisheries as in Chain 9, and then processed in Norway with 39 % of by-products used for feed. Packed in EPS-boxes on ice and transported to Oslo from weighted average cod landing spot (1200 km + 100 km positioning transport).



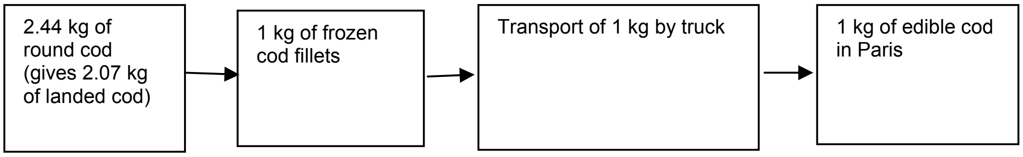
Chain 11: Fresh cod fillets to Paris

Similar to Chain 9 except that product is fillets rather than whole cod, so by-products are used as in Chain 10.



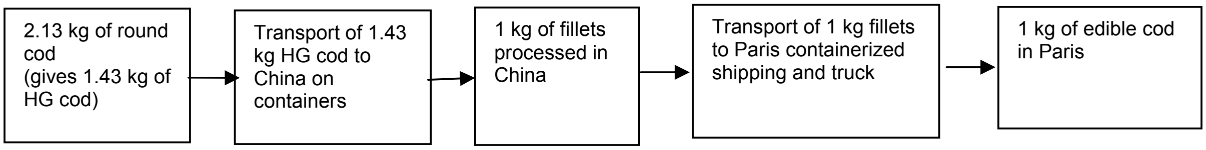
Chain 12: Frozen cod fillets to Paris, processed in Norway

As Chain 11, but fillets are frozen before export and the transport is hence done in cardboard boxes and without ice after three months of storage. By-product use as in Chain 10.



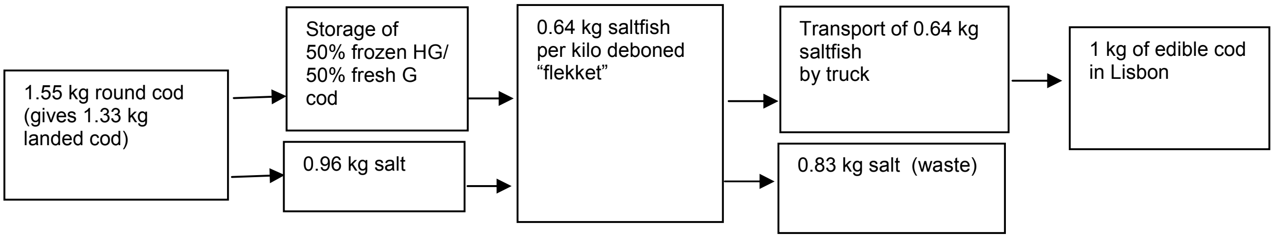
Chain 13: Frozen cod fillets to Paris, processed in China

The cod is landed headed and gutted (HG) frozen at sea, meaning that neither head nor guts are used, but discarded at sea. The frozen HG cod is after three months of storage transported in refrigerated containers from Narvik to Rotterdam (2090 km) and from there on a return trip to Qingdao, China (19900 km). Processing in China (i.e. thawing and re-freezing) is done using Chinese average electricity production and filleting is done manually with an edible yield of 70 %. The higher edible yield explains the lower amount of fish required in this chain. By-products from processing are used as chicken feed. The re-frozen product is after processing being shipped back to Europe and then trucked from Rotterdam to Paris (404 km).



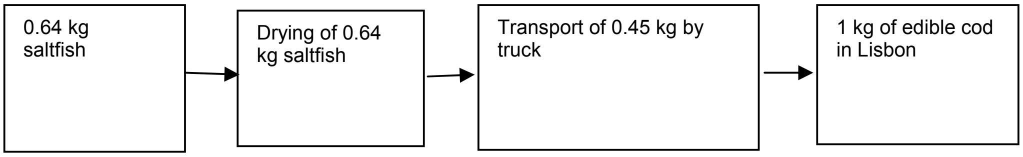
Chain 14: Cod saltfish to Lisbon

Cod from the same "average Norwegian cod fishery" is half landed fresh only gutted at sea and half landed frozen, headed and gutted at sea. The fresh fish is stored for five days as in the other chains, frozen fish for three months before being processed. The cod is then taken into the salting process in which it is first deboned and split (if fresh first of all headed) and then salted during several (2-3) weeks of cold storage. By-product use for whitefish as before. While 1.5 kg of salt is used per kg of saltfish produced, the salted fish contains around 20 % salt, and the remaining salt is wasted. Transport from northern Norway (average landing location) to Lisbon via carferry Göteborg-Frederikshavn is done in cardboard boxes by truck, a distance of 1300 km (to Oslo) and 3129 km (Oslo-Lisbon). The product is desalted in water again prior to consumption, a process in which part of the salt is again replaced with water. We chose this edible form of the product as the end of our supply chain to ensure comparability with other, edible, products. The different amount of cod required is due to yield and the fact that a part of the product is salt rather than fish.



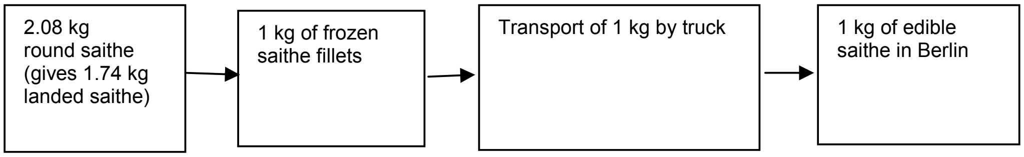
Chain 15: Cod clipfish to Lisbon

Clipfish is dried saltfish. It is dried using electricity and various drying techniques to a water content of 40-45 %. The yield from saltfish to clipfish is 70 %. Transport from northern Norway is the same as for saltfish, but the amount transported is smaller due to lower water content. In analogy with the saltfish chain, since the product is hydrated/desalted prior to consumption, we chose the directly edible form of the product as the end of this supply chain to ensure comparability.



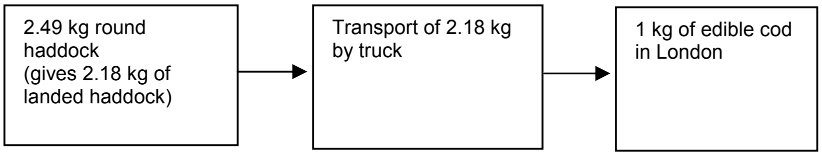
Chain 16: Frozen saithe fillets to Berlin

Saithe caught in Norwegian fisheries by various different fishing gears (52 % bottom trawl, 5 % Danish seine, 17 % gillnets, 1 % auto-lines, 19 % by purse seines, 1 % by pelagic trawls and 5 % by other coastal fishing methods), gutted on-board with no use of by-products. The saithe is then processed in Norway with use of by-products as for other whitefish species (39 %), packed in cardboard boxes and transported to Berlin (1200+100 km to Oslo and 835 km Oslo-Berlin) after three months of storage. The average point of landing of cod was used for saithe (and haddock) aswell since they to a large degree are landed in the same fisheries.



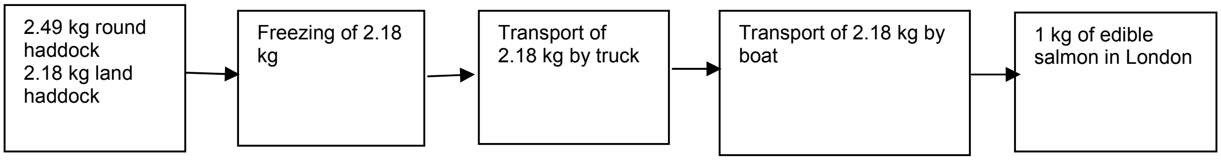
Chain 17: Fresh gutted haddock to London

Haddock caught in Norwegian fisheries by various different fishing gears (41 % bottom trawl, 15 % Danish seine, 5 % gillnets, 22 % auto-lines and 16 % other types of long-lines), gutted on-board with no use of by-products. The haddock is not processed, just packed in EPS boxes and trucked to Stavanger (600+100 km) after five days of storage. From there transport on a RoRo vessel to Newcastle (633 km) and truck Newcastle-London (444 km).



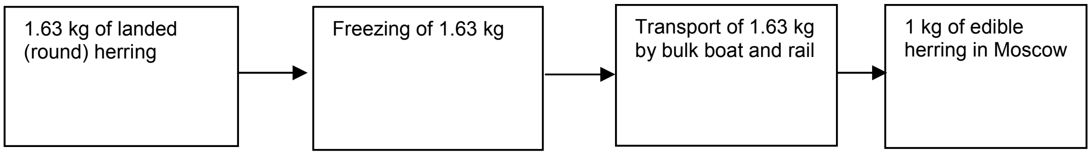
Chain 18: Frozen gutted haddock to London

Fishing as Chain 17, freezing either at sea or in processing plant, packaging in cardboard boxes, then after three months of storage bulk freight on ship from northern Norway to Newcastle (2126 km) with 75 % empty return and then trucked from Newcastle-London (444 km).



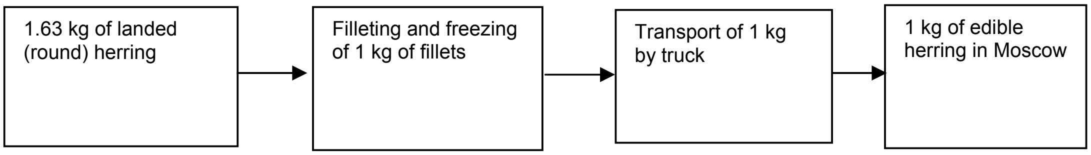
Chain 19: Round frozen herring to Moscow

Herring caught by the Norwegian pelagic fleet (12 % pelagic trawls and 88 % by purse seines), landed and frozen round in Norway. An average point of landing for pelagic species was identified as the starting point for transportation based on the landings statistics at the Norwegian Directorate of Fisheries from which the herring after storage is transported frozen to St. Petersburg (2395 km) by a bulk freight ship in cardboard boxes, 2/3 of the return is assumed to be empty. From St. Petersburg to Moscow it is transported by refrigerated rail freight (814 km).



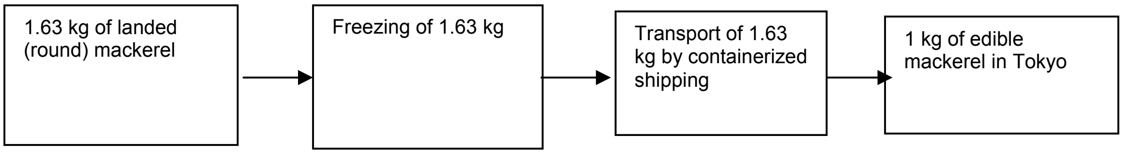
Chain 20: Frozen deskinned herring fillets to Moscow

Identical chain to Chain 19 with regard to fishing. After fishing, the herring is filleted and frozen, stored and then exported in cardboard boxes by truck. By-product use is 95 % for pelagic species. Distance from northern Norway to Stockholm 1420 km, car ferry Stockholm-Turkku (284 km) and Turkku-Moscow 1281 km.



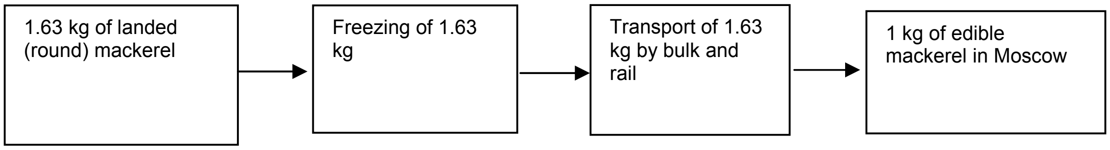
Chain 21: Round frozen mackerel to Tokyo

Mackerel caught by the Norwegian pelagic fleet (3 % pelagic trawls, 88 % purse seines and 9 % trolling line), landed and frozen round in Norway. The product is transported by containerized shipping frozen from Narvik to Rotterdam (2090 km) and on to the port of Yokohama (just outside Tokyo) (20700 km) in cardboard boxes after storage in Norway for three months.



Chain 22: Round frozen mackerel to Moscow

Identical to Chain 21 with regard to fishing and freezing. The mackerel is transported frozen to St. Petersburg by a bulk freight ship in cardboard boxes. The distance is 2395 km and 2/3 of the return is assumed to be empty. From St. Petersburg to Moscow it is transported by refrigerated rail freight (814 km).



4.2 Capture fisheries

4.2.1 Fuel use in fishing

The fishing sector is a highly regulated and politicized sector (Hersoug 2005). The energy efficiency in fisheries is, among many factors, determined by the framework set by fisheries management systems (Standal 2005 and Driscoll and Tyedmers 2009) with components such as:

- Total available quotas and quota allocation policy
- Structural policies to cut down unprofitable overcapacity
- Technical regulations and spatial and temporal limitations of fisheries, these also includes demands on when and where landings can be delivered
- Auctioning systems for pelagic species that influence economically feasible travelling distances and subsidizing of travelling expenses
- Geographical aspects of where and when specific fisheries are open
- Regulations connected to gear adaptations and rules for minimum size to avoid catches of juvenile fish

These are examples of regulations that have an important influence on the energy efficiency of fisheries. Fuel use in fisheries is therefore a complex function with many variables; the type of fishing gear used and the behaviour of individual fishermen is only a part of the equation.

The species specific fuel consumption (e.g. litre diesel combusted to land one kilo of round cod) was calculated by combining data from the annual profitability survey on the Norwegian fishing fleet[4] and sales statistics[5] from the Norwegian fishermen's sales organizations[6]. Both data sets come from the Norwegian Directorate of Fisheries (Fiskeridirektoratet 2008a and 2008b). The profitability survey provided data on the fuel consumption in different fisheries and the sales statistics how the different species was caught (by which fisheries). The calculations will be further explained below.

Gear specific fuel factors and the profitability survey

The profitability survey is a questionnaire, sent out to a selection of licensed fishermen in Norway on an annual basis. The data e.g. comprise annual catches by different types of fishing gear, annual

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[4] Lønnsomhetsundersøkelsen

[5] Sluttseddel

[6] Salgslagene

fuel use, vessel size and fishing area. In 2007, 741 out of Norway's 1709 vessels over 8 m operating all year received the survey, 634 replied and of these 624 replies were found to be valid for further data processing. The number and types of vessels included were chosen by statistical methods to ensure a representative sample. Table 4.1 presents the sample selection and the reply ratio for different segments of the Norwegian fleet in 2007 (ratio between vessels that were asked and those who replied well enough).

The reply rate in the profitability survey, in terms of number of vessels that are asked relative to the total number, is highly variable between different fleet segments; in general it is lower for smaller vessels (20-30 %) and higher for larger vessels (60-70 %). In terms of landed tonnage, the data is more representative, since the larger vessels land the bulk of the fish, see Table 4.2. Cod is the species for which the data is least representative (45 %) and where the largest proportion is landed by small, coastal vessels (20 % by vessels under 8 m and 28 % by vessels between 8-15 m long).

Some adjustments to the raw data were made:

- Some vessels have used different types of fuels. Around 15 % of the fuel use reported by the survey was Marine Special Distillate (MSD) for which the refining process is more intensive. Therefore energy use and greenhouse gas emissions are slightly higher for this fuel (2.8 vs. 2.6 kg CO_2e/l fuel for MSD and marine diesel oil; personal communication Statoil). For each vessel in the profitability survey the use of MSD was included by calculating that consumption into marine diesel equivalents using the ration 2.8/2.6.
- In some occasions (around 0.5% of the data) product weight was larger than round weight, in these cases round weight was set to the higher of the two values.
- Boats that reported zero fuel consumption or zero catch were excluded, thus the number of boats used in the calculation was lower than 624, 458 boats.

These latter adjustments demonstrate the uncertainty that lies in data based on a questionnaire where the replier can misunderstand the question or give inadequate/wrong information. Other emissions from fuel combustion that contribute to climate impact included were dinitrogen monoxide (N_2O), carbon monoxide (CO) and methane (CH_4). Sulphur and nitrogen oxides do not contribute to climate impact, although to other impact categories such as acidification and eutrophication, and were therefore not included.

Table 4.1 Sample selection and reply rate for different capture fisheries in the 2007 profitability survey

		Received survey	Replies used	Reply rate**
Coastal fisheries	Demersal with conventional gears*	502	406	0.81
	Pelagic with purse seine	75	70	0.93
Ocean fisheries	Trawlers	46	42	0.91
	Autoliners	26	24	0.92
	Pelagic with purse seine	69	61	0.88
	Pelagic trawl	23	21	0.91
	Total	741	624	

* *gillnets, coastal line, jig and other*

*** ratio between number of surveys that were used and sent out*

Table 4.2 Proportion of total landings in 2007 covered by the profitability survey

Species	Proportion (%)
Herring	71
Mackerel	69
Cod	45
Saithe	66
Haddock	59

Calculation of gear specific fuel factors

Equation 4.1 presents how the gear specific fuel factors (FS_j) where calculated. The total fuel used by each boat (D_i) was allocated to the different fishing gears it used (FD_{ij}). The allocation was based on the ratio between the boats landing with each gear type (f_{ij}) and the sum of all its landings (F_i). Finally the gear specific fuel factor was calculated by dividing the sum fuel allocated to each equipment by the landings of the same equipment. All weights are in round weight.

Equation 4.1 Calculation of gear specific fuel factors from profitability survey

$$FS_j = \frac{\sum_i^n FD_{ij}}{\sum_i^n f_{ij}} = \frac{\sum_i^n \frac{f_{ij} D_i}{F_i}}{\sum_i^n f_{ij}}$$

Explanation of terms in Equation 4.1:

- FS_j: Fuel factor for equipment j [l/kg]
- FD_{ij}: Fuel allocated to equipment j on boat i [l]
- f_{ij}: Landings by equipment j on boat i [kg]
- D_i: Total fuel consumed by boat i [l]
- F_i: Sum of all landings by boat i [kg]
- n: number of boats in profitability survey after data corrections

The results of the calculations are presented in Table 4.3. The coefficients of variation in Table 4.3 show that the variations in the values behind the calculation of the average values are high.

It is important to be aware that the profitability survey provides each vessel's annual fuel consumption (D_i) and not the fuel consumed by each landing. This fuel consumption also includes steaming to and from the fishing fields and energy to cooling and processing systems on board. For an example for trawlers the fuel used for actual trawling only can account for 54 % of the trawlers total fuel consumption and for pelagic ocean vessels steaming can account for a higher proportion of the fuel use than the actual fishing (Dale 2007 and 2009).

The fact that the fuel consumption data (D_i) is the vessel's total fuel consumption also means that for trawlers and auto liners, energy for processing and freezing is included, that is: In the gear specific fuel factor for trawlers and auto liners lies also filleting, packing and freezing, while for many of the other gears the fish is delivered fresh and gutted and needs processing and freezing on shore.

For vessels that use different types of gears the approach of mass allocating the vessel's total fuel consumption means that it is assumed that these vessels have the same fuel efficiency for all their gears. This is of course not correct as it is evident that the vessel's fuel consumption will depend on what gear it uses, but this approach was used as there exist no extensive data set with fuel consumption for each gear on vessels that use several types. This is by all means an important assumption that influences the calculated fuel factors and may be an important reason that gears that are typically used in combination end up with almost identical fuel factors, like e.g. Gilnet, long lines, trolling line and hand line in Table 4.3. At the same time it can be quite correct that these gears have very similar fuel factors as it is fair to assume that steaming to and from the fishing spots is more important for the fuel consumption than the actual fishing phase of these passive gears.

The coefficients of variation in Table 4.3 show that the variation in the values behind the calculation of the average values are high and highest for the typical coastal gears, gears that are typically used in combination.

