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Life Cycle Assessment of High-Sea Fish and Salmon Aquaculture

Benedikt Buchspies
Sunnie J. Tölle
Niels Jungbluth

ESU-services Ltd.

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Practical training report

ESU-services Ltd.	Kanzleistrasse 4	CH - 8610 Uster
Rolf Frischknecht	T +41 44 940 61 91	frischknecht@esu-services.ch
Niels Jungbluth	T +41 44 940 61 32	jungbluth@esu-services.ch
Sybille Büsser	T +41 44 940 61 35	buesser@esu-services.ch
Karin Flury	T +41 44 940 61 02	flury@esu-services.ch
René Itten	T +41 44 940 61 38	itten@esu-services.ch
Matthias Stucki	T +41 44 940 67 94	stucki@esu-services.ch
www.esu-services.ch	F +41 44 940 61 94	

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Authors	Benedikt Buchspies, Sunnie Tölle, Niels Jungbluth ESU-services Ltd., fair consulting in sustainability Kanzleistr. 4, CH-8610 Uster jungbluth@esu-services.ch www.esu-services.ch Phone 044 940 61 32, Fax +41 44 940 61 94
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Abstract

The aim of this study is to assess environmental impacts of different fish products sold in Swiss supermarkets. The defined functional unit is one kg of frozen cod, canned mackerel, canned herring or smoked salmon. The former three are caught and processed in Denmark; the latter is farmed and processed in Norway. To evaluate environmental impacts, the ecological scarcity method 2006 and global warming potential 2007 are used. Furthermore, results are compared to several meat products.

When comparing the results with the ecological scarcity method 2006, high sea fish is at the lower end of range for all compared products. Fishing and packaging are main determinant in regard to environmental impacts of high sea fishing. Salomon's environmental impacts are nearly as high as those of veal. Feed production and the nutrient emissions into the sea are quite important for the total environmental impacts. In regard to the global warming potential, fish offers an alternative to meat. Depending on the type of fish, emission per kg of filet range between 3.7 and 6.6 kg CO_2-eq. For farmed salmon indirect dinitrogen monoxide emissions from nutrient emissions need to be considered. Fish cannot be regarded generally as a more environmentally friendly food product than meat, because environmental impacts of different fish products might be quite variable and be even higher than these of meat.

Kurzfassung

Ziel dieser Studie ist es die Umwelteinflüsse verschiedener, in der Schweiz verkaufter, Fischprodukte zu quantifizieren. Die Untersuchten Produkte sind tiefgefrorener Kabeljau, Hering und Makrele in Öl, sowie geräucherter Lachs. Kabeljau, Makrele und Hering werden in Dänemark gefangen und verarbeitet. Der Lachs stammt aus einer norwegischen Aquakultur und wird ebenfalls in Norwegen verarbeitet. Alle Fischprodukte werden dann zu Schweizer Supermärkten transportiert, dort gelagert und verkauft.

Die Umwelteinwirkungen werden anhand der Methode der ökologischen Knappheit 2006 (ecological scarcity 2006) sowie dem Treibhauspotential 2007 (global warming potential 2007) quantifiziert und verglichen. Um die Ergebnisse besser einordnen zu können, werden diese mit verschiedenen Fleischprodukten verglichen.

Die Ergebnisse der Methode der ökologischen Knappheit 2006 zeigen, dass gefangener Fisch vergleichsweise geringe Umwelteinwirkungen verursacht. Der Großteil der Umwelteinwirkungen wird durch den Fang und bei Hering und Makrele durch die Verpackung (Aluminiumdose) verursacht. Im Gegensatz dazu verursacht der gezüchtete Lachs Umwelteinwirkungen, die fast so hoch sind, wie die von Kalbfleisch. Ein Großteil dieser Belastungen stammt aus der Futtermittelherstellung und von Nährstoffemissionen. Betrachtet man das Treibhauspotential, so zeigt sich, dass Fisch eine Alternative zu Fleischprodukten bietet: Die Treibhausgasemissionen der Fischprodukte liegen zwischen 3.7 und 6.6 kg CO_2 Äquivalenten. Ein großer Teil der Emissionen von Fisch aus der Hochseefischerei stammt aus den Dieselmotoren der Fischerboote. Im Falle des gezüchteten Lachs spielen indirekte Treibhausgasemissionen aus emittierten Nährstoffen eine wichtige Rolle. Zusammenfassend kann festgestellt werden, dass Fisch im Vergleich zu Fleischprodukten etwas geringe Mengen an Treibhausgasen verursacht. Jedoch gibt es weitere Faktoren, wie z.B. Überfischung, (Zer-)Störung von Ökosystemen, usw., die bei der Betrachtung der Umwelteinflüsse eine wichtige Rolle spielen. Deshalb kann nicht pauschal darauf geschlossen werden, dass Fisch eine umweltfreundliche Alternative zu Fleisch darstellt.