The significance of the standard deviation can be understood by studying the fuel factor for trawling that has an average value of 0.43 l/kg and a standard deviation of 0.24 l/kg. Assuming a normal distribution of the values this means that 95% of the vessels may have used from 0.19 to 0.67 l/kg, this further illustrates the high variation behind these calculations and show that, it can not, based on these results, be said that e.g. long-lining in general is more energy efficient than bottom trawling or fishing with gillnets is more efficient than long-lining. There is, though, a tendency that pelagic fishing methods, especially purse seining and pelagic trawling, are most efficient, coastal fishing methods somewhat less energy efficient and automated long-lining and bottom trawling are found to be the most fuel intensive fisheries. But this is given the current (or 2007) circumstances with regard to regulations and stock status and hence reflects much more than the energy efficiency of the gear type.

Hence, the gear type used is only one of many parameters that determine the vessel's energy efficiency, the large variation between vessels found within the same vessel groups, using the same type of gear and operating under the same regulations, demonstrates a considerable improvement potential based on the way a fishing vessel is technologically equipped and operated.

Table 4.3 Gear specific fuel factors

Fishing gear	Fuel use [l / kg]*	Standard deviation	Coefficient of variation**
Other long lines (Andre liner)	0.15	0.069	0.5
Long-line (Autoline)	0.31	0.12	0.4
Bottom trawl (Bunntrål)	0.43	0.24	0.6
Trolling line (Dorg/harp/snik)	0.14	0.14	1.0
Pelagic line (Flyteline)	0.10	0.051	0.5
Pelagic trawl (Flytetrål)	0.098	0.12	1.2
Pelagic pair trawl (Flytetrål par)	0.093	0.022	0.2
Hand line/ jig (Juksa/pilk)	0.15	0.19	1.3
Gillnet (Settegarn)	0.15	0.18	1.2
Purse seine (Snurpenot/ringnot)	0.089	0.03	0.3
Danish seine (Snurrevad/Rundfisktrål/Flyndretrål)	0.12	0.20	1.7
Undefined gillnet (Udefinert garn)	0.25	0.26	1.0
Undefined seine (Udefinert not)	0.083	0.16	1.9
*liters fuel per kilo landed catch in round weight ** coefficient of variation= standard deviation / average value			

Species specific fuel factors

The gear specific fuel factors from Table 4.3 were combined with sales statistics showing how (with what gear types) each species was caught. These statistics cover the complete Norwegian fisheries in 2007 and are presented in Table 4.4. This table also presents how the same distribution would look like if it was based on the profitability survey. It is evident that the smaller boats using coastal gear are underrepresented in the profitability data, at least for demersal species. The true proportion of catches landed by coastal fishing methods is around twice as high for cod and haddock compared to the profitability survey. This was the reason for combining the two data sets rather than using the profitability survey only.

Table 4.4 Distribution of landings on different gear types according to sales statistics (left) and profitability survey (right) in 2007

Species	Distribution sales statistics [%]						Distribution profitability survey [%]					
	PS	PT	BT	DS	AL	CG	PS	PT	BT	DS	AL	CG
Cod	0	3	29	17	9	42	20	1	58	3	1	17
Haddock	0	0	41	15	22	22	92	2	0	0	0	6
Saithe	16	1	52	5	1	25	88	10	0	0	0	2
Herring	88	12	0	0	0	0	0	0	50	17	13	20
Mackerel	88	3	0	0	0	9	0	0	53	12	24	11
PS=Purse seine, PT=Pelagic trawl, BT=Bottom trawl, DS=Danish seine, AL=Auto-line, CG= Other coastal gears (gillnets, coastal line, jig and other)												

Table 4.5 Species specific fuel factors

	Fuel factors [litre fuel / kg landed round weight]	Standard deviation
Cod	0.24	0.096
Haddock	0.29	0.11
Saithe	0.29	0.13
Herring	0.091	0.029
Mackerel	0.094	0.031

For verification of the calculated gear specific data, data was collected from individual vessels, some of Norway's biggest fishing vessel ship owners and scientific reports and articles (e.g. Eyjólfsdóttir et al. 2003, Tyedmers 2001, Tyedmers 2004). Some of these results are represented in Table 4.6. According to these data, the gear specific fuel use calculated in this study corresponds very well for long-line and purse seining, but was lower for trawlers, although the range in fuel use for trawlers is very high both in our data and in literature. This could of course be due to a bias in the profitability data with trawlers that are over average fuel efficient responding to the survey. This finding could also reflect improvements that have happened in recent years due to structural changes in the fishing fleet, e.g. a decrease of over-capacity in the fleet, see discussion of results in the chapters following.

Table 4.6 Miscellaneous gear specific fuel factors used for verification

Fishing equipment	Fuel use, average value [litre fuel / kg round weight]	Data range [litre fuel / kg round weight]
Bottom trawlers	0.63	0.33 – 1.0
Purse seiners	0.077	0.036 – 0.11
Long liners	0.31	0.18 – 0.49

4.2.2 Refrigerants

Refrigerants used in the Norwegian fishing fleet include R22, ammonia and CO_2. The most important one, in terms of global warming potential, is R22 (HCFC-22) with a climate impact indicator of 1810 kg CO_2e/kg (IPCC 2007). R22 also has high ozone depletion potential.

Emission rates of R22 were calculated based on information that was obtained from producers of cooling systems, service technicians and refrigerant wholesalers/importers.

Since 2002 installation of new R22 systems has been banned and import of R22 is only allowed for refilling of existing systems. There has been a maximum limit to the import and production of R22 and from 2010 this will be zero, that is; from 2010 refilling of R22 is only possible with regenerated R22 from systems that are no longer in use (Produktforskriften 2009). R22 is mainly regulated due to its high ozone depletion potential and rgulated by the Montreal protocol (UN 2006)

A complete data set on how R22 imported to Norway is distributed and used does not exist. In 2007 the total import of R22 was 323 tonnes (SFH pers. comm). It was imported by five different companies and after contact with these companies it was concluded that a reasonable estimate is that around 200 of these tonnes were used on fishing vessels. The estimate is based on assumptions from experienced salesmen in this sector and there seemed to be a strong consensus that fishing vessels are the main consumer of R22 in Norway. Further it was assumed that these 200 tonnes equal the total emissions of R22 in 2007. This assumption is based on the fact that new R22 systems are no longer permitted and only refilling is allowed. It was also investigated if some R22 was collected from fishing vessels and delivered for secure destruction, but this amount was confirmed to be insignificant by Stiftelsen Returgass that are responsible for collection and destruction of e.g. refrigerants in Norway (Returgass pers.comm). It is also possible that some of these 200 tonnes is stock piled, but from the fact that refilling with virgin R22 will not be allowed from 2010 stock piling of R22 will neither be allowed (Produktforskriften 2009).

Refrigerant use on pelagic vessels

Pelagic vessels mainly use refrigerants in their RSW (Refrigerated Sea Water) systems. In a perfect RSW system refrigerants are not emitted, but in practice emissions occur by leaks and during repairs and services.

An annual emission rate of 30 % was assumed. In the literature refrigerant emission rates on fishing vessels are estimated at 20 – 40 % (Sandbakk 1991, Senter NOVEM 2006, Klingenberg 2005). Further it was assumed that 70 % of the pelagic vessels still use R22 and that pelagic vessels above 28 m have 1200 kg R22 per RSW system, and that vessels under 28 m have 600 kg R22. These assumptions combined with landings statistics for the pelagic fleet from the profitability survey led to an emission rate of 0.023 g R22 per kilo landed fish in round weight.

Refrigerant use on demersal vessels

Emission of R22 from the demersal fleet was calculated by subtracting the amount of R22 emitted by the pelagic fleet from the total mass of R22 emitted by Norwegian fisheries (around 200 tonnes). The remaining amount was divided by the total Norwegian landings in 2007 minus pelagic species (722.148 tonnes). This calculation resulted in an emission rate of 0.224 g R22 per kilo round weight in the demersal fleet.

Brief discussion of refrigerant emission rates

Due to its high global warming potential, R22 emissions play an important role in the over all climate impact of seafood production systems using this refrigerant. The data and research in this field are very limited.

The most important assumption is that the total emission of R22 from Norwegian fishing vessels is as much as 200 tonnes. The second most important assumption is how this was shared between the pelagic and demersal fleet. It is fair to assume that the emission rate from the pelagic fleet is less than from other vessels: RSW systems have less leaks than freezing and cooling systems used in the demersal fleet, the pelagic fleet is more modern and pelagic vessels have larger catches per vessel compared to the remaining fleet. Thrane (2004b) found a lower general emission rate for refrigerants, 0.03 g/kg fish landed, which is more in line with our estimate for pelagic fish. However, our sources have given us strong reason to conclude that the annual emission of R22 in 2007 is 200 tonnes, the figure 100-125 tonnes R22 used in all Nordic fisheries referred to by Thrane, originally found in a report from the Nordic Council of Ministers (NMR 2000), is therefore seems to an underestimation.

4.3 Aquaculture

4.3.1 Salmon feed production

The composition of a salmon feed representative of the grow-out phase of Norwegian salmon was constructed by using the average composition of marine feed inputs in Norwegian feed production (of which 97 %) is used in salmon farming in Norway, see Table 4.7 (FHL 2009). Due to the expected importance of the feed composition we modelled 2007 and 2008, since it is evident that the variation in composition between years is considerable. The same report also provided the economic feed conversion ratio used which was 1.2 kg dry feed/kg live weight salmon slaughtered.

Table 4.7 Composition of marine part of Norwegian produced fish feed in 2007 and 2008 based on data from the three main producers of aqua feeds in Norway.

Species	Proportion of fish meal used in 2007 (%)	Proportion of fish oil used in 2007 (%)	Proportion of fish meal used in 2008 (%)	Proportion of fish oil used in 2008 (%)
Anchovy[1]	23	21	23	22
Blue whiting	37	14	27	8
Capelin	4	2	1	1
Herring	16	26	17	23
Herring cuttings	3	4	4	12
Sand eel	2	7	14	7
Sprat	5	14	4	9
Mackerel	1	<1	1	-
Horse mackerel	1	<1	-	1
Jack mackerel[1]	5	<1	6	1
Pilchard[1]	-	3	-	5
“Trimmings”	2	5	1	-
Menhaden[1]	-	4	-	7
Other species	<1	-	2	3
Sum	99	100	100	99
[1]Not fished in Norway				

Data regarding the energy use for fishing of species used as feed was found in Schau et al. (2009). Unpublished data regarding the energy use for Anchoveta was provided by one of the leading producers of aqua feeds in Norway (

Table 4.8). The Anchoveta data was assumed to be valid also for Jack mackerel. Pilchard and menhaden, two oily fish, were assumed to have the same fuel use which was found in Driscoll & Tyedmers (2009). Data for the use of energy and chemicals for the reduction process was taken from DEFRA (2007) and assumed to be independent of the species that is processed (
Table 4.9). These data represent the world’s second largest fish reduction plant in 2007, located in Esbjerg, Denmark.

Confidential species-specific meal and oil yields were provided by one of the Norwegian feed producers, examples of public data on yields are shown in
Table 4.10. Data for farming and processing of crop ingredients was taken from Ecoinvent (2009) and the SIK Feed database (Flysjö et al. 2007). The composition of this part of the feed was modelled based on information from one of the aquafeed companies, see Table 4.11, as was the final production of the feed from the various inputs (Table 4.12). The average proportion of marine inputs used in salmon feed (60 % marine vs 40 % agricultural inputs) was found in FHL (2009).

Table 4.8 Resource use and yield for Anchoveta fishing and reduction (source: feed producer)

Inputs	Amount
Anchoveta	4500 kg
Diesel	85 liters for fishing
Heavy fuel oil	132 liters for reduction
Anchoveta meal	1000 kg (22 %)
Anchoveta oil	180 kg (4 %)

Table 4.9 Resource use and yield for fish reduction (from DEFRA 2007)

Inputs	Amount
Fish	1000 kg
Sodium hydroxide (NaOH)	1.03 kg
Formaldehyde[1]	0.86 kg
Methanol[1]	1.46 kg
Sulphuric acid (H_2SO_4)	0.45 kg
Nitric acid (HNO_3)	0.11 kg
Hydrochloric acid (HCl)	0.082 kg
Heat (from natural gas)	1331 MJ
Electricity	40.8 kWh
Outputs	
Fish meal	215 kg
Fish oil	45 kg

[1] together 2.3 kg of formalin

Table 4.10 Meal and oil yields for some common marine inputs in salmon feed (%)

Species	Fish meal	Fish oil	Source
Anchoveta	23.0	5.0	IFFO
Menhaden	24.0	13	IFFO
Sand eel	21.5	4.5	DEFRA
Species independent (average)	21.6	3.4	DEFRA

Table 4.11 Composition of land-based part of salmon feed (data from feed producer)

Crop	Proportion of vegetable part of the feed (%)	Country of orirgin
Rape seed oil	34	Denmark
Soy meal*	33	Brazil
Sunflower meal	11	France
Wheat	20	France
Wheat gluten	2.6	France
* Direct and indirect greenhosue gas emissions resulting from deforestation were not included		

Table 4.12 Production of salmon feeds in Norway, average of three plants (data from feed producer)

Inputs	Amount
Water	3.0 tonnes
Diesel oil	0.22 liters
Electricity	0.011 kWh
Heat, Light fuel oil	15 kWh
Heat, Natural gas	51 kWh
Liquified petroleum gas (LPG)	1.3 liters
Steam	74 kilos*
Outputs	
Fish feed	1000 kg
*or 82 kWh	

4.3.2 Salmon farming

For resource use and production in salmon farming, data from Norway’s largest salmon producer was used (Table 4.13).

Table 4.13 In- and outputs at the farm site affecting energy/carbon footprint per tonne live weight salmon produced (data from salmon producer)

Inputs	Amount
Feed	1200 kilos
Electricity	24 kWh
Diesel	15 litres
Petrol	0.24 kg
Heat (from natural gas)	0.075 kWh
Smolt	20 kg
Outputs	
Live-weight salmon	1000 kilos

Dead salmon to ensilage	50 kilos

Data regarding the use of by-products was found in Bekkevold and Olafsen (2007), stating that 100% of by-products from Norwegian salmon farming are used.

Smolt production was modelled using a slightly higher proportion of marine inputs (65 % as opposed to 59.5 % in the grow-out phase), but the same composition of feed and feed conversion ratio as in the grow-out phase. The energy use in smolt rearing was found to be 14129 kWh/tonne of smolt (FHL 2009) and the use of smolt was around 20 kg/ tonne of live-weight salmon produced.

4.3.3 Mussel farming and processing

Data for mussel farms was obtained from three active companies of which two shared the same processing facility. Data has been weighted together with three farming sites and two processing plants. The data sample is not considered to represent Norwegian mussel farming, it is therefore recommended that this case is interpreted as a case study, not as a supply chain representing the mussel sector. The used inputs and production are shown in Table 4.14. Diesel is used on smaller boats at the cultivation site for maintenance and harvesting. Plastics, mainly nylon, and steel is used as farming equipment.

Table 4.14 Material inputs and production in mussel supply chain (source: three mussel farms)

Cultivation	Amount	Unit
Diesel	0.047	kg/kg raw product
Plastics	0.0063	kg/kg raw product
Iron	0.0088	kg/kg raw product
Transport		
Distance	200	km
Ice	0.3	kg/kg raw product
Processing, Packaging		
Electricity	0.046	kWh/kg product
Expanded polystyrene (EPS)	0.063	kg/kg product

4.4 Fish processing

4.4.1 Salmon harvesting

For resource use and production in salmon harvesting, data from Norway's largest producer, was used (Table 4.15). Data regarding the use of by-products from farming was found in Bekkevold and Olafsen (2007), stating that 100 % of by-products from salmon slaughter are used.

Table 4.15 In- and outputs at the salmon slaughter plant affecting energy/carbon footprint per tonne live weight salmon produced (source: major salmon producer)

Inputs	Amount
Live-weight salmon	1000 kilos
Electricity	81 kWh
Carbon dioxide	0.15 kg
Water	3500 litres
Refrigerant R22	0.45 g
Refrigerant NH_3	7.4 g
Ice	207 kg
Outputs	
Salmon, head-on, gutted[1]	822 kilos
Salmon by-products to ensilage	178 kilos
[1] Including losses at slaughter plant	

4.4.2 Filleting

Data for resource use and yield in fish filleting was provided by a major whitefish processing plant producing mainly frozen products and one salmon processing plant producing mainly fresh products (Table 4.16). These data were compared with literature data for fish processing. It was decided that the resolution of the data not allowed separation between species, i.e. based on the data found, we modelled a general fish filleting process, which in case of frozen products was complemented by adding a general fish freezing process (see following section). Climate neutral refrigerants are most common, so energy use and product yield (and proportion of by-products used) are the main determinants of results in the processing phase.

Table 4.16 Energy use for fish processing (source: major salmon producer and major whitefish producer)

Energy use (kWh/tonne product)	Total	Filleting	Freezing
Whitefish plant	794	661	133 (see freezing below)
Salmon plant	701	568	133 (see freezing below)
Average	748	615	133 (see freezing below)

Data regarding the use of by-products was found in Bekkevold and Olafsen (2007), stating that 100% of by-products from farming are used, 39 % of by-products from cod processing and 95 % of by-products from herring processing.

4.4.3 Freezing

Freezing is assumed to be done to equal extents by two different freezing technologies (batch freezing tunnel/band freezers) requiring 106 and 160 kWh/tonne, respectively (Magnussen and Nordtvedt 2006), hence an average of 133 kWh per tonne of fish frozen. Use of climate neutral refrigerants is most common and is therefore negligible. Note that only freezing is included in this figure and it can therefore only be used as an add-on to other processing, such as gutting or filleting.

In cases where fish was frozen round, i.e. in some of the pelagic chains, an energy use of 216 kWh/tonne was used, which is an average of three processing plants for pelagic fish (Dale 2006). This figure includes all energy use at the plant, i.e. freezing, storage, ventilation, heating etc., but freezing is the single most important activity corresponding to approximately 60 % of total energy use (130 kWh/tonne), corresponding well with the figure above.

4.4.4 Storage

Fresh fish was assumed to be stored for five days before transport, frozen fish for 90 days (independent of species). There is no official data to support this, but this was the most reasonable estimate to conclude after contact with the processing companies involved. Energy use for storage was found in Thrane 2004b who reports 0.438 KJ/kg*day for cold storage and 2.6 KJ/kg*day for frozen storage.

4.4.5 Salting

Mass balances for the production of saltfish and clipfish were found out with aid from producing companies, FHL and official Norwegian conversion factors as was the amount of resources used in the various steps. The cod is to equal extents fresh and frozen cod that has been headed and gutted before entering the salting process. Fresh cod was stored for five days prior to salting, frozen for three months. The fish is then deboned and split before being placed on pallets with salt in between. Salt use was 1.5 kg salt/kg saltfish produced.

The fish looses around 33 % of its weight during the salting process (mainly water and some protein), the yield of saltfish is hence 67 % of headed and gutted cod. The salt content of the finished product is 20 %, so a considerable proportion of the salt is wasted, but it cannot be reused.

4.4.6 Drying

For the drying of saltfish to clipfish, two literature data were found representing two different technologies[7]. It was assumed that half of the clipfish is produced by one technology using 0.164 kWh/kg clipfish and half by the other using 0.265 kWh/kg clipfish (Jonassen et al 2007). A yield of clipfish from saltfish 70 % was used.