Acknowledgements

This report has been written during a practical training at ESU-services Ltd.. I owe thanks to Niels Jungbluth for his supervision and helpful guidance and Sunnie Toelle for her previous work on high-sea fishery products. Her work is the basis for the assessment of high-sea fishery products carried out in this report. Furthermore, I thank Friederike Ziegler and Ian Vázquez-Rowe for contributing important data to this report.

Table of Contents

1 Life Cycle Assessment (LCA) Methodology

The life cycle assessment (LCA) – sometimes also called ecobalance – is a method to assess the environmental impacts of a product[1]. The LCA is based on a perspective which includes the whole life cycle. Hence, the environmental impacts of a product are evaluated from cradle to grave, which means from the resource extraction up to the disposal of the product and also the production wastes.

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

A LCA consists of four phases (Fig. 1.1):

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

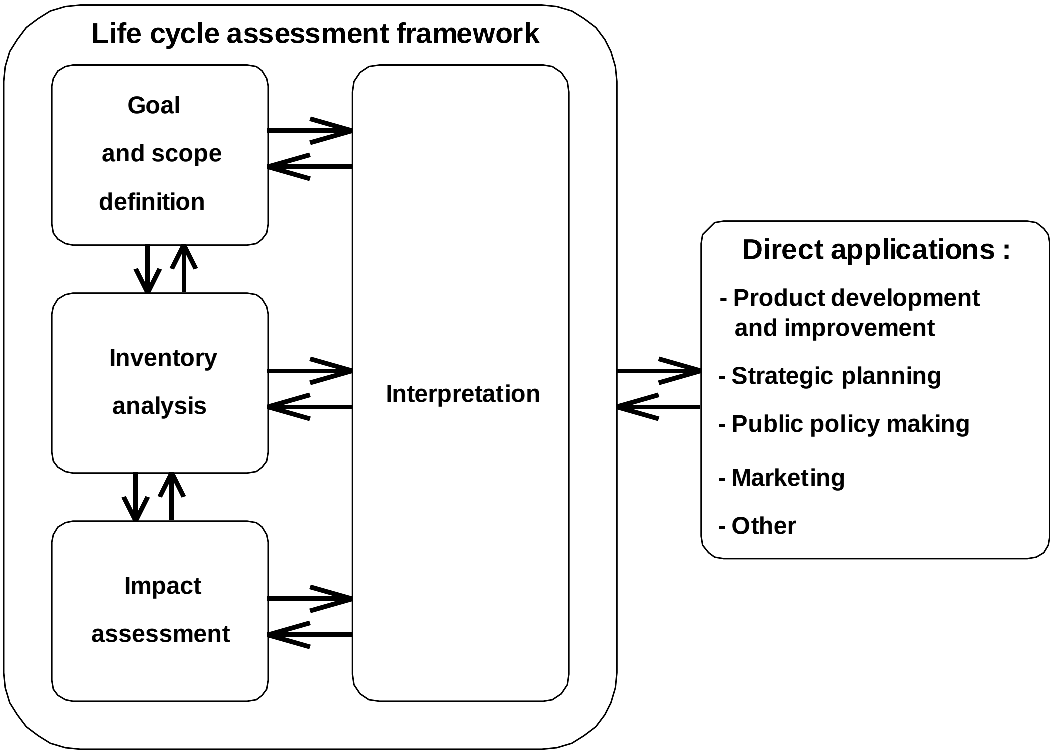

Fig. 1.1 Components of a life cycle assessment (LCA) according to International Organization for Standardization

The *Goal Definition* (phase 1) covers a description of the object of investigation. The environmental aspects to be considered in the interpretation are also defined here. The *Scope Definition* includes the way of modelling the object of investigation, the identification as well as the description of processes of importance towards the object of investigation. The functional unit, which determines a base for comparison, is defined here.

All inputs and outputs, such as direct environmental impacts[2], the required amount of semi-finished products, required auxiliary materials and energy of the processes involved in the life cycle are deter-

[1] The term product also encompasses services

[2] Resource extraction and emission of pollutants

mined and inventoried in the *Inventory Analysis* (phase 2). This data is set in relation to the object of investigation, i.e. the functional unit. The final outcome consists of cumulative resource demands and emissions of pollutants.

The Inventory Analysis provides the basis for the *Impact Assessment* (phase 3). Evaluation methods, e.g. eco-indicator, ecological scarcity or CML are applied to the inventory results. The results of the inventory analysis and the impact assessment are analysed and commented in the *Interpretation* (phase 4) according to the initially defined goal and scope of the LCA. Final conclusions are drawn and recommendations are given.