4.5 Transport

For all types of transports, infrastructure was included specifically for each transport as a background process from Ecoinvent (2009). Data for operation, refrigeration, load factors etc. was collected within the project. Every transport process was modelled with a component of propulsion (ships) /operation (trucks) emission related to distance and one component of cooling emission related to time. Overall results for each mode of transport included in the present study is shown in Table 4.17 and the underlying data used to obtain these results is presented in sections. 4.5.1-4.5.5

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[7] “Langblåst” and ”tvärblåst tørke”

Table 4.17 Greenhouse gas emissions related to transportation of one tonne of product one kilometer

Main Transport Processes	GHG emissions (g CO_2e/tonne*km)
Airfreight, Boeing 747-400	879
Lorry, Norway rural, 18 tonnes fresh fish	93
Lorry, Norway rural, 22 tonnes frozen fish	91
Lorry, European motorway, 18 tonnes fresh fish	76
Lorry, European motorway, 22 tonnes frozen fish	67
RoRo Car ferry (18 tonnes fresh fish)	52
RoRo Car ferry (22 tonnes frozen fish)	43
Containership (Small, 17knots)	36
Containership (Large Slow, 14knots)	18
Freight train (using Russian electricity)	7
Bulk ship Herring	<35[1]
Truck Cooling	10 222[2]
Truck Freezing	9 919[2]
Boat Cooling	6 129[2]

[1] includes cooling
[2] (g CO_2e/hour of refrigeration needed)

4.5.1 Road

Frequently used lorries used in fish export from Norway are models such as Volvo FH and Scania R500. Figure 4.1 presents a picture of the former. The total amount of goods that can be loaded per truck is limited to around 24 tonnes. A typical isolated hanger on these lorries can load 33 euro pallets.

Figure 4.1 Picture of a Volvo FH semi-trailer

Specific fuel use per km was obtained from the logistics department at one of the larger Norwegian salmon producers and verified against other sources, se Table 4.18. For Norwegian (hilly) roads a fuel use of 0.42 l/km was used and for European (flat terrain) 0.32 l/km.

Table 4.18 Fuel factors for semi-trailer

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

In this inventory the load factor for fresh and frozen fish was found by interviewing some of the larger exporters of fish products from Norway. Table 4.19 presents the load factors used in this analysis:

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

The numbers in brackets in Table 4.19 represents the range given from the interviews.

Table 4.19 Product specific load factors for semi trailers

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

Land transport distances were calculated using web-based route calculators (www.maps.google.com and www.viamichelin.com). Export routes were all considered without return trips except in the first transports from slaughter / processing within Norway where an additional positioning distance to nearest transport hub were used. The reason to exclude return transports by truck was that the information that was obtained indicated that trucks are operated in a complex logistical network and that it was not reasonable to assume that they are empty to any great extent, not even from Oslo and northwards. It was discussed that although there may be goods transported back to Norway, these may not contribute as much to the income as the fish. However, it was decided that this was too speculative to model as it could well be the other way around as well.

The average distances for road transport of salmon and whitefish to Oslo was calculated by weighting the distances from each county with their production of slaughtered salmon or landings of whitefish, i.e. the distances from each county was weighted according to their production relative to the total Norwegian production of each product. For transport of salmon to Oslo this approach resulted in an average distance of 842 km and for whitefish to Oslo the average distance was 1200 km.

4.5.2 Rail

Distances by rail were calculated using based on information from Green Cargo (Green Cargo 2009). The round frozen herring is transported in containers from St. Petersburg to Moscow (814 km) a transport estimated to take approximately 12 hours. Energy use for rail freight was between 0.034-0.043 kWh/t*km depending on how hilly the area is (NTM 2008c). Refrigeration of containers was modelled similar to refrigeration on trucks.

4.5.3 Sea transportation

Marine distances were calculated using www.distances.com

Bulk freight

Round frozen fish is transported in bulk on a relatively small ship (loading around 2000 tons of fish directly on an equal amount of euro pallets). This boat was assumed to be 2/3 to 3/4 empty on the way back, depending on the route. The bulk ship was the only case where an empty return transport was added due to the information that these vessels to a large extent actually are empty on the way back. A fuel use of 0.011 l/t*km was used after personal communication with several reefer ship owners.

RoRo car ferry

The chosen ferry data are based on emission data from NTM (2008b) using a “modern” RoRo Cargo ship with specific fuel consumption of 77 kg diesel/km and 3800 lane meters and cargo deck. Emissions were allocated with 58 % to the cargo and 42 % to the passenger according to how much area each of them occupy, as suggested by NTM. The emission rate per semi trailer was calculated according to the 17 lane meters truck and trailer occupy and the corresponding weight of cargo load.

Container

Typical cargo flow represents a 40-feet container (typical container size: 2 TEU[8]) that is either delivered directly to port or loaded at warehouse near the harbour from a connecting transport. Fuel use per cargo (Table 4.20) for container ships origins from Lindstad and Mørkve (2009) and it is assumed that 56 % of the cargo capacity is utilized. In addition to the fuel use for propulsion of the vessel, the electricity demand of refrigerated containers was added in the same way as was done for trucks, but with the container plugged into the ship using 160g diesel per kWh onboard[9]. Maersk's own data for propulsion per container are considerably lower and were considered not representative for an unspecified global fleet, when compared with other available data.

Table 4.20 Sea transportation

Vessel type	Fuel use [g fuel / tonne*km]
RoRo car ferry	22*
Large slow (2000 TEU) containership, 14 knots	4.5**
Average sized (350 TEU) containership, 17 knots	12**
* (NTM, 2008a) ** (Lindstad og Mørkve 2009) and unpublished calculations at SINTEF Fisheries and aquaculture	

Climate impact from construction and maintenance of harbours, ships and ferries were modelled using the infrastructure background process from Ecoinvent 2.0. These processes have a total GWP of 0.0017 kg CO_2e / tonne*km.

4.5.4 Air

The distance for airfreight between Oslo and Tokyo was calculated using www.airrouting.com. The air transport has been modelled by using a Boeing 747 400 in the NTM database (NTM 2008b), as the closest match to Boeing 747 400ERS commonly used for salmon exports (Wesby, SAS, pers comm.). These aircrafts are dedicated cargo planes and do not take passengers. Specific kerosene consumption (Table 4.21) was calculated from given values of takeoff consumption (CEF) and in-flight consumption (VEF), based on a flight Oslo-Tokyo. A load of 3.5 tonnes of fish is usually loaded in a flight container of 4.5 tonnes including ice and packages (Wesby, SAS, pers. comm. and salmon producer). The data from NTM (2008a) represents a 100 % freight factor with maximum load of 93 tonnes, however a general load factor of 0.7 was used motivated by the general uncertainties related to return flights and sample representativity for the whole fleet. No extra factor for emissions at high altitude was used.

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[8] Twenty foot Equivalent Unit (TEU)

[9] Personal contact, Karl Jivén,Manager Health Safety, Security & Environment, Maersk Sweden AB

Table 4.21 Data used for calculation of emissions from air freight

Parameter	Value	Unit
VEF (in-flight)	36	kg $C0_2$/km
CEF (take-off/landing)	10215	kg $C0_2$ at take off/landing
Distance	8380	km
Maximum load	93	tonnes
Load factor	0.7	

Final kerosene consumption per tonne km was calculated and modelled in Sima Pro with lifecycle data from Ecoinvent 2.0 including airport infrastructure and fuel production resulting in emission of 879 g CO_2e/tonme*km.

4.5.5 Refrigeration during transport

Refrigeration on trucks

The cooling system contributes with greenhouse gas emissions in two ways 1) directly through the energy required to power the cooling system and 2) via leakage of cooling agents with high global warming potential. Several sources confirmed diesel consumption to be around 2-4 l/h, varying depending on load and season. Technical specification Table 4.22 of the two most frequently used systems was obtained the company dominating the market in Sweden and Norway10.

Table 4.22 Fuel consumption in cooling systems

Cooling system temperature	Fuel (l/h)				Average
	SL-200e		SL-400e		
°C	High	Low	High	Low	All
-20	3.27	2.1	4.33	2.2	**3.0**
0	3.62	2.12	4.78	2.05	**3.1**

Leakage of refrigerants was estimated to 5-10 % of refrigerant volume (NTM 2008). In trailers the total refrigerant volume is approximately 6.5kg. Most commonly used refrigerants are R134a and R404a with Global Warming Potential of 3300 respectively 4800. Due to lack of data on the distribution between the two, the average Global Warming Potential of 4 050 is used, assuming equal use of R134a and R404a. The emissions were calculated by dividing the annual leakage by 2000 working hours, based on an assumption of 250 working days, each 10 hours. This roughly equals an additional fuel consumption of 0.3 l diesel/h regarding greenhouse gas emissions.

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[10] Personal communication Ulf Olsson, HO-Nilsson Göteborg, Themoking retailer

Refrigeration in sea transports

In sea transport the same containers are usually used as in land transport, but are plugged into the ships power system, and are thus still powered by diesel but with a larger and more efficient engine than in land transport. Electricity consumption of the same cooling system as above was therefore run by 160 g fuel/kWh (range 140-180)[11] as described in the section on container transports above, lowering the emission per hour with 44 % compared to road transport.

Cooling system running time

The cooling system running time (CS) was estimated separately for each transport, with an average speed of 70 km/h on land, 14 knots for the large containership (2000 TEU) and 17 knots for the smaller containership (350 TEU). Travelling time is taken from Stena Line Ferries12. In addition one hour loading time for all ferry transports is added as well as resting time of drivers. In the bulk ship data, however the cooling system was included in the fuel consumption data.

Table 4.23presents the green house gas emissions from transports used in this study and the contribution from propulsion/thrust and cooling.

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[11] Personel contact Karl Jivén, Maersk Sealine

[12] www.stena-line.se

Table 4.23 Greenhouse gas emissions from transports used in this study, showing the varying contribution of refrigeration

Grrenhouse Gas emissions (g CO_2e/tonne*km)	Propulsion/thrust	Cooling[1]	Total
Lorry Frozen goods hilly terrain			
Farm to Oslo 850 km, CS 15h	91.2	8.0	99
Lorry Frozen goods flat terrain			
Oslo-Göteborg;Fredrikshavn-Paris 300+1400km, CS 18h	66.7	6.6	73
Lorry Fresh goods flat terrain			
Oslo-Göteborg, Fredrikshavn-Paris 300 + 1400km, CS 18h	76.5	8.4	85
Lorry Fresh whitefish hilly terrain			
Landing site to Oslo 1200+100km, approx 20h, CS 20h	93.4	8.5	102
Carferry (Frozen Fish)			
Gothenburg-Frederikshavn 95km, CS 4,25	51.7	11.9	64
Carferry (Fresh fish)			
Gothenburg-Frederikshavn 95km, CS 4,25	50.4	15.2	66
Large Container ship (14knots)			
Rotterdam – Qingdao 17 751km, CS 32+1 day	18.2	18.9	37
Small Container ship (17knots)			
Narvik - Rotterdam 1860 km, CS 2,75+1 day	35.6	20.5	56
Bulkship (pelagic fish)			
Narvik - St Petersburg 2395km	n/a	n/a	35
Air freight			
Oslo-Tokyo Cargoflight 8380 km, CS 12h	879	1.2	880
Freight train using Russian electricity			
St Petersburg - Moscow 814km, CS 24h	7.3	6.9	14
[1] Note that cooling emissions are time dependent and varies between different routes as the cooling system runs continuously during up- and deloading, drivers breaks etc CS= running time for cooling system			

4.6 Transport packaging

In this analysis fresh products are transported on ice in Expanded Polystyrene boxes (EPS) that can take around 20 kg of fish and frozen products are transported in card board boxes that can take around 25 kg of fish. Table 4.24 presents their material composition, data from personal communication with major producers.

Table 4.24 Material use for transport packaging

Packaging	Material	Amount [kg]
Cardboard box for 20 kg frozen fish	Recycled cardboard	2.0*
Polystyrene box for 20 kg fresh fish on ice	Expanded Polystyrene (EPS)	0.5**
* Peterson Emballasje ** Brødrene Sunde AS		

4.7 Electricity production

Electricity use in the Nordic countries, included Norway, was included as NORDEL average production mix. In other countries (China and Russia) the average national electricity production with grid losses was modelled according to the Internationel Energy Agency (IEA 2009). This choice was based on the fact that Nordic grids are interconnected to a greater extent than in many other regions. NORDEL has a higher proportion of fossil fuel which leads to more than four times higher GHG emissions (0.18 kg CO2e/kWh) compared to Norwegian grid mix (0.04 kg CO2e/kWh). See
Table 4.25 for composition of the NORDEL electricity mix.

Table 4.25 Proportion of different countries electricity production in NORDEL (Ecoinvent 2007)

Country	Proportion (%)
Sweden	39
Finland	22
Denmark	10
Norway	29

5 Results

Over all results for all the products are found in Figure 5.19, Figure 5.20, Table 5.1 and Table 5.2.

5.1 Aquaculture

The results up to the farm-gate will be presented in this section. The results for mussels are much lower than for salmon and the fish from capture fisheries when live-weight harvested is compared (Figure 5.1 and Figure 5.2). The reason why the final result of the mussel supply chain is not much lower than fish, but rather in the same range as the other products (Table 5.1 and Figure 5.16 to Figure 5.20) is the low edible yield from harvested mass and that the by-products at harvest and processing are not used. It should be recalled, though, that the data underlying the results for mussels cannot be said to represent Norwegian mussel farming in general.

As has been shown many times before (Pelletier and Tyedmers 2007, Tyedmers et al. 2007, Pelletier et al. 2009, Ellingsen et al. 2009), the carbon footprint of farmed salmon is heavily dominated by the feed production. The resulting carbon footprint of 2.0 kg CO_2e per kilo live-weight salmon farmed is in line with previous findings (e.g. 1.8 kg CO_2e per kilo live-weight Norwegian salmon in Pelletier et al. 2009).

The relatively similar result is somewhat surprising considering that other data regarding production of feed inputs, feed composition and feed use as well as another method for co-product allocation (gross energy content) were used in these calculations, indicating the results of this and previous studies are relatively robust. The slightly higher value found here can be explained by including refrigerant use in all pelagic fisheries producing marine feed inputs used in the salmon feed in the same way as was done for Norwegian pelagic fisheries (these refrigerants being responsible for 0.12 kg CO_2e/kg live-weight salmon). In addition, a very high energy use in smolt production was found (FHL 2009), being responsible for 0.05 kg CO_2e/kg live-weight salmon. Also a slightly higher economical feed conversion ratio was used here (FCR=1.2 kg feed/kg LW salmon produced) as opposed to Pelletier et al. 2009, who used an economical FCR of 1.1kg feed/kg LW salmon produced .

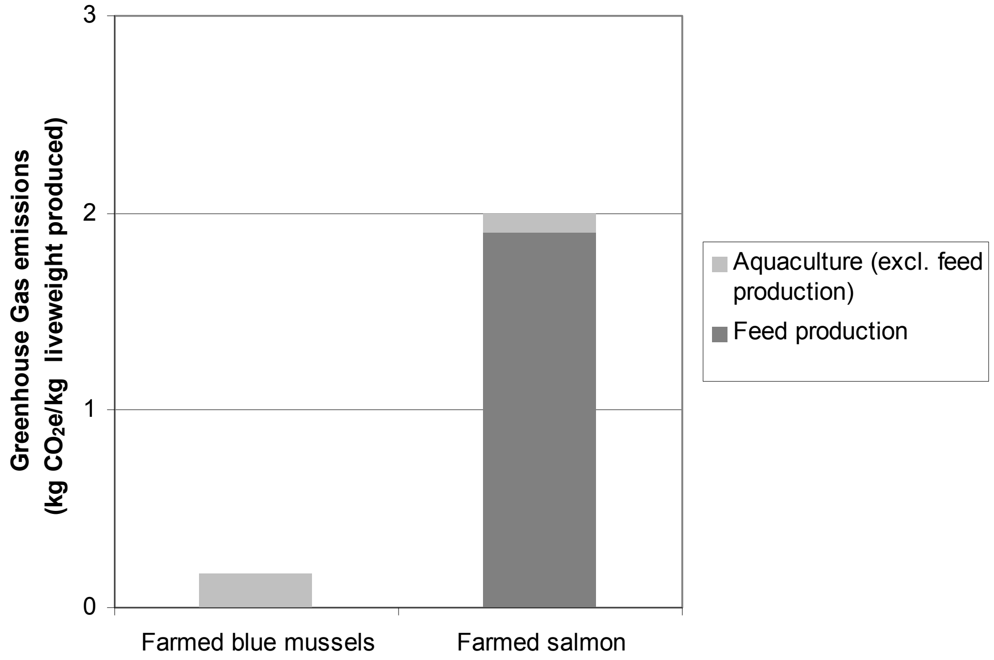

Figure 5.1 Carbon footprint per kilo of live-weight mussels and salmon at farm gate produced in Norwegian aquaculture

5.2 Capture fisheries

This section addresses the climate impact in the fishery stage of the wild caught products.

The use of fuel and refrigerants dominates the overall carbon footprint for seafood from capture fisheries (Table 5.2). Figure 5.2 presents climate impact from the fishing phase for the wild caught species and shows that pelagic fisheries have a much lower climate impact than demersal fisheries: They use less fuel and emit less refrigerants per kilo landed. These properties are already shown in the species specific fuel factors in Table 4.5 and in the refrigerants inventory in Chapter 4. The difference in fuel use (Table 4.3) and refrigerant emissions translates all the way through to the overall carbon footprint for the products, and gives the herring and mackerel products a considerably lower carbon footprint than the demersal species (cod, saithe and haddock), see Figure 5.20. The difference is further enhanced by the higher refrigerant emissions on the vessels in demersal fisheries. The energy use and climate impact correlate for the fishing phase although refrigerants emissions only contribute to climate impact.

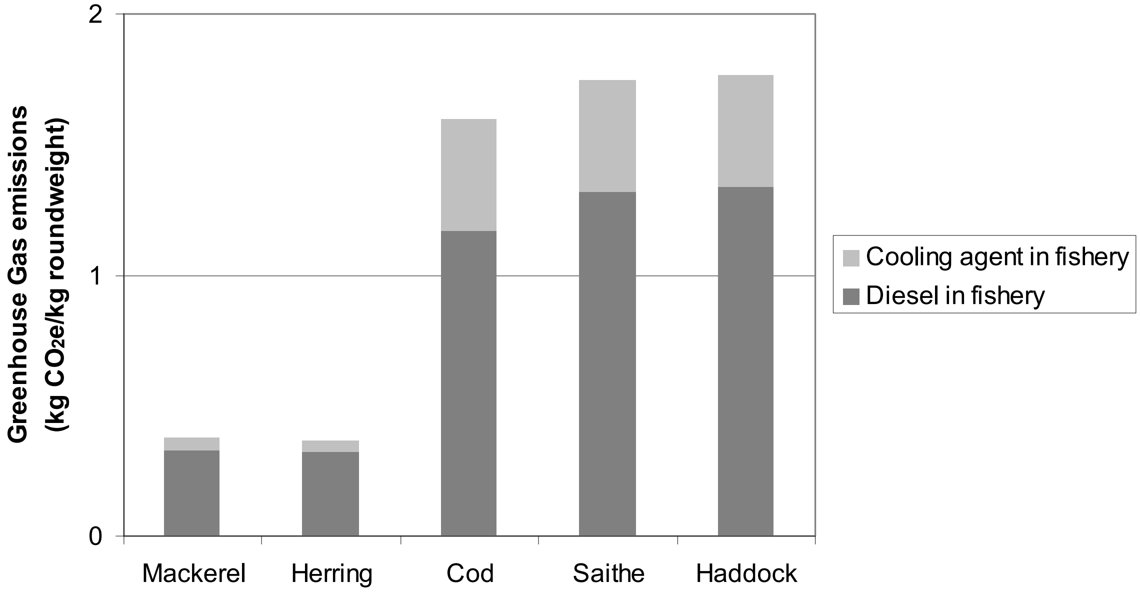

Figure 5.2 Carbon footprint results for the fishing phase of supply chains from capture fisheries.

Perhaps the most surprising result in the fishing phase is the relatively large contribution from refrigerant (R22) emissions. As explained in chapter 4.2.2 the use of R22 has decreased for many years due to strict regulations; import quotas, banning installation of new R22 systems and banning all import of virgin R22 from 2010. The use of R22 is now being phased out due to its' high ozone depletion potential, but these results show that it also has an important climate impact and the importance of replacing R22 with more environmentally friendly refrigerants, as quickly as possible, can not be overstated. It represents the single most important improvement option in the fishing phase. It is emphasized that it is important to choose climate neutral refrigerants to replace R22 since the HFCs (such as R507a or R404a) that sometimes are used to replace R22, actually have an even higher climate impact (more than twice as high).

The relatively low fuel factors for the demersal species, compared to what has been reported for demersal fisheries in the literature, is also interesting. It is explained by a relatively high proportion of coastal, passive fishing gear especially in the cod fishery and relatively well-managed fish stocks. Norway has been identified as the country complying with the largest proportion of the FAO Code of Conduct for Responsible Fisheries in the world (Pitcher et al. 2009). Nevertheless even Norway only complies with around 60 % of the Code, meaning there is room for considerable improvement which also would result in improved carbon footprint results. There are strong indications that over-fishing leads to increased fuel use in the fishing stage and thereby a higher carbon footprint (Schau et al 2009, Tyedmers 2001, 2004). The fuel intensity to a large extent depends on the management system, e.g. a decrease or increase in quotas with the same structure of the fishing fleet would lead to different fuel efficiencies (Driscoll and Tyedmers 2009).

The main objective of the Norwegian profitability survey is not to calculate carbon footprint, but to our knowledge, it is unique in its coverage of a whole nation's fishery. Even higher coverage and modification of the survey to do it even more usable for carbon foot printing purposes would be useful. To be able to go more into detail and tell the carbon footprint of a specific product rather than "the average Norwegian product", greater resolution is needed. Currently our model uses the same "average Norwegian cod fishery" to produce all cod products and this is in practice not the case. The reason for doing so was that it proved difficult to find statistical information about how fish from different fisheries was processed into different products, we could only obtain individual estimates from companies and these were highly variable and therefore irrelevant to use to represent the average Norwegian production of that product.

5.3 Processing in Norway vs. abroad

A number of chains were included in order to demonstrate the difference between processing in Norway exporting fillets compared to exporting whole fish to be processed abroad. The results for cod and salmon are shown in Figure 5.3 and Figure 5.4.

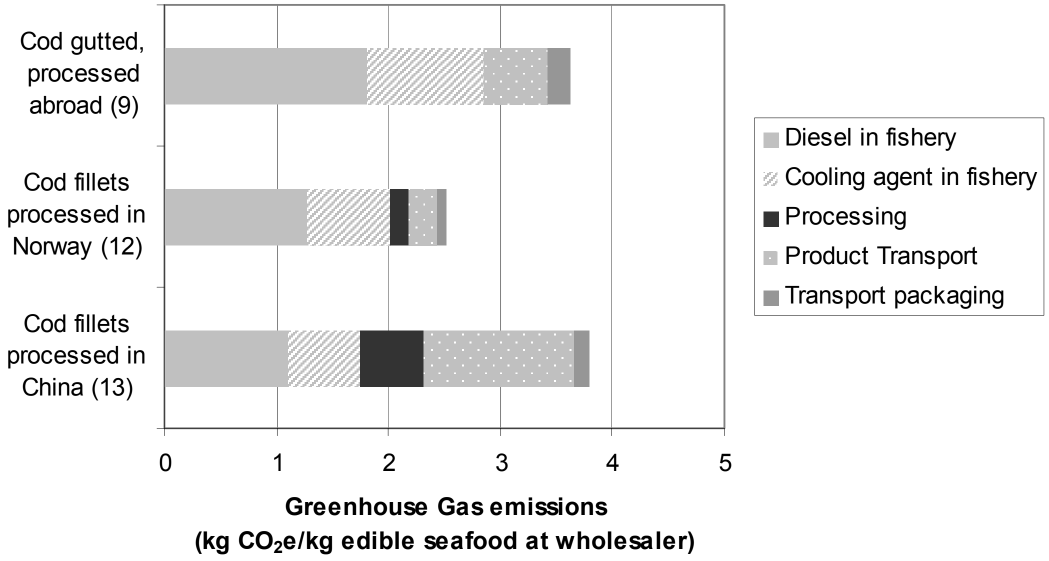

Figure 5.3 Cod processed to fillets either in Norway (with parts of the by-products used), in China (with all of the by-products used) or in France (with no use of by-products)

The relatively large contribution of processing when the cod is processed in China is due to Chinese electricity production being dominated by coal and the large contribution of the transport is due to the large distance. Marine container transportation is per tonne*km more efficient than truck transport (see Table 4.17). The reason for different contributions of the fishing phase in the three cases is different degrees of by-product use and edible yields in cases where the by-products are not used. It must be recalled that mass allocation does not capture the advantage of higher fillet yield in manual compared to automated processing, since equal burden is placed on product and by-product.

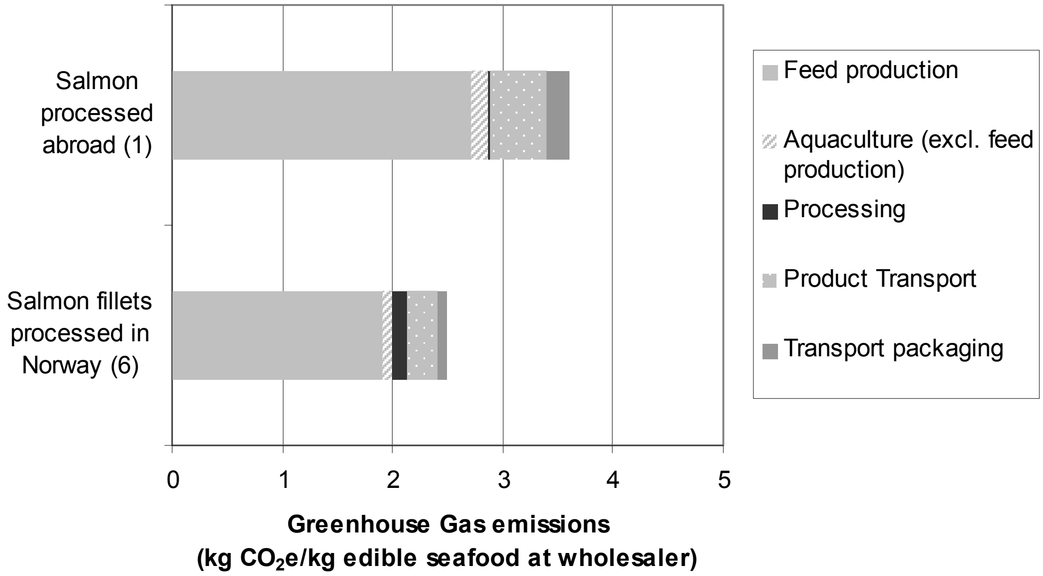

Figure 5.4 Salmon processed to fillets either in Norway (with by-products used) or in France (with no use of by-products), both after truck transport

Due to our choice of mass as the basis for allocation, it becomes very important whether the by-products are used or not. This proved to be easy to find out in the case of processing in Norway due to the existence of extensive research in the area of by-product utilisation aiming at increasing the use of by-products from seafood processing (Bekkevold and Olafsen 2007).

It proved to be difficult to impossible in the case of processing in other countries, despite considerable effort using all means from research and industry contacts in Norway and abroad. The only processing activity abroad for which we could conclude use of by-products was in whitefish processing in China, where two independent sources stated that 100 % is used as chicken feed. While it is probable that at least some of the by-products resulting from salmon and cod processing in France and Shanghai, processing of pelagic fish in Russia and Japan and haddock processing in the UK are used, in lack of data we assumed no use which places higher burden on these chains. Due to the importance of this aspect for the final result, we suggest improved data of the use of by-products in the countries of export. However, we do believe that the use of by-products is higher in large-scale processing plants in Norway than in smaller scale facilities at wholesalers or retailers abroad. We also believe that the mere existence of this type of data motivates that it should be used rather than choosing the worst-case-scenario assuming that by-products are not used anywhere.

5.4 Fresh or frozen

In Figure 5.5 and Figure 5.6, it is evident that the product form, i.e. whether the fish is fresh or frozen, does influence the results somewhat, even though all other assumptions are the same in the two chains. The contribution of processing is somewhat larger, due to the electricity used for freezing and the contribution of the transport is somewhat lower, due to the fact that no ice is needed when transporting frozen fish, hence more fish can be loaded per truck. The total result of the two chains is almost identical.

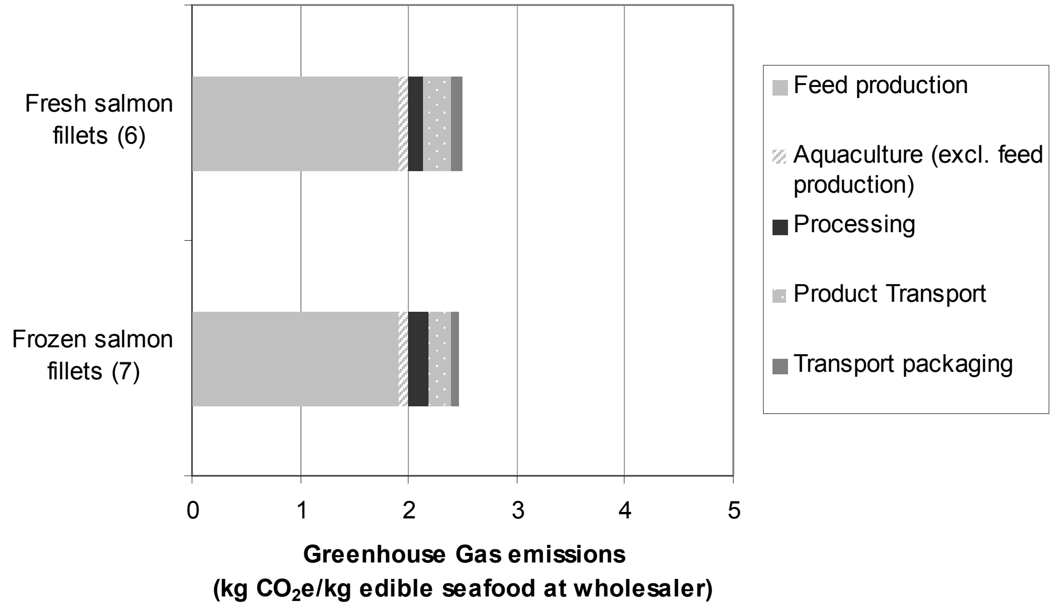

Figure 5.5 Fresh and frozen salmon fillets transported to Paris by truck

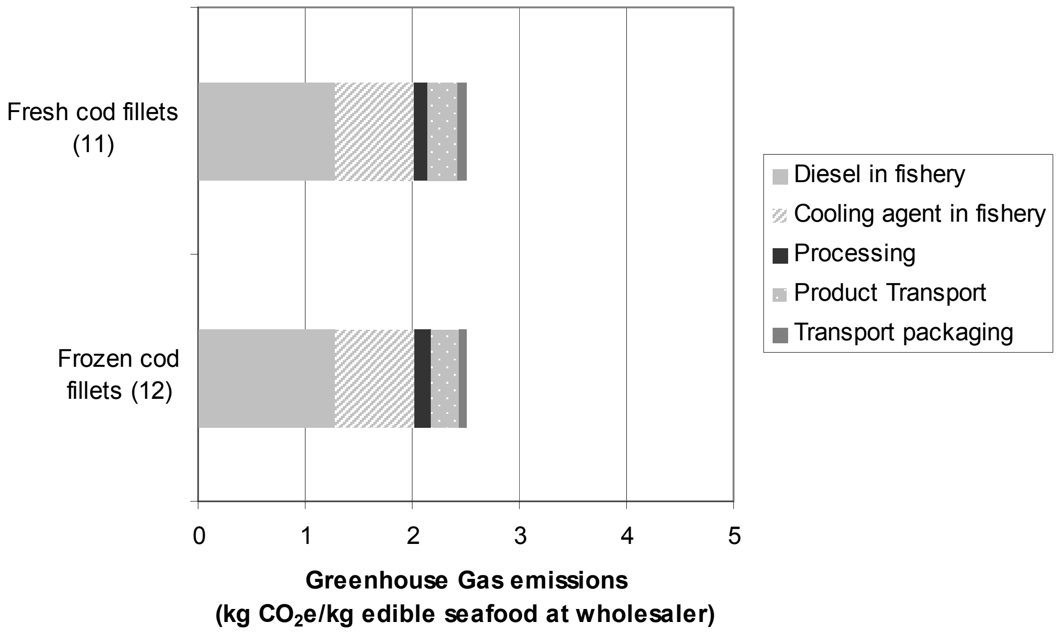

Figure 5.6 Fresh and frozen cod fillets transported to Paris by truck

The difference is much more pronounced when freezing makes it possible to transport the product by a much more efficient mode of transport, such as replacing RoRo car ferry with bulk freight (Figure 5.7) or replacing airfreight of fresh fish by containerized shipping of frozen fish (Figure 5.8).

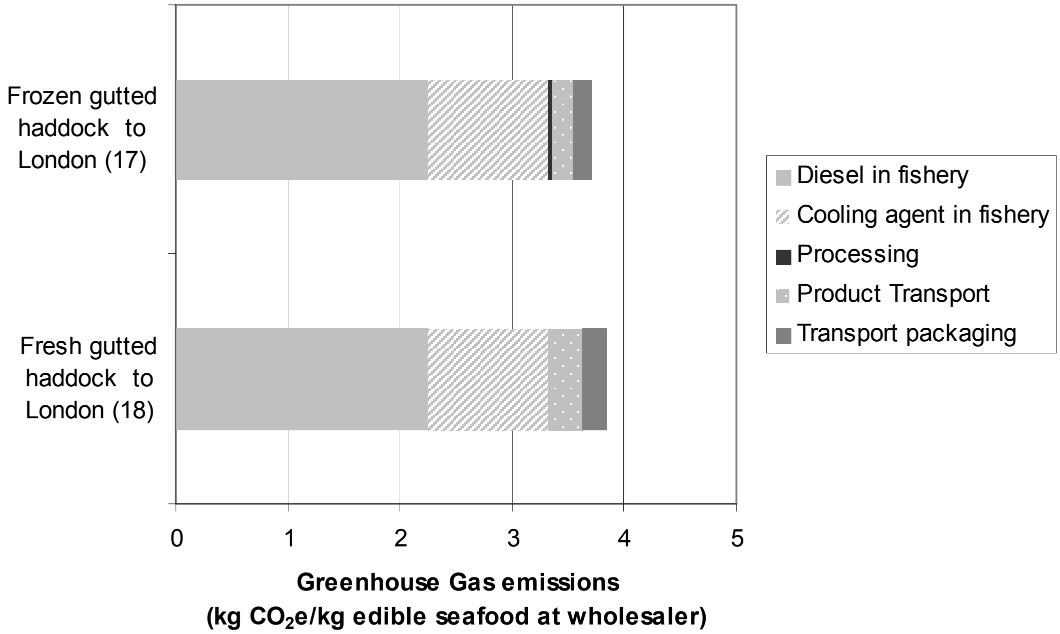

Figure 5.7 Fresh and frozen, gutted haddock shipped to London by two different types of sea transport (fresh haddock by RoRo vessel and frozen by bulk freight) and a short truck transport.

It is recognised (e.g. in chapter 4) that a part of the whitefish, e.g. gutted haddock, is frozen at sea, meaning that energy for freezing is included in the onboard fuel use from some vessels. Adding freezing in a processing plant on land in this case leads to that the energy use for freezing is included twice. Adjustments for this were discussed, but dismissed, since there was too little information about the overall proportion of fish frozen at sea for each species and about which supply chains used fish that had been frozen at sea. In addition, since all the other supply chains were based on the "average Norwegian fishery", we felt that it was inconsistent to make an exception from this for one or two chains, based on vague information and rather accepted the possible minimal double-accounting that results from this choice.

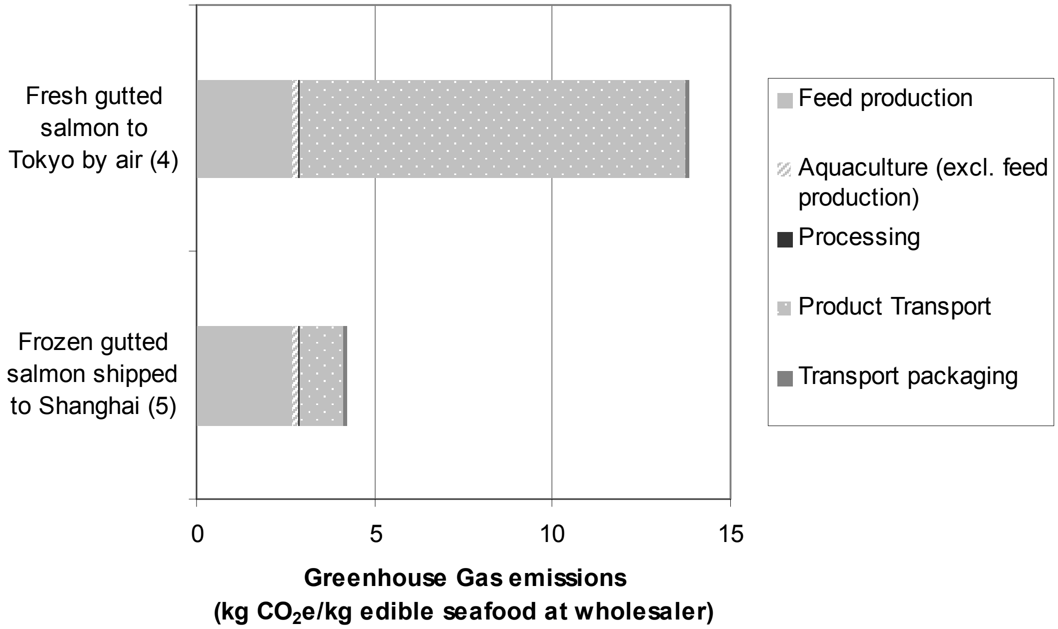

Figure 5.8 Fresh and frozen, gutted salmon air-freighted to Tokyo or shipped to Shanghai, respectively

The remarkable emissions related to air-freighting of fresh salmon to Tokyo is related both due to a highly resource demanding mode of transport (section 4.5) and the very long distance. Fresh and frozen products are conceived differently by consumers, although the quality of frozen fish may be as good as or higher than that of fresh fish. The product form affects the carbon footprint/energy use in two ways. Freezing does require energy, often in the form of electricity, whether the fish is frozen round or frozen after filleting, the impact of which depends on the energy source used. After a product is frozen, however, its shelf-life increases from days to months compared to fresh fish. The longer shelf-life opens up more possible solutions for logistics, i.e. other means of transportation become possible when the fish is frozen, e.g. train and boat become competitive alternatives to road and air transport.

Especially for the longest intercontinental transports that, when it comes to fresh fish, have to be done by airfreight, frozen fish can be shipped either in containers, or even more efficient, in bulk. Even though containerized shipping of refrigerated goods around the globe in this study was shown to require more resources than previously reported (Ziegler 2008, Seafish 2008), it is still among the most efficient means of transportation per tonne*km. However, transport distance and time also play an important role in extreme long-distance transports.

Super-cooling of fish becomes increasingly popular and has some interesting characteristics in this perspective. Very briefly super-cooling means that fresh fish is cooled to just below the freezing point (between -1 to -2°C). The muscle cells are in this way not damaged by formation of ice as in the traditional freezing/thawing process and the quality of the product is by consumers experienced as that of fresh fish, although the shelf-life of super-cooled salmon at -2°C e.g. is 30 days compared to 9 days when stored at 5°C. The increase in shelf-life makes it possible to ship products that could only be transported by airfreight before, e.g. fresh salmon products from Norway to the east coast of the U.S. An additional positive effect of super-cooling is that ice is not required during transport and processing since the cell fluid works as a coolant. The method is still under development, but it seems to have potential to improve the environmental performance of the supply chain of fresh salmon, especially when involving long-distance transport.

5.5 Farmed or wild

Many are those who have asked: Is it better to eat farmed or wild fish? Capture fisheries and fish farming lead to a range of environmental impacts that in part overlap, but some of which are very specific to each system. Capture fisheries using demersal fishing gear e.g. cause benthic impacts and fish farming as an example has its challenges with influencing wild salmon stocks. Hence, the overall impact can hardly be compared and when a metric is chosen that can be compared (like energy use or carbon footprint), it is important to keep in mind, that essential parts of the environmental impact are left out. Modern industrialised aquaculture is not independent of capture fisheries either, rather it depends on them for the supply of fish meal and oil inputs to feeds for carnivorous species such as salmon.

Nevertheless it is interesting to compare the single-metric results for two seafood products produced in highly different ways and taken to the same markets. In fact, the results of the present study are that farmed salmon and the demersal species cod, haddock and saithe have a similar carbon footprint (Figure 5.9 and Figure 5.10) whereas pelagic species are considerably lower. This is shown in Figure 5.9 to Figure 5.12 where the chains of comparable products that end up in a Paris, Tokyo and Moscow are deployed.

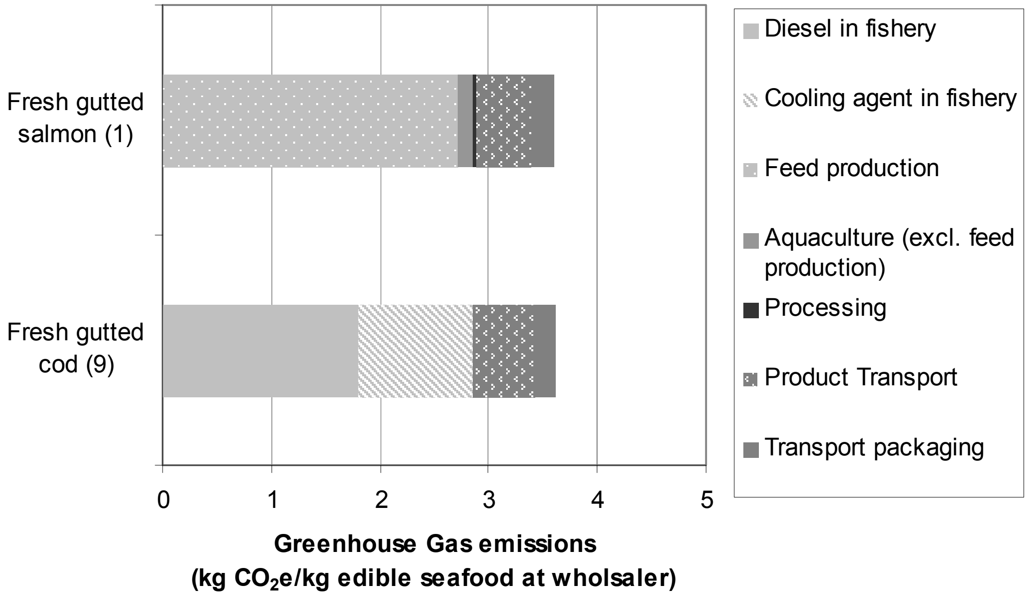

Figure 5.9 Fresh gutted salmon and cod trucked to Paris

The result that the gutted fish has higher impacts than fillets is, again, due to the fact that allocation is based on mass. In addition, whether by-products are used becomes very important. We have not been able to find data on by-product use when Norwegian fish is exported whole to e.g. France and therefore no use was assumed, as explained previously. We do, however, believe that it is reasonable to assume that by-product use is higher in Norway than after export. In addition, in the case of exporting fillets, the by-products do not need to be transported, so the contribution of transport is higher for gutted fish than for fillets.

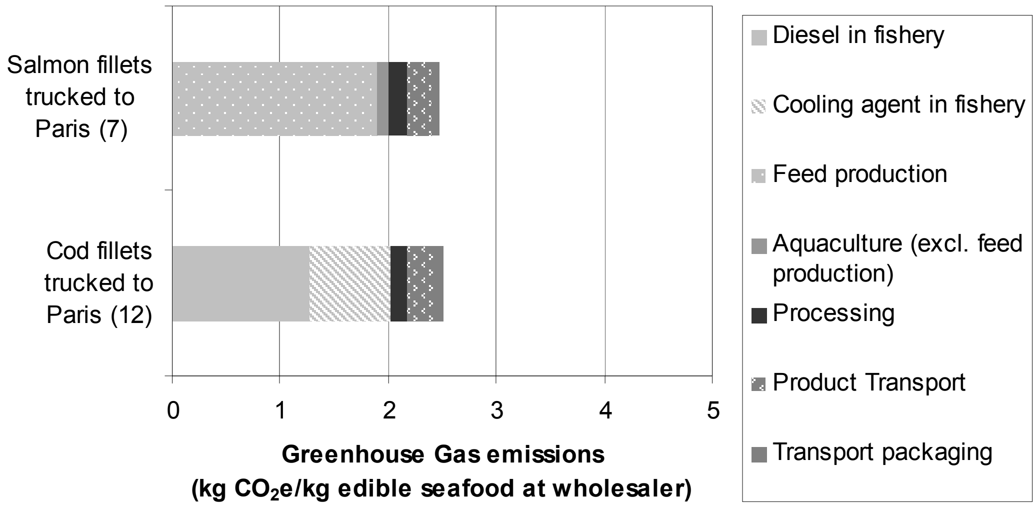

Figure 5.10 Frozen salmon and cod fillets trucked to Paris

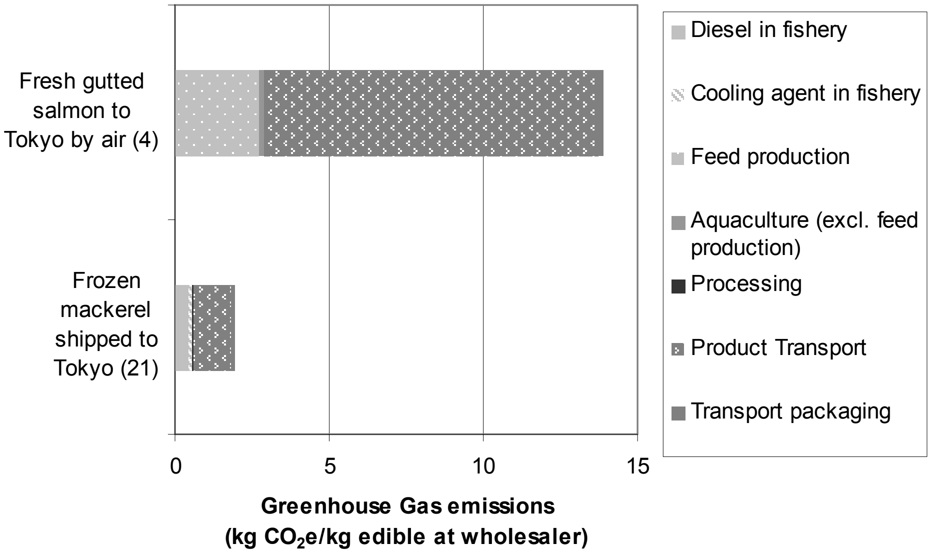

Figure 5.11 Fresh salmon and frozen mackerel, air-freighted and shipped to Tokyo, respectively

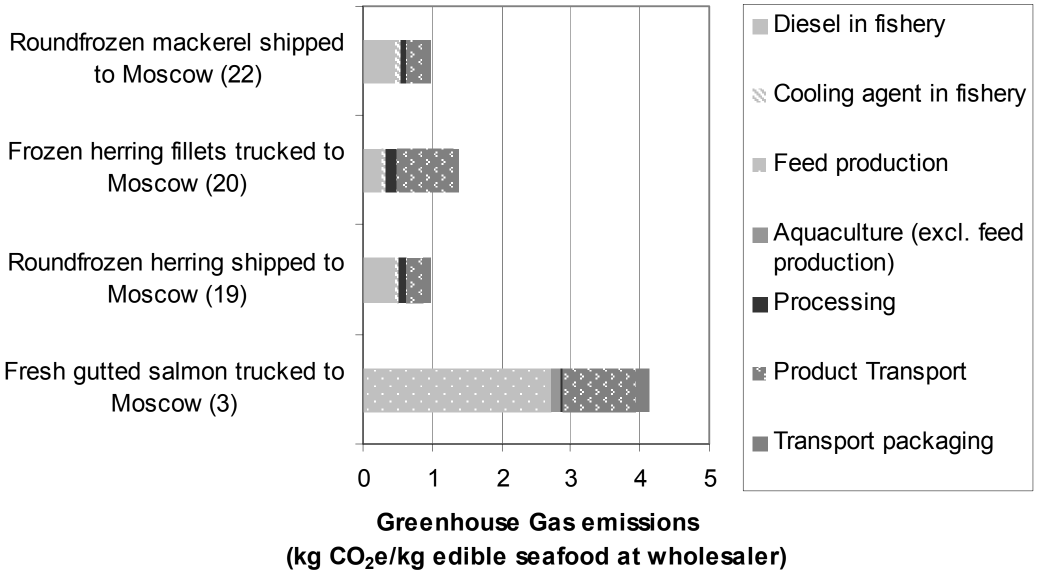

Figure 5.12 Fresh salmon and frozen pelagic fish trucked and shipped to Moscow, respectively

With regard to Figure 5.12, the larger contribution of transportation in the case of herring fillets is due to trucking rather than bulk freight and train, despite the larger mass than has to be transported when round fish is transported rather than fillets. The processing phase is larger due to our inventory result that filleting requires more energy than freezing.

5.6 Transport distance and transport mode

The importance of transport mode and transport distance has already been shown in some of the comparisons presented above (Figure 5.7, Figure 5.8, Figure 5.11 and Figure 5.12). Here, some examples that isolates the effect of distances are shown in Figure 5.13 and Figure 5.14 and although primary production, i.e. fishing, feed production and fish farming dominate the over all results, it is evident that transport distance also matters.

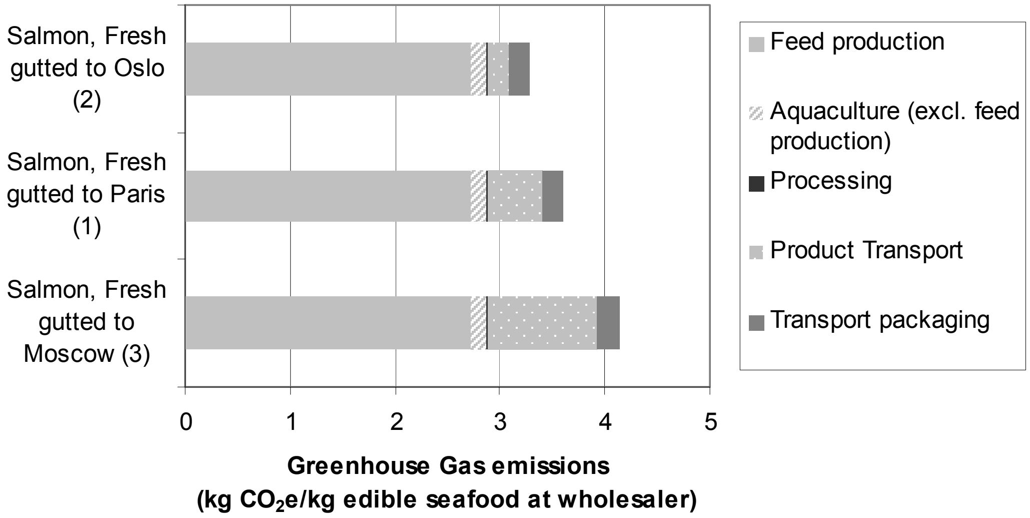

Figure 5.13 Fresh, gutted salmon trucked to Oslo, Paris and Moscow (increasing distance)

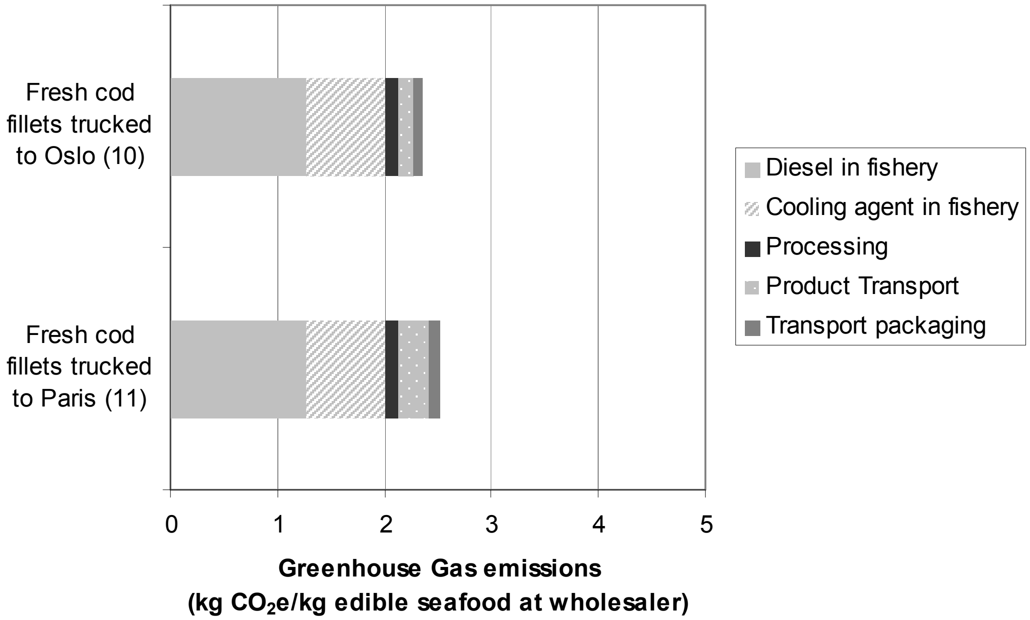

Figure 5.14 Fresh cod fillets trucked to Oslo and Paris (increasing distance)

The result in Figure 5.15 is not only due to the longer distance to Tokyo, but also to the more efficient transport in bulk which is done to St. Petersburg, followed by train transport to Moscow compared to containerized shipping used in shipping to Tokyo (section 4.5).

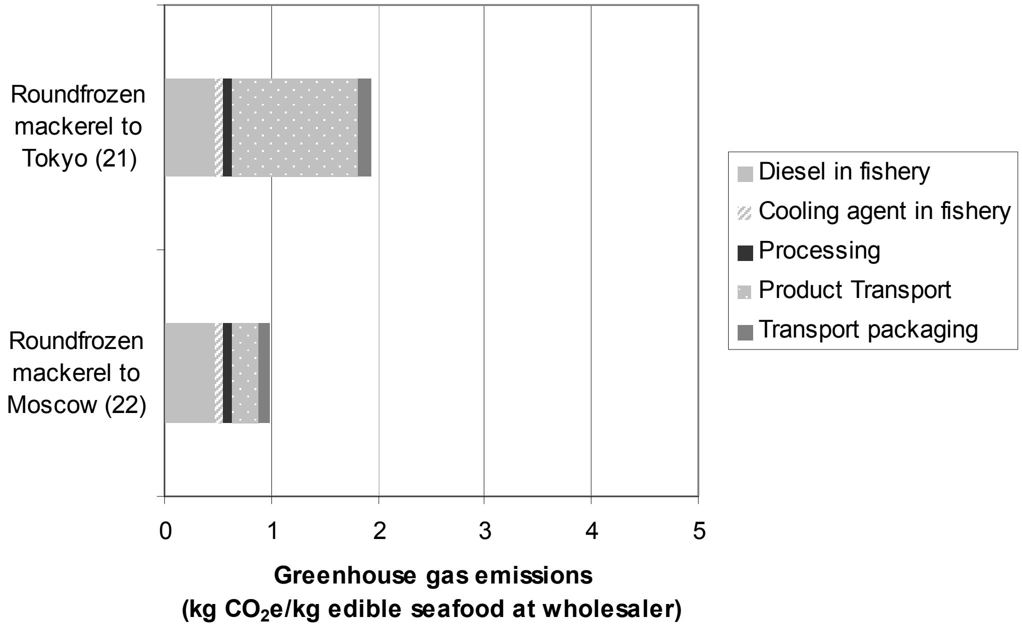

Figure 5.15 Round frozen mackerel shipped to Tokyo and Moscow by container and bulk freight, respectively

Transport efficiency is a result of many variables such as truck/ship size, fuel use, transport distance, transport time, transport packaging affecting the load factor and product form affecting both load capacity and need for refrigeration. It is certainly more complicated than just looking at the mere distance a product is transported.

The more widespread use of super-cooling seems to be a promising way to satisfy the desire for fresh fish in a more resource-efficient way than today. However, if the goal is to reduce CO_2-emissions, one should on the long term also try to change consumer attitudes towards frozen fish that has an even longer shelf-life, lower product waste and can be transported in a highly efficient manner, without necessarily leading to lower quality than fresh fish. The improvement potential regarding seafood product transportation in increasing the share of frozen products, while decreasing the proportion that is air-freighted, is large (Ellingsen *et al.* 2009).

5.7 Traditional and new products

Saltfish and clipfish represent products that have been produced in Norway for centuries both for domestic consumption and for export, being preserved by the traditional methods salting and drying. They still represent an important export volume and value. It is perhaps intuitive to think that the quite time-consuming processing phase, first salting the fish during several weeks, then drying it, nowadays using electricity, is a very resource-demanding process, especially considering that the fisheries turned out to be very efficient. But the result tells the opposite, despite our rather conservative choice to choose the Nordic electricity mix with five times higher greenhouse gas emissions compared to the Norwegian average grid mix.

In fact, these processed cod products had a lower carbon footprint than the other cod products (Figure 5.16). One fact influencing this result is that in the edible product, a part of the fish has been replaced by salt, meaning that in order to produce a kilo of product, less fish is needed. Fish, when fished in modern industrialised fisheries, no matter how efficient, will have a larger carbon footprint than salt per kilo, meaning that replacing fish by salt lowers the carbon footprint of the product. Another advantage of the salted and dried products is that a smaller amount needs to be transported, lowering the impact of the transport phase.

It should be kept in mind that the products were all modelled as if they all came from the same "average Norwegian" cod fishery. There are indications (but no data) that the saltfish and clipfish mainly come from the more efficient coastal fisheries, which, if that had been taken into account, had led to that these products would have had even lower results. However, these were the two products for which it was most difficult to establish a reliable mass flow and it is still surrounded by some uncertainty.

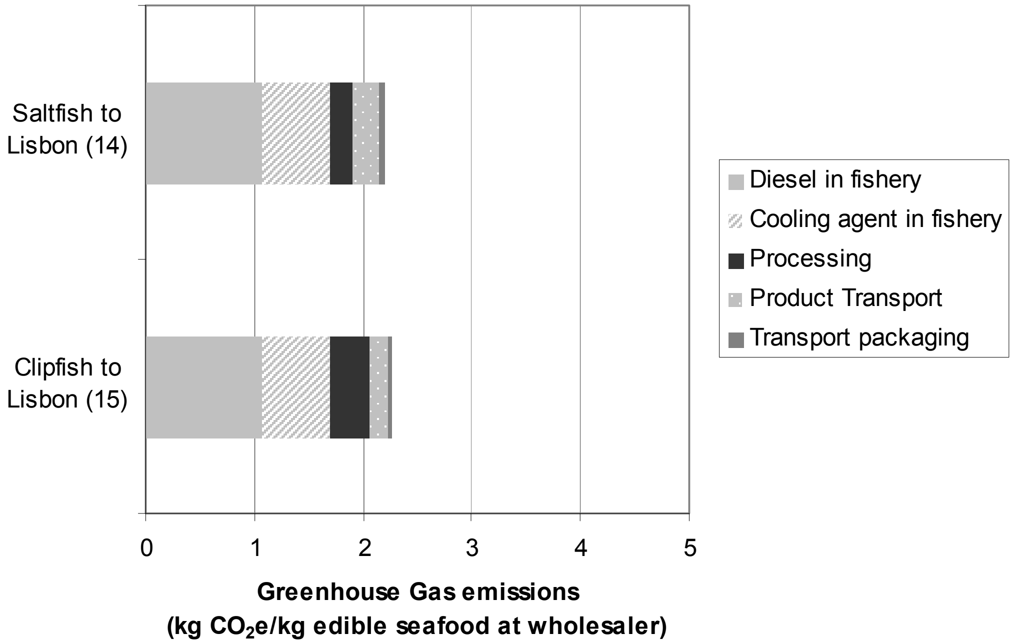

Figure 5.16 Saltfish and Clipfish (dried saltfish) trucked to Lisbon

Live blue mussels are an untypical product in this selection of Norwegian seafood products in that it today represents a very small volume which was included both because it is a production system different from both capture fisheries and salmon aquaculture and due to its potential to grow. The results for this product can hardly bee seen as representative for Norwegian mussel farming in general and should rather be seen as a snapshot of three mussel farms in Norway in 2007.

Figure 5.17 shows that the carbon footprint of mussels is comparable with the other supply chains, despite the low result per kilo of live-weight mussel farmed Figure 5.17 and our expectations that they would come out much lower due to the absence of the resource intensive feed production in salmon farming and the absence of the fuel intensive fishing phase.

The explanation lies in a rather substantial fuel use for the vessel used for maintenance and harvest of mussels in combination with the low edible yield per tonne mussels harvested. Moreover, in this chain, capital goods in the form of farming equipment was included representing about 8% of the total carbon footprint. Higher figures have been reported previously (referenced in Tyedmers et al. 2007, stating that 58% of the energy inputs into mussel farming were due to structures equipment) and the data set used here was probably not complete and underestimates the importance of capital goods. The low yield is both due to large proportion of small and crushed mussels and organic waste in the mass harvested and due to relatively low meat content of the mussels (24 %). In the sensitivity analysis (section 5.8), a considerable improvement potential was identified for mussel production in increasing the yield at harvest, using the by-products as feed and decreasing the fuel use. Again, it is emphasized the mussel supply chain is more of a case study than truly representing Norwegian mussel production.

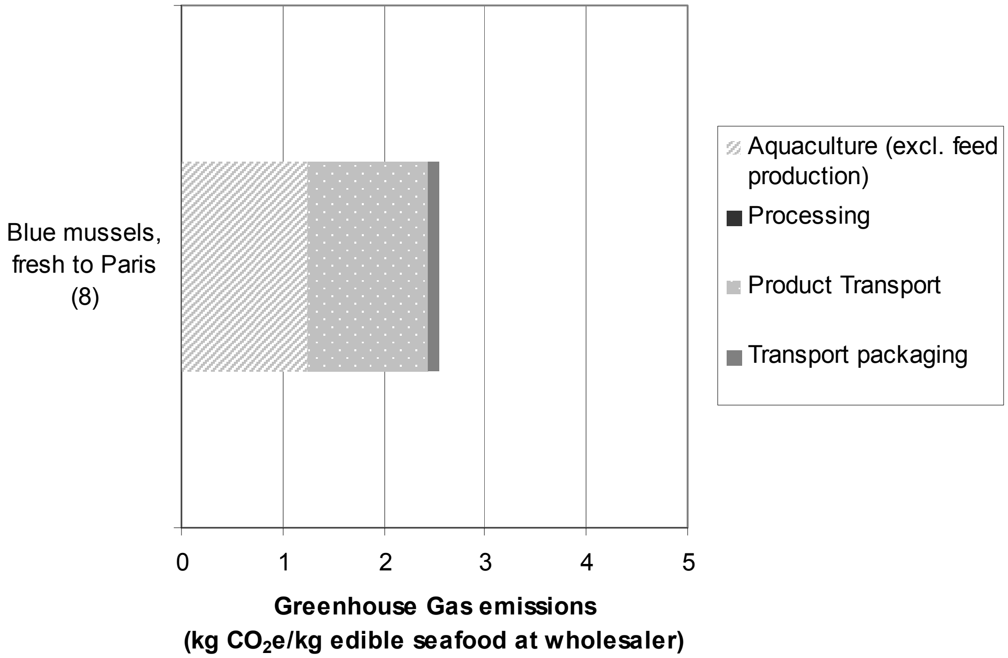

Figure 5.17 Live, farmed blue mussels trucked to Paris

5.8 Energy use

The results presented above only concern the carbon footprint, but the study included two impact categories - the other one being primary energy use. Primary energy use as calculated by the impact assessment method Cumulative Energy Demand (CED) is, in the studied chains, highly correlated to the carbon footprint. This result shows that the carbon footprint is largely determined by the use of fossil fuels in the different chains both for fishing, transportation and to some extent production of packaging and electricity. The main differences are that the refrigerants used in the fishing phase almost only contribute to the carbon footprint, hardly to energy use at all. The processing phase contributes more to the impact category energy use than to carbon footprint, since some of the energy used in this phase does not contribute to the carbon footprint. But the overall results for the two categories are very similar as can be seen in Table 5.1.

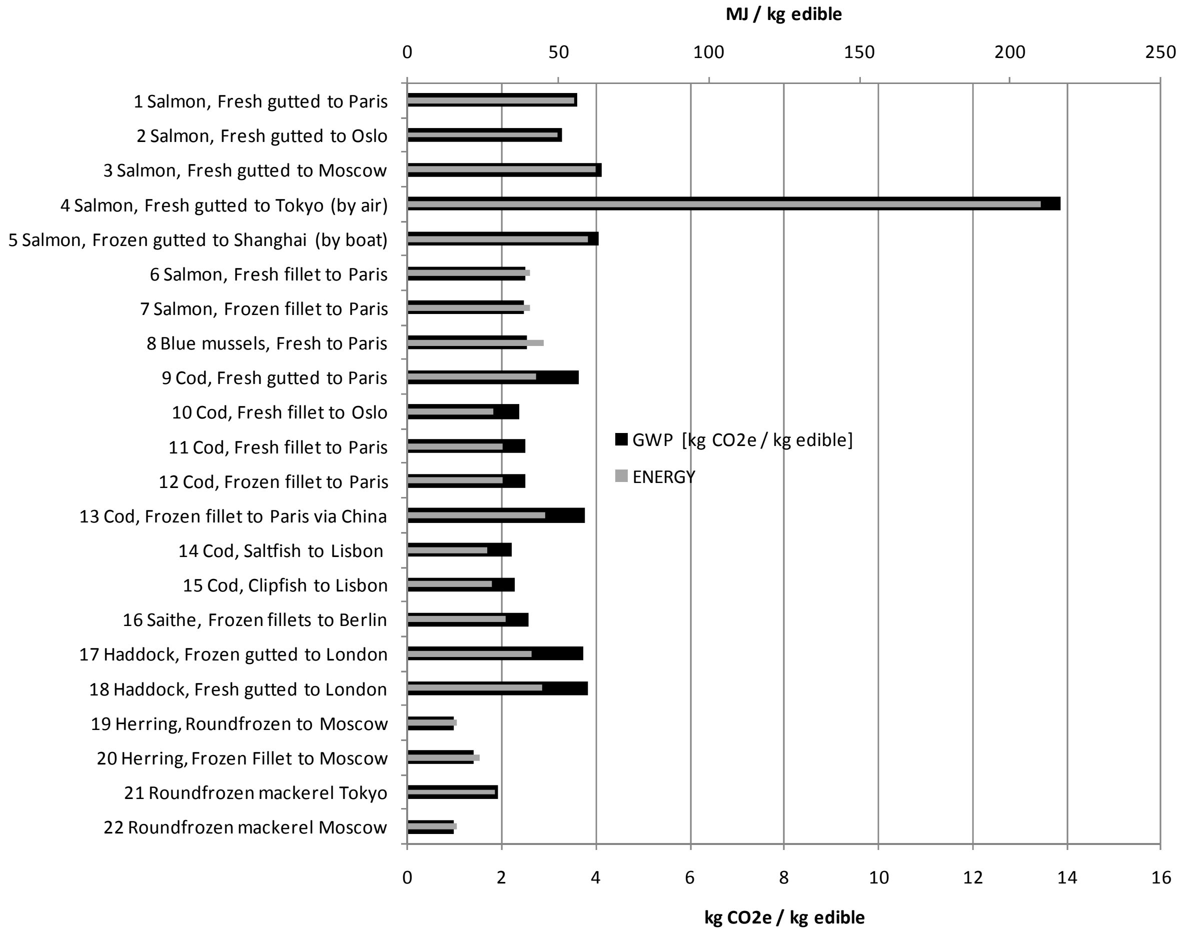

Figure 5.18 Total results primary energy use and climate impact. Energy use on top axis and climate impact on lower axis.

Table 5.1 Overall results for chains originating in aquaculture

	Greenhouse Gas emissions [kg CO_2e/kg edible product at wholesaler]						Energy
Aquaculture	**Total**	**Feed production**	**Aquaculture (excl. feed production)**	**Processing**	**Product Transport**	**Transport packaging**	**Total**
1 Salmon, Fresh gutted to Paris	3.60	2.72	0.14	0.03	0.51	0.20	55.4
2 Salmon, Fresh gutted to Oslo	3.29	2.72	0.14	0.03	0.20	0.20	49.9
3 Salmon, Fresh gutted to Moscow	4.13	2.72	0.14	0.03	1.05	0.20	62.3
4 Salmon, Fresh gutted to Tokyo (by air)	13.86	2.72	0.14	0.03	10.83	0.14	210.2
5 Salmon, Frozen gutted to Shanghai (by boat)	4.20	2.72	0.14	0.05	1.18	0.11	61.5
6 Salmon, Fresh fillet to Paris	2.50	1.90	0.10	0.14	0.26	0.09	40.7
7 Salmon, Frozen fillet to Paris	2.47	1.90	0.10	0.18	0.21	0.07	40.7
8 Blue mussels, Fresh to Paris	2.54	0.00	1.24	0.00	1.19	0.11	45.1

Table 5.2 Overall results for chains originating in capture fisheries

	Greenhouse Gas emissions [kg CO_2e/kg edible product at wholesaler]						Energy
Capture fisheries	**Total**	**Diesel in fishery**	**Cooling agent in fishery**	**Processing**	**Product Transport**	**Transport packaging**	**Total**
9 Cod, Fresh gutted to Paris	3.62	1.81	1.05	0.00	0.57	0.19	42.6
10 Cod, Fresh fillet to Oslo	2.36	1.27	0.74	0.12	0.13	0.09	28.6
11 Cod, Fresh fillet to Paris	2.51	1.27	0.74	0.12	0.28	0.09	31.3
12 Cod, Frozen fillet to Paris	2.51	1.27	0.74	0.17	0.26	0.07	31.5
13 Cod, Frozen fillet to Paris via China	3.78	1.10	0.64	0.57	1.34	0.13	45.7
14 Cod, Saltfish to Lisbon	2.20	1.08	0.62	0.21	0.24	0.05	26.6
15 Cod, Clipfish to Lisbon	2.26	1.08	0.62	0.36	0.17	0.03	28.0
16 Saithe, Frozen fillets to Berlin	2.56	1.44	0.69	0.17	0.19	0.07	32.7
17 Haddock, Frozen gutted to London	3.72	2.26	1.07	0.03	0.20	0.16	40.9
18 Haddock, Fresh gutted to London	3.84	2.26	1.07	0.00	0.30	0.21	44.7
19 Herring, Round frozen to Moscow	0.98	0.45	0.07	0.09	0.24	0.12	16.1
20 Herring, Frozen Fillet to Moscow	1.39	0.28	0.04	0.16	0.83	0.07	23.8
21 Round frozen mackerel Tokyo	1.92	0.47	0.07	0.09	1.18	0.12	29.0
22 Round frozen mackerel Moscow	0.99	0.47	0.07	0.09	0.24	0.12	16.3

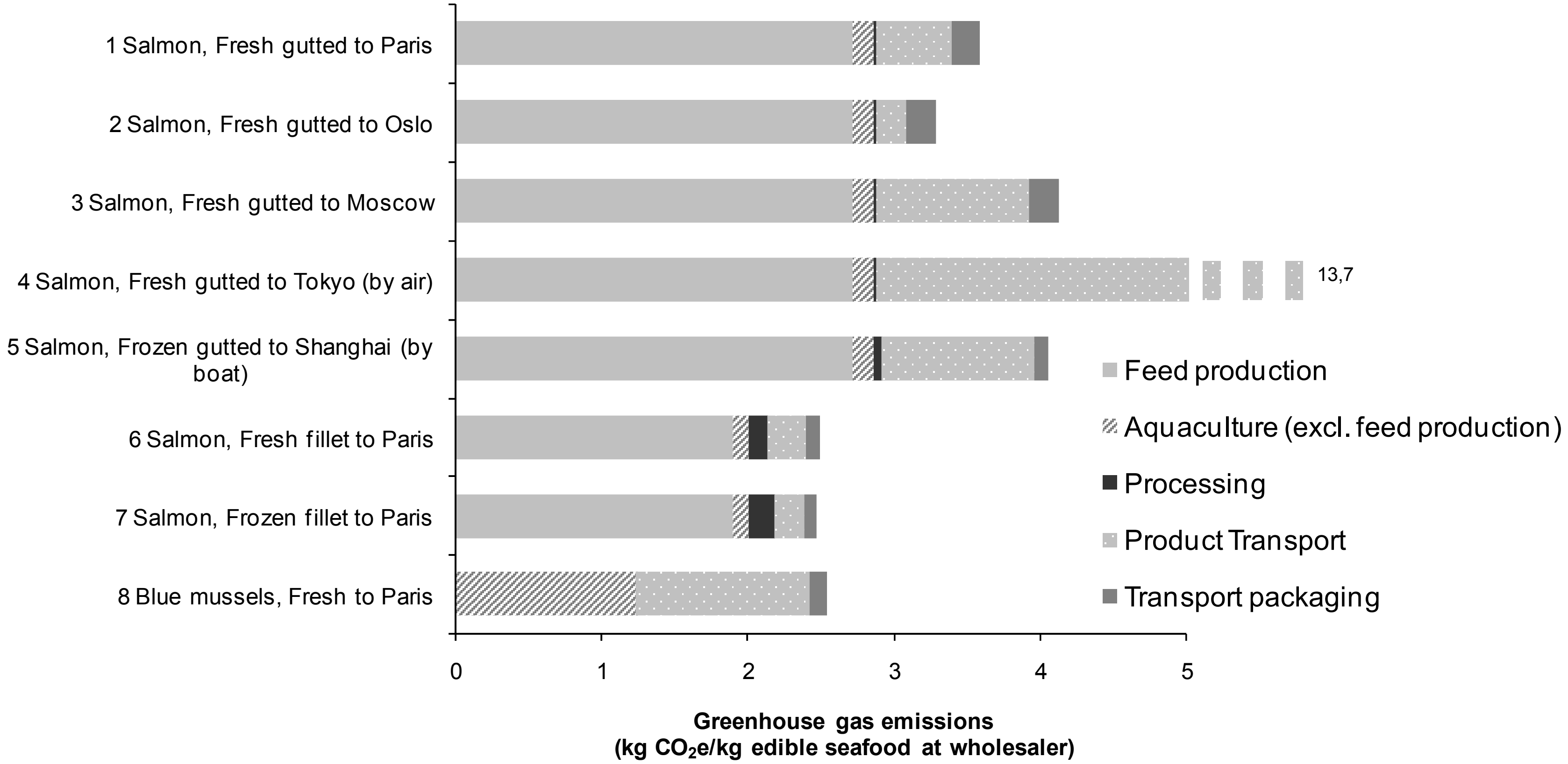

Figure 5.19 Overall results for Greenhouse gas emissions for products from aquaculture showing contribution of different life cycle phases. Note that chain 4 goes over axis.

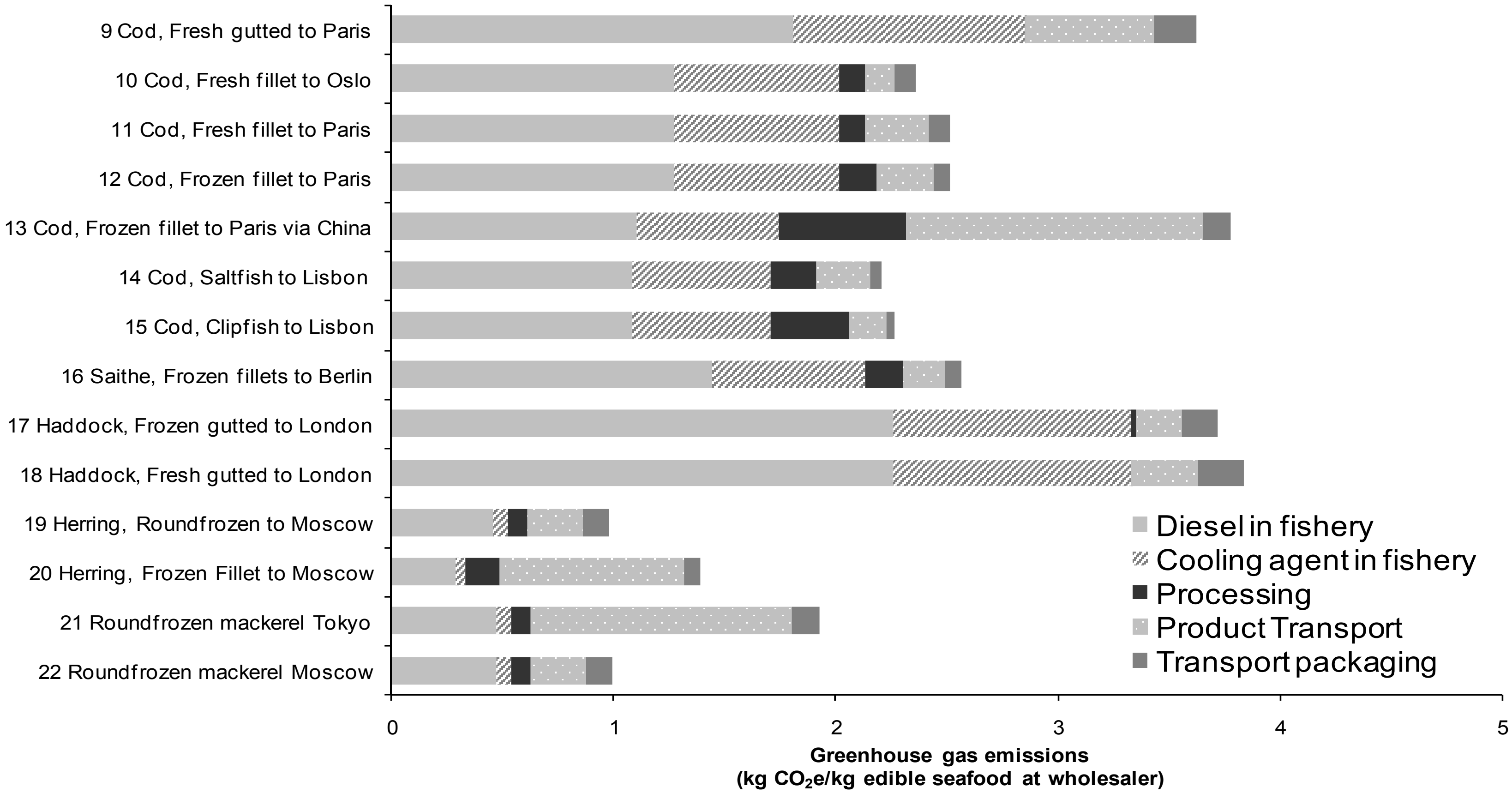

Figure 5.20 Overall results for Greenhouse gas emissions for products from capture fisheries showing contributions of different life cycle phases

5.9 Sensitivity analysis

In the inventory and modelling of the chains several important assumptions had to be done. The quality of these assumptions depend on the data we have been able to find. Their influence on the over all results are some times high. This sensitivity analysis points at some of the most important parameters – important in terms of influence on over all result - and illustrates their importance by applying different assumptions on example chains. E. g. the importance of yield from gutted to cod to edible product is illustrated by calculating chain 12 (frozen cod filet to Paris by semitrailer) with two different yields: 62% and 70%. Table 5.3 presents a summary of the sensitivity analysis that are performed. In the following the different sensitivity analysis in Table 5.3 are referred to by a number in brackets.

Economic allocation for cod and salmon was done by collecting data about the relative value of the various co-products generated in the production of feed inputs, the landing value of different species landed and in the processing phase. The data for this purpose were obtained from feed producers, the Norwegian Directorate of Fisheries and seafood processing plants. Economic allocation places higher burden on the higher value species cod and haddock vs. saithe and considerably higher burden on the fillet compared to the by-products skin, head and bones.

In feed production the values are surprisingly similar to mass allocation, i.e. there were no major differences in prices between the feed components produced jointly. Results of sensitivity analysis (Table 5.3) show that the choice of the allocation method (4.) has a significant influence on the overall results and should therefore **only** be compared to results achieved using the same methodology. The choice of allocation method also results in the great importance of by-product use (5.).

Product waste, i.e. loss of product along the supply chain, is an area where we failed to find data, but which has some impact on the final result (2.), directly proportional to the amount of product wasted. The choice of the electricity mix (1.) has some effect, especially in the chains that have a relatively large proportional contribution of processing either due to high energy use in processing (clipfish) or to high efficiency in other phases (frozen herring fillets). An increase in edible yield for cod represents an improvement option in a situation where by-products are not used or only used to some extent (as in the case included here) (3.).

With regard to the salmon feed, a lower amount used to produce one unit of fish (6.), lower proportion of marine inputs in the feed (7.) and choosing the most efficient marine inputs (8.) each leads to improvements, especially the latter. No evaluation whether Anchoveta stocks would sustain such an increased use is done. And the mussel supply chain can be improved considerably by optimisation (9.).

Replacing the refrigerants to completely ozone and climate neutral ones represents a major improvement option in capture fisheries, especially in the demersal fisheries (10.), and can decrease the carbon footprint by almost 30%.

Table 5.3 Aspects studied in the sensitivity analysis including results and improvement potentials. Table goes over two pages.

Change	Chain	Carbon footprint (kg CO_2e/kg edible part at wholesaler)	Change compared to Base case
1. ELECTRICITY MIX			
Replace Nordic electricity by Norwegian	Chain19	0.907	-7 %
Base case (Nordic)	Chain 19	0.977	-
2. PRODUCT WASTE			
a) Product waste in processing 2 %	Chain 7	2.51	+1.6 %
b) Product waste in processing 2 % and at wholesaler 5 %	Chain 7	2.59	+4.9 %
Base case (0 % product waste)	Chain 7	2.47	-
3. EDIBLE YIELD			
Increased cod yield 70 % from HG cod	Chain 12	2.37	-5.6 %
Base case (62 %)	Chain 12	2.51	-
4. ALLOCATION			
a) Economic allocation cod	Chain 12	3.50	+39 %
Base case (mass allocation)	Chain 12	2.51	-
b) Economic allocation salmon	Chain 7	4.35	+76 %
Base case (mass allocation)	Chain 7	2.47	-
5. BY-PRODUCT USE			
a) Cod by-products used abroad as in Norway	Chains 9 vs. 12	2.66 vs. 2.51	-
b) Cod by-products fully used both abroad and in Norway	Chains 9 vs. 12	1.97 vs. 1.87	-
c) Cod by-products not used at all	Chains 9 vs. 12	3.62 vs. 3.36	-
Base case (not used abroad, used partially in Norway)	Chains 9 vs. 12	3.62 vs. 2.51	-
a) Salmon by-products fully used both abroad and in Norway	Chains 1vs.7	2.52 vs. 2.47	-
b) Salmon by-products not used at all	Chains 1vs.7	3.59 vs. 4.96	-
Base case (not used abroad, used fully in Norway)	Chains 1vs.7	3.59 vs. 2.47	-

6. FCR			
Feed Conversion Ratio=1.0	Chain 7	2.16	-13 %
Base case (FCR=1.2)	Chain 7	2.47	-
7. MARINE FEED			
Only 30 % marine inputs	Chain 7	2.25	-9 %
Base case (60 %)	Chain 7	2.47	-
8. MARINE SPECIES			
Only Anchoveta used as marine input	Chain 7	1.69	-32 %
Base case (28 % of fish oil and fish meal)	Chain 7	2.47	-
9. OPTIMAL MUSSEL			
Optimised mussel chain (lower waste at harvest, lower fuel use, use of by-products)	Chain 8	1.67	-44 %
Base case (high waste, high diesel use and no use of by-products)	Chain 8	2.54	-
10. REFRIGERANTS			
Only climate neutral refrigerants	Chain 12	1.85	-26 %
Base case (use of R22)	Chain 12	2.51	-

5.10 Comparison with competing products

The carbon footprint of the fish and meat products at the point of landing/slaughter is shown in Table 5.4. The meat production is modelled by recent (2005) data for Swedish production (Cederberg et al. 2009). There is reason to believe that emissions of European production are very likely higher, see Table 5.5. The reason to choose the Swedish data in the comparison was that these could be modified with regard to methodological choices such as system boundaries and method for co-product allocation.

Since one of the aims of the current study were to compare Norwegian seafood products with land-based meat products competing with Norwegian seafood products on the market, using data for Swedish meat production to represent European production in this comparison will not favour seafood products in any way, rather underestimate the true impact of European meat products.

Table 5.4 Carbon footprint and energy results for meat and seafood at the landing/slaughter site (no use of by-products)

Species	Carbon footprint (kg CO_2e/kg edible part at slaughter/landing)	Energy use (MJe/kg edible part at slaughter/landing)	Reference
Beef, Swedish	30	79	Cederberg et al. 2009
Pork, Swedish	5.9	41	Cederberg et al. 2009
Chicken, Swedish	2.7	29	Cederberg et al. 2009
Salmon	2.9	40	Current study
Cod	2.9	27	Current study
Haddock	3.3	34	Current study
Mackerel	0.54	7.1	Current study
Herring	0.52	6.8	Current study

Table 5.5 Carbon footprint (per kilo of carcass weight) for European meat production using a different methodology (I/O analysis) and for Swedish meat production using the same methodology as in the current study.

Species	European production (Weidema et al. 2008) (kg CO_2e/kg carcass weight)	Swedish production (Cederberg et al. 2009) (kg CO_2e/kg carcass weight)
Beef	29	20
Pork	11	3.5
Chicken	3.6	2.1

In order to compare the full chains, it was assumed that this meat production took place in France, so the electricity used at the slaughter plant was replaced by a French grid mix and a truck transport was added to take the products to Paris.

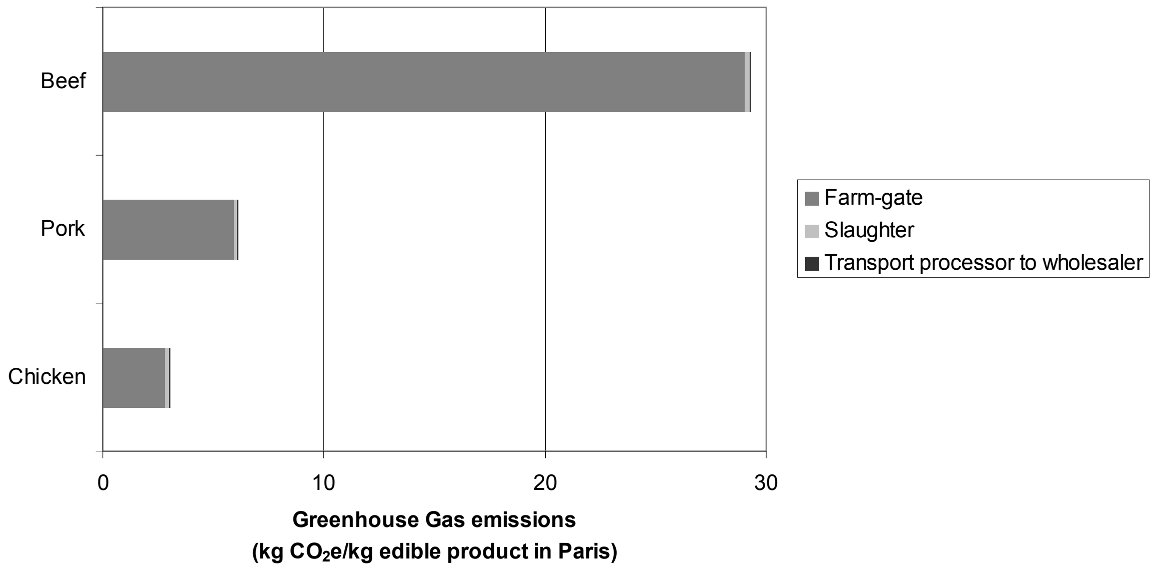

Figure 5.21 Meat products trucked to Paris

6 Discussion

6.1 Overall discussion of results

In the supply chains starting from capture fisheries, diesel and refrigerant use in fishing were in most cases the two most important contributors to the total carbon footprint, with diesel use representing between 20-60 % and refrigerants 3-29 % of total results. Diesel use in fishing has in most seafood LCAs been identified as the single most important input (Thrane 2004a,b; Ziegler et al. 2003, Hospido and Tyedmers 2005, Ziegler and Valentinsson 2008, Ziegler et al. 2009), but the importance of the refrigerant use has not been documented in the same way. Thrane (2004b) has tried to estimate it using relatively coarse data. This seems to be a data gap in previous studies, since there is not much reason to believe that this is a problem only in Norway.

Despite being the most important input, the diesel use in the fisheries studied is relatively low (0.091-0.30 l/kg round weight) compared to other data, certainly well under the global average of 0.62 l/kg fish landed (Tyedmers et al. 2005). In addition, at least concerning demersal species, it is lower than values found in Thrane (2004b), Tyedmers (2001), lower than the 0.65 l/kg fish found in an LCA of Icelandic cod products (Eyjólfsdóttir et al. 2003) and even lower than a very recent analysis of Norwegian fisheries (Schau et al 2009), who found a fuel use in Norwegian cod fisheries of 0.35 kg fuel or 0.41 l fuel/kg fish compared to the 0.24 l fuel /kg cod found in this study (Table 4.4). The reason for the discrepancy to the latter is that Schau et al. based their analysis completely on data from the profitability survey, in which, as has been described previously in this report, the smaller vessels deploying passive gear types are underrepresented. In our analysis we paired the gear-specific results from the profitability study for 2007 with the total distribution on different gear types and believe that this represents Norwegian fisheries in a better way.

However, even when one compares only gear specific fuel factors from the profitability data for the period 2001-2004 with the same data for 2007, the fuel use is somewhat lower which can be an effect of several elements including: Higher fuel prices leading to a more fuel-saving behaviour, improved stock status with higher catches per effort or higher quotas and and regulatory schemes to decrease unprofitable over capacity in the Norwegian fishing fleet. From 2002 to 2007 the number of Norwegian fishing vessels decreased from 2206 to 1709. During the same period, income from Norwegian fisheries increased by 2% while the total landings of demersal species increased by 6% and landings of pelagic species decreased by 20%, the decrease in pelagic fisheries was mainly due to lower landings of blue whiting, which is an energy intensive fishery. The landings of Norwegian spring spawning herring have increased. To conclude, more fish is fished today by fewer boats and this has increased the over all energy efficiency.

The relatively high fuel efficiency in the fisheries included here is hence probably explained by a combination of relatively well-managed stocks (Pitcher et al. 2009) and a large proportion being landed by relatively resource-efficient fishing methods (more discussion of this in section 5.1).

However, considerable options for improvements do exist e.g. by replacing R22 refrigerants (and other HCFC refrigerants) and by increasing the part of the landings caught by resource-efficient fishing methods further, as well as taking carbon footprint and energy efficiency into account in the design of the fisheries management systems of the future.

Considering the role of activities after landing or slaughter of the fish, processing and packaging were shown to be of minor importance. Processing contributes most to the carbon footprint when either the energy use is large (e.g. clipfish) or the resource use for other parts of the supply chains is relatively low (e.g. herring fillets) or when the energy used has a high climate impact (e.g. processing using Chinese electricity).

Processing before export is positive due to a better potential for using by-products and the use of less climate-impacting energy sources. Moreover, the transportation of excess mass of fish head, skin and bones and packaging can in this way be avoided. Interestingly, the traditional products saltfish and clipfish had a relatively low carbon footprint. This was due to the fact that the edible yield per amount of fish was high and that the product contains salt. Transportation of these products is more efficient since they contain less water.

Packaging likewise becomes most important when the rest of the chains are relatively efficient and the polystyrene boxes (used for fresh fish) are more resource-intensive than cardboard boxes (used for frozen fish). Since the same amount of packaging is needed irrespective of the distance transported, packaging becomes most important when the distance transported is short (the chains ending up in Oslo).

With regard to transportation from processing to the wholesaler it can be concluded that, although typically representing around 5-15 % of the total carbon footprint, exceptions where this transport contributes more can be found. This occurs either when resource-demanding means of transport are used in intercontinental transports (e.g. fresh salmon to Japan by air) or when very long distances are involved (cod taken to China on containers for processing and frozen mackerel to Japan) or when the other parts of the supply chain are relatively efficient (herring fillets to Russia).

With regard to seafood transportation, transport distance and mode are two important factors. However, speed, the amount of load per pallet or truck for each product and transportation time for goods requiring refrigeration are likewise important factors and make climate impact calculations of transports more complex . In addition, the product form sometimes determines which transport modes are possible to use. Frozen and super-cooled fish can be transported slower, i.e. by boat instead of air or by train instead of truck, even over very long distances, due to their longer shelf-life resulting in much lower resource use for transportation.

In general it seems that the Norwegian seafood products studied here are relatively efficient in terms of carbon footprint and energy use, not only compared to literature data for other seafood products, but also compared to European production of meat products. This is due to the fact that fish are cold-blooded animals that require less intake of energy per unit of meat produced to maintain body temperature than do warm-blooded animals. Fish farming is therefore a relatively efficient energy converter, at least compared to meat production on land, due to the important metabolic difference between animals described above. Farmed salmon, despite being a top predator, hence requires less input of feed compared to land-based animal rearing. Considering the great importance of the feed in the results, it is not very surprising that salmon and especially mussels can be produced at lower environmental costs than meat products, it would be surprising if it was otherwise.

6.2 The role of post-wholesaler activities

The supply chains in this study were followed only to the wholesaler. While fishing and fish farming have been shown to be the most important life cycle phases of seafood products (Thrane 2004a,b, Ziegler et al. 2003), post-wholesaler activities are far from unimportant. Rather they were excluded mainly due to difficulties in obtaining data for these activities from all the countries included. Therefore we will briefly discuss important aspects of the activities after the wholesaler. A number of factors come into play in the supply chain after the wholesaler. Generally it can be said that these steps are more diverse and variable and there is much more uncertainty involved than in earlier steps.

Due to the great importance of the early life cycle phases (fishing and feed production), perhaps the most important aspect in the chain from the wholesaler to the consumer is product yield. By yield we mean the amount of edible product actually reaching the consumer and not being wasted on the way through a) suboptimal filleting yield or b) product being wasted at some stage. With regard to the former it can be said that generally manual filleting gives a higher product yield than automated and that large-scale processing (filleting of one species in a processing plant) probably gives higher yield than small scale (filleting of many different types of fish at a wholesaler or retailer) and that the potential to make use of the by-products in some way are better in large-scale facilities.

Seafood transports from wholesalers to retailers are much shorter than the pre-wholesaler transport, but they may be done with smaller vehicles that have higher emissions per tonne*km. Moreover, they may not be using the full load capacity of the vehicle. These two factors can make a distribution transport almost as resource intensive as airfreight per tonne*km.

At the wholesaler and retailer, in addition to the important choice of which seafood to sell, maintaining the quality, avoiding product loss and maximising yield, energy efficiency of storages and counters as well as type and amount of refrigerants refilled all matters. Losses of fresh fish at the retailer can be up to 3-4 % and are much lower for frozen fish that has a much longer shelf-life. It is a great challenge for the links involved in fresh seafood chains, to minimise losses in order to improve the environmental efficiency.

The most important measure a seafood consumer can do to is probably to choose the types of seafood that have been produced in a resource-efficient way. Other things that matter that are directly affected by consumer behaviour are the way the seafood is taken from the store to the household. If the transport home of food purchases is done by car, it is often the most important transport involved in the chain and not seldom the second most important activity after fishing/farming (Thrane 2004a, Ziegler et al. 2003, Ziegler & Valentinsson 2008). The amount of goods transported is small compared to the fuel use of a car, but there are no good statistics on the distances driven to supermarkets and amounts bought at one occasion and therefore many of these calculations are based on assumptions. Without question marks, however, is the fact that the home transport can be an environmental hot spot.

Storage and preparation of the products in the household is the next and final phase to be discussed here. Energy use of fridges and freezers and storage time are important factors as are the mode of preparation, i.e. whether the stove, oven or microwave are used to prepare the dish. Microwave preparation uses least energy, oven preparation most. Of course, wastage of edible product both during preparation and discarding leftovers are important issues also in this phase. We would assume that losses of fresh fish are higher before preparation than those of frozen fish, just like in the earlier phases. Frozen fish is sometimes thawed in the microwave before preparation and this adds some energy use to the total picture. Some products like pickled herring, boiled crayfish or smoked salmon, have had higher energy use in the processing phase but need no preparation in the household.

To conclude this section, the post-wholesaler supply chain of seafood products is highly variable and there is a number of factors of importance for the environmental impact of these phases, many of which we do not know much about currently.

6.3 Methodological aspects

The functional unit and allocation method chosen is supposed to reflect the function of the product (ISO 2006 a, b) and the function in this case is providing food. While food certainly has many functions fulfilling various nutritional as well as other needs, we believe that a weight unit of edible meat is a good basis to compare different high-protein food items such as seafood and meat products. An alternative could have been to choose an amount of protein, but we believe that it is unlikely that people eat less of a meat type with high protein content and more of one with a lower protein content. Therefore, we chose a mass-based functional unit. It is important to know, though, that in this way, we make no difference between e.g. cod mince and loins.

It was shown that the allocation method had a significant impact on the results, as expected, and therefore the results should be used with caution and **only** be compared with other studies using the same method. The results for the supply chains studied would have been higher if economic allocation would have been used throughout the study. The absolute values would have been higher, but we are confident that the climate hotspots would have been the same. However, the results would have been less stable and more difficult to update had economic allocation been used throughout. The main disadvantage of the chosen allocation methodology is the great importance of the use (or non-use) of by-products and the lack of data that we found regarding this matter outside Norway. Therefore, we still would recommend the development of an allocation methodology that takes into account what the by-products are used for as well as improved data availability regarding by-product use (e.g. a requirement to document how they are used) in the future. A weakness of the methodology is also that in cases when the by-products are fully used, no positive impact of higher edible yield is captured, i.e. it makes no difference whether the fish is used for food or feed, as long as it is used at all. The strength of the methodology (an reason why it was chosen) is that the results will be stable over time and if they are updated with new data to evaluate whether any improvement has occurred, changes will reflect true changes in resource use and not changes in price relationships between co-products.

6.4 Limitation of application of results

It was not a goal of the project to guide seafood consumers in one direction or the other. This is due to the limited production of capture fisheries and the quota-based management system which implies that no matter what consumers do, the same amount of fish will be landed, the only difference is that it is sold on different markets. This is true for many species, although not all. Therefore, recommending consumers to eat more pelagic fish and less demersal fish does not immediately lead to any environmental improvement.

A general increase in demand for seafood is driving the development of the aquaculture sector, i.e. the marginal fish is a farmed one (when more fish is demanded it is aquaculture that grows rather than fisheries due to the limitations in production of capture fisheries). There are some changes in demand that actually can change seafood production, one is increased demand for fish currently used as feed on the consumer market, e.g. if people eat more herring directly rather than making fish meal and oil of it to feed salmon or chicken. The proportion of herring in the marine part of the salmon feed was surprisingly high (30% of fish oil and around 20% of fish meal) and although it is stated that whole herring is only used when there is no market for human consumption, much lower climate impact would result if people would eat more herring and mackerel rather than salmon. Another is increased demand for organic production through eco-labelled seafood products which is currently pushing a rapidly increasing volume of fish from conventional fisheries to certified ones. Although eco-labels are currently most concerned with biological indicators for sustainability, these indicators are often correlated to energy use and climate impact.

It is also important to realize that the results can not be used for statements about an individual product, since we have modelled the “average Norwegian product” for each chain.

6.5 Improvement options

A number of improvement options with regard to carbon footprint/ energy use could be identified whose improvement potential in part was illustrated in the sensitivity analysis, these will just be mentioned here. Other improvement options did not emerge from the data due to its resolution, these will be commented briefly here.

The most immediate measure that would reduce the carbon footprint of the products from demersal fisheries by up to 30 % is replacing the old generation of refrigerants with climate neutral ones. It is of utmost importance to avoid replacing HCFCs with HFCs, since they are only positive from an ozone layer perspective, but they increase the climate impact of refrigerants, given the leakage is the same.

For mussels, considerable optimisation can be done by increasing the proportion of the harvest that can be sold and by using the by-products that are produced. Important is also to improve the fuel efficiency of vessels used in mussel farming.

For salmon the most important improvement options remain decreasing the amount of feed used to produce one unit of fish and optimising the composition of the feed with regard to climate impact. A general improvement option is to export more fish in processed form preferably frozen or super-cooled rather than fresh.

Some improvement options remain hidden in the resolution of the data. Fuel use in fishing is a very important input and it is determined by various factors. In the profitability survey, significant differences in fuel efficiency between different fishing techniques were identified and hence, the more widespread use of the most fuel-efficient fishing methods would be beneficial for the overall fuel efficiency in Norwegian fisheries. In part, the distribution of e.g. cod catches on different fishing methods is fixed since the quota is divided between different gear segments in a fixed way. The fishing method is only one of many aspects regulated in fisheries management that has importance for environmental performance. It would be worthwhile to evaluate the environmental impact of fishing activities that is due to different measures in fisheries management, such as temporal distribution of quotas, regulations affecting selectivity, TAC levels and alternative ways to limit fisheries. Such knowledge would allow for optimisation of the fisheries management system from an environmental perspective, a perspective that has so far not often been taken into account.

This type of work would be facilitated by improved data availability through the introduction of traceability systems in the supply chain for seafood products and energy logging systems in the fishing vessels.

7 Conclusions and outlook

The conclusions from this work include that Norwegian seafood products are competitive from a carbon footprint and energy use perspective, both compared to other seafood products and compared to land-based production of meat products. Important areas to focus on for fisheries are improving the fuel efficiency further and replacing refrigerants with high greenhouse gas emissions used in onboard cooling systems by climate neutral ones. With regard to salmon farming, optimising feed use and feed composition with regard to climate impact are paramount. For mussel farming increased edible yield from harvested mass and increasing by-product use while decreasing fuel use on vessels used for maintenance and harvest are areas to focus on.

General conclusions for all types of products are that increasing the proportion of frozen and super-cooled seafood to fresh, which in turn decreases the need for air freight and other resource-intensive means of transport, would lead to major improvement. Increasing the edible yield and use of by-products would likewise lead to lower emissions and processing more seafood in Norway before export is advantageous because of better possibilities to make use of by-products and decreased need for transportation when exporting products rather than whole fish.

To reach more realistic results, modelling of the products with higher resolution with regard to which fisheries that deliver fish to individual supply chains would be desirable, that would also allow for more detailed recommendations for improvement.

On the long-term, it is desirable to increase the knowledge of the impact of individual measures in fisheries management in order to be able to optimise the management system also from an environmental point of view. Taking carbon footprint and energy efficiency into account in the design of the fisheries management systems of the future would help making seafood production an even more sustainable and less resource-demanding business.

All together, the Norwegian seafood products studied here are on the right way towards sustainability and have many of the essential elements of sustainable production in place already. However, there are many actions both on the short and long term that can improve the situation further and it is very important to deal with these questions in a proactive way if Norway wants to maintain its position as the worlds leading producer of sustainable seafood.

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APPENDIX A: External review

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Final critical review statement

20th of November 2009

By Assoc. Prof. Mikkel Thrane

Project name: Carbon footprint and energy use of Norwegian seafood products.
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Consultants responsible for project: SINTEF Fisheries and Aquaculture (Norway) and SIK – The Swedish Institute for Food and biotechnology (Sweden)
Project manager: Ulf Winther (SINTEF)
Commisioners/clients: The Norwegian Seafood Federation (FHL) and The Norwegian Fishermens association, funded by the Fishery and Aquaculture Industry Research Fund (FHF).

The following document includes a final external critical review of the report 'Carbon footprint and energy use of Norwegian seafood products' referred to as the parent study in the following. The review was conducted by Associate Professor Mikkel Thrane, Department of Development and Planning, Aalborg University (thrane@plan.aau.dk).

It has been chosen to conduct an integrated review, which provides the opportunity to address and correct problems at an early phase. The following review is the last review in this process, and therefore relatively short as most methodological issues have been discussed and adjusted during the process. It should be stressed that objective criteria for LCA reviews do not exist in all areas, but some choices are more justifiable than others. Hence, any review according to the standard will include subjective judgements based on professional experience. In this regard, it should be no secret, that the reviewer prefers consequential modelling in LCA studies. The authors have stressed that the applied modelling approach is attributional which is widely used in the LCA community, and the parent study is therefore reviewed in this perspective.

The parent study is considered to be in accordance with the ISO 14040 and 14044 standards. As any LCA, the study is based on a number of choices and assumptions that obviously have influenced the outcome. It is particularly important to be aware that the parent study has applied mass allocation for the production of feed inputs used in fish farming (i.e. mass allocation between fish meal and fish oil), in the fishing stage (between different types of fish that are landed), and for fish processing (between fish filets and different types of fish by-products used for other purposes). Acknowledging that it has been practically impossible to apply system expansion for co-product allocation for the fishing stage, it is still the reviewer's opinion that system expansion could have been used for the processing of feed inputs to fish farming as well as for the fish processing stage. This would provide a more accurate modelling of the causal relationships and would allow distinguishing between different uses of the co-products (i.e. difference between using fish waste to food, feed and other purposes). Alternatively, economic allocation could have been used, despite the challenges with varying prices – e.g. by using average prices over longer periods of time. Both system expansion and economic allocation would provide a more accurate modelling of the causal relationships according to the reviewer's opinion. However, the authors should be credited for including economic allocation in the sensitivity analysis, and for providing an overview of how the different methodological choices e.g. the choice of co-product allocation method, have influenced the results. The authors should also be credited for a detailed and transparent study that is reproducible. Finally, it is excellent that the parent study includes a section about how the results should and could be used – including a discussion of the limitations in relation to guiding consumer decisions, due to quota regulations.

In conclusion, the reviewer is content with the scientific level of the study, despite of minor shortcomings. Most important of all, the study is transparent and the conclusions reflect the obtained results as well as the results of the sensitivity analysis.

APPENDIX B: Allocation rationale

This appendix was produced in order to explain how the project group arrived at the conclusion of using mass allocation as the main method of allocation.

1. Background

International standards have a somewhat different recommendation order of various methods, see table 1.

Table 1 Order of recommendation of allocation methods in the ISO and PAS standards

	ISO	PAS 2050
1	Avoid allocation*	Avoid allocation*
2	System expansion	System expansion
3	Physical relationship	Economic allocation
4	Other relationship	-
*i.e. split up resource use between the co-products		

In seafood production, three main allocation situations arise: 1) when fisheries land several species together, 2) when processing of agricultural or marine feed inputs gives rise to several feed ingredients and 3) when seafood is processed into products. In the initial discussion about allocation during the first working group meeting in Trondheim in October 2008, seven different strategies for dealing with co-product allocation were identified:

1. Mass allocation: Dividing resource use according to the mass of the co-products
2. Economic allocation: Dividing resource use according the proportion of the value of total production
3. Mass allocation applying factor for by-product use. Like mass allocation but weighting food co-products with a factor 1, feed co-products with a factor 0.5 and energy co-products with a factor 0.25 (or making system expansion). The factors could also be based on the translation into human food MJs, i.e. the lower the level of use of co-products , the lower the impact (i.e. resembles economic allocation).
4. Do several of the above (at least for some products)
5. Inverse economic allocation or inverse 3. Gives higher impact when co-products are used on a low level.
6. Economic allocation using new data in old model when updates are done (to avoid variation in value to be causing difference in environmental impact).
7. Energy allocation: Dividing resource use according to the content of energy of the co-products

Avoiding allocation and system expansion was decided not to be possible or feasible options. Avoiding since the co-products are produced simultaneously using the same resources, hence one resource cannot be attributed to only one product.

System expansion was considered to require too many choices of what type of production is replaced by the co-products and this would introduce additional uncertainty and variation over time into the models. Fish feed composition e.g. varies a lot over time and feed components with certain nutritional characteristics are sourced wherever they are cheapest that week or month. So say e.g. that the environmental impact of rape seed oil vs. rape seed meal is estimated by assuming that the rape seed oil replaces the same amount of fish oil or sunflower oil of a certain origin. Primarily, there is variation between sunflower oil production in different regions.The choice of replacing the rape seed oil with sunflower oil or fish oil will have a tremendous effect on the results for rape seed meal. It must be ensured that the data used for fish or sunflower oil (and that the region of production is the right one!) are calculated using the same methodology (allocation principle, system boundaries etc.), which is often not the case. If the additional system is included in the study, this takes resources from the initial inventory/analysis. In theory, the use of system expansion, creates an endless loop of system expansions backwards in the system (replacing rape seed oil with sunflower oil where there is a similar situation with two co-products and it can be questioned which one is the main and which one is the by-product) and the effects of doing or not doing so are very difficult to understand both for the expert and for laymen.

Sometimes it is actually impossible to identify a product that replaces the by-product fully, e.g. the high-value feed component beet pulp. In addition, in some special cases, such as the use of by-products from fish processing in feeds, they replace the use of fish meals and oils from dedicated feed fish fisheries but this does not lead to lower levels of feed fish being caught. The decisions about how much fish are to be harvested are not market based, the quota or effort or whatever limits the fishery is a political decision. Moreover, in the allocation of the landing of several fish species it was considered impossible to use system expansion since there are no fisheries only landing one species at a time.

Hence, we decided that some way of allocating the environmental load between co-products had to be chosen. The purpose of this choice is 1) to achieve best possible comparability between the products included in the study and 2) to be able to identify improvement options. From our joint extensive experience in the field of LCA, we are aware that each allocation method has its specific advantages and drawbacks, depending on the perspective that is taken and the goal of the study. An overview of these is provided in Table 2.

Table 2 Overview over advantages and drawbacks of different allocation methods as well as impact from a main and a by-product perspective

Allocation method	Advantages	Drawbacks	Main product perspective	Co-product perspective
Avoiding allocation	Represents the only true division of resource use between co-products	In many cases impossible since there is no way to separate the products from each other	The only correct reflection of environmental load between main and by-product	The only correct reflection of environmental load between main and by-product
System expansion	In situations where it is very clear that a by-product replaces production of something else, and there are good, comparable data for that system, the method makes it possible to avoid allocation without the drawbacks mentioned to the right	The choice of what replaces the by-product has a big impact on the result. Market changes lead to changes in environmental impact without actual change in resource use (similar to economic allocation) When data from other studies are used for system expansion, this introduces uncertainty as to data quality and methodology, when data comes from the same study the inventory work increases or less effort can be placed on the inventory of the original system to be studied. In some cases there simply is no good replacement of the co-product (beet pulp e.g.)	Completely dependant on the choice of what the by-product replaces and the data used in the calculations. In truth there is variation both in the type of product that replaces the by-product and in the type of production/origin (there is a range around different types of rape seed oil e.g.)	Completely dependant on the choice of what the by-product replaces and the data used in the calculations. In truth there is variation both in the type of product that replaces the by-product and in the type of production/origin (there is a range around different types of rape seed oil e.g.)
Mass	Simple and stable over time given the same technology is used, independent of economic valuation	Sharp line between use/non-use of by-products and all use is equal Product yield makes no difference if by-products are used. Does not reflect driving force behind production.	Low load on main product Positive to use by-products (decreases load if main product considerably)	Large load on by-products Negative for those using by-products of intensive human food production systems compared to efficient feed production systems

Economic value	May better reflect driving force behind production than mass and energy	Requires representative data on economic value, these data introduce additional uncertainty and variation over time. Market changes lead to changes in environmental impact without actual change in resource use. Landing value of fish is not market-based since quotas drive production and fisheries are subsidized	Large load on main product Does not create much incentive to use by-products, increasing value of by-products means lower load on main product	Low load on by-products (but not necessarily lower than dedicated feed production) Relatively positive to use them, increased value of by-products increases the load on them
Economic margin	Reflects the driving force behind the production*	Requires representative data on economic margin (very difficult to obtain)	Normally the largest load will be placed on the main product Increased value/profitability of by-products very positive for the main product	Normally (but not always!) a lower load on by-products Increased value/profitability of by-products increases the load put on them
Energy content	Stable over time, may better reflect drivers behind production than mass in some cases (e.g. in reduction of fish) Providing energy is one of the main functions of food systems.	Data collection- energy content of all by-products is not readily available (and varies!) Sometimes energy content of by-products exceeds main product (cod/cod guts) Energy content is not always the main function of a co-product	Similar load on main product as in mass allocation, may be both lower and higher depending on the energy content of by-products relative to main product	Similar load on by-products as in mass allocation, may be both lower and higher depending on the energy content of by-products relative to main product
Mass, by-products graded**	Simple, takes into account the way by-products are used, i.e. combines advantages of mass and economic allocation	Introduces a subjective valuation of by-product use which has a great impact on results	Large load on main product Creates incentives for using by-products on a higher level (i.e. food rather than feed rather than energy)	Low load on by-products Larger load when by-products are used on higher level

Mass, food energy adjusted***	Combines advantages of mass and economic allocation, and does not contain subjective valuation like Mass, by-products graded	Requires extensive development of factors to translate by-products into food energy equivalents in various systems	Large load on main product Creates incentives for using by-products on a higher level (i.e. food rather than feed rather than energy)	Low load on by-products Larger load when by-products are used on higher level

*although there are exceptions, groundfish fisheries in Norway are e.g. more driven by the quota system than by the economic margin.

**i.e. according to by-product use categories (food, feed, energy…) where lower level use is weighed down compared to higher level by a factor e.g. 0.5 for feed, 0.25 for energy.

***i.e. according to by-products translated into human available food energy, i.e. food by-products receive a greater share than do feed or energy by-products since the latter result in less human available food energy. For by-products used for energy, system expansion may be a feasible option.

2. Initial choice

The initial choice of the project group was Mass, food energy adjusted due to its advantages. At that time though, we were unaware of its drawbacks... After having spent some time internally in our organisations discussing and trying to make the approach more concrete by developing the factors that would be used for weighting of by-products, we had to take a step back and conclude that the development of that method, as interesting as it would be, is a task that is too big within the framework of the project and would also introduce a risk, since it is completely new and untested. Based on the difficulties presented below, we therefore postpone the development of this idea to a later project comprising methodological development.

Table 3 Examples of by-products that occur in fishing, farming, feed and food processing, with typical or actual use and conversion factor into human accessible energy (human accessible energy in by-product relative to main product)

Type of activity	Activity	By-product	Use (typical or real)	Conversion factor (human accessible energy ratio)
Farming	Corn farming	Corn gluten	Salmon feed	1
		Corn starch	Salmon feed	1
	Wheat farming	Wheat gluten	Salmon feed	1
		Wheat	Salmon feed	1
	Wheat farming	Wheat gluten	Food	1
		Wheat	Food	1
	Wheat farming	Wheat gluten	Salmon feed	<1*
		Wheat	Food	1
	Wheat farming	Wheat gluten	Food	1
		Wheat	Cod feed	<<1*
Feed processing	Anchoveta reduction	Anchoveta oil	Feed	
	Anchoveta reduction	Anchoveta meal	Feed	
Fishing (not really a case since either all is used for food-or discarded- or all for feed…)	Bottom trawling	Cod	Food	1
	Bottom trawling	Saithe	Food	1
	Bottom trawling	Unwanted species	Feed (in theory)	<1
Fish processing	Cod filletting	Fillets	Food	1
	Cod filletting	Mince	Food	1
	Cod filletting	Head, skin, bones	Feed	<1
*based on feed conversion of salmon/cod of wheat gluten energy into salmon energy… (% of feed per same % of salmon…as if you could produce the fish with only wheat gluten?)				

Problems identified in this process:

1. Depends on activity, use of main product and use of by-product (generally-feed- and specifically- salmon or chicken feed?)
2. Better to produce feed by-products when feed is the main product than when it is food (wheat e.g.)!?
3. Not always obvious what is the main product!
4. Food gets high impact, energy low (because it converts into few human accessible MJe), makes sense from a main product perspective (should use by-products at highest possible level), but not from a by-product perspective (by-product gets away with less impact if used for energy than for food). Argument similar for economic allocation (difference that more stable and less dependant on critical data).
5. How about other areas of by-product use than food production (fuel or energy for other things…)? System expansion?

Going through Table 2 again at the next working meeting in Göteborg in December 2008, we ended up deciding that energy allocation may be a good option as long as by-products have equal or less energy content compared to the main product. Then it would be something in between mass and economic allocation. This was checked for salmon and cod processing and while the energy content of salmon by-products was similar as that of salmon fillet, it was higher for cod by-products than for cod fillet. This fact made us decide on simply using mass allocation, being aware of its drawbacks and doing either economic allocation or (if that is not possible) mass allocation with by-product graded according to their use for one wild-caught product (cod) and a farmed product (salmon). Still a very important decision that has to be made in each case it whether the by-products are used or not used.

3. Review

The external reviewer recommended after reviewing the Goal and Scope part of the report to consider changing the allocation method to economic allocation. This was discussed over e-mail and a telephone meeting. It was argued (as stated in Table 2) that the value reflected the drivers behind seafood production better than the mass and that, if system expansion was not possible, economic allocation was the second best option. Some time was spent on dicussing what is actually meant by the term "phycial relationship" in the third tier of the standard. The reviewer argued that that meant a way in which inputs and outputs of the system could be varied independently. The project group reacted saying that in that case, that would rather be the first tier: Avoiding allocation. The project group understands the third tier as comprising physical properties such as mass, energy or protein content, properties that reflect parts of the function of the product. Although effort was spent on finding out how ISO views this, no uniform conclusion was drawn (yet). In the end it does not matter for the present project whether the allocation method chosen is tier three (physical relationship) or four (other relationshsip), but the reviewer argued that the only cases of good tier-four allocation so far is economic allocation.

However, due the fact that fish, both salmon and cod, prices have varied extremely much recently (salmon has increased, cod decreased), which makes it difficult to establish a reliable price relationship between main and by-products, the project has chosen to keep economic allocation as the alternative that will be evaluated in the sensitivity analysis. Contributing to this are the facts that a change in the price relationship will lead to a change in environmental impact even though the resource use of the system remains the same and that fish production is not driven only by the landing value. To a large extent it is driven by the quota or other regulating system. The same is true for by-products from resource-intensive production systems which by using economic allocation or system expansion are given very low environmental load while contributing to the profitability of these systems and making it possible for them to operate on a larger scale or for longer time that what would have been the case otherwise. For all of these reasons we keep mass allocation as our preferred methodology for allocation, but will certainly spend considerable effort in analysing the implications of this choice both theoretically and practically by doing economic allocation in two systems.

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