2 Goal and Scope

2.1 Outline of the Study

Due to the absence of a datasets on fish, its environmental impact has been roughly assumed in previous studies of ESU-services to be similar to that of meat (Jungbluth 2000). However, the activity of raising cattle on a farm is distinctly different from catching fish in the sea or farming fish in aquacultures. Hence, the goal of this study is to quantify the environmental impacts of high-sea fishing and salmon aquaculture, fish processing, transport and distribution to supermarkets across Switzerland. Moreover, this life cycle inventory data completes the ESU-database[3]. Finally, it should be noted that this is an internal study made during the internships of Benedikt Buchspies and Sunnie Tölle at ESU-services Ltd..

In the course of this paper, the following key questions are addressed:

- What emissions are caused by high sea fishing?
- What are the emissions caused by Salmon aquaculture?
- What are the environmental hotspots associated with fishing and aquaculture? How can their environmental impacts be minimized?
- Are the environmental impacts of fish similar to those of meat?

2.2 Functional Unit

In this study it is assumed that codfish is caught in the Northeast Atlantic Ocean by trawl or gillnet vessels whereas mackerel and herring are caught by trawl nets only. Codfish fillets are usually packaged in plastic laminated cardboard boxes and can be bought in the freezer section of supermarkets across Switzerland. Mackerel and herring, on other hand, are canned and do not require any refrigeration. Salmon is raised in net-pen aquacultures, processed and kippered. Usually, smoked Salmon fillet is sliced and packed in plastic. Since the weight of fish per package and the package itself varies according to each product, the functional unit is **one kilogram of fish fillet sold in a Swiss supermarket**.

[3] http://www.esu-services.ch/ourservices/lci/database/

2.3 System Boundaries

Fig. 2.1 and Fig. 2.2 depict the system boundaries and main life cycle stages for high see fishing and for salmon farming.

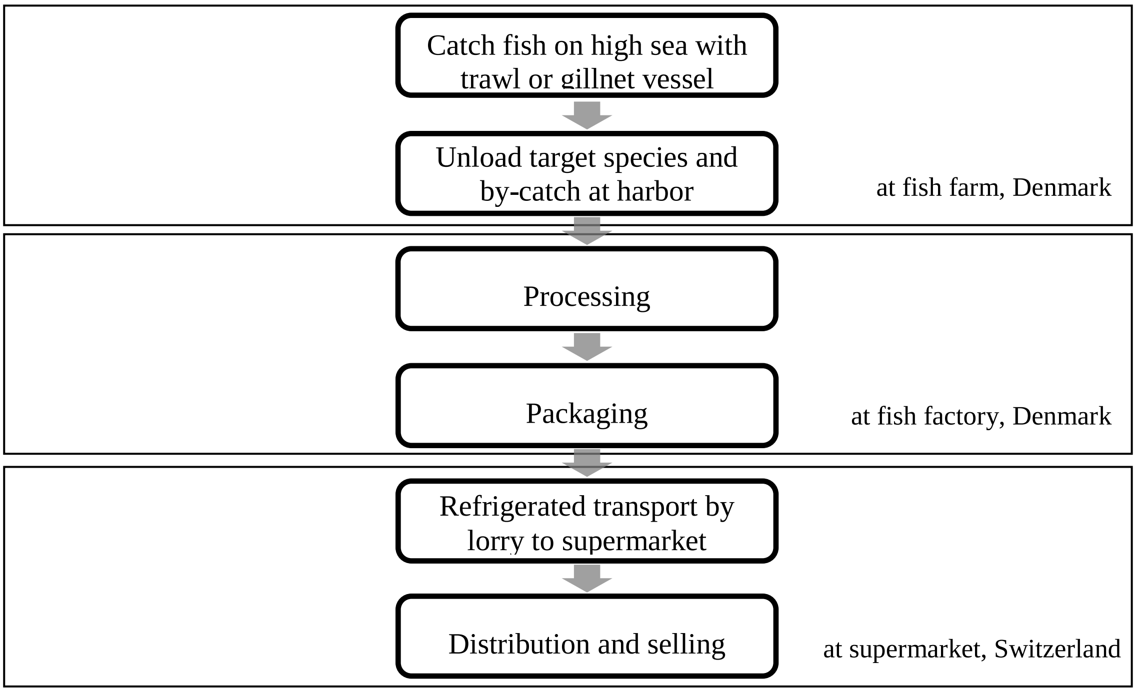

Fig. 2.1 Process chart for the production of packaged fish fillet ready to buy in supermarkets in Switzerland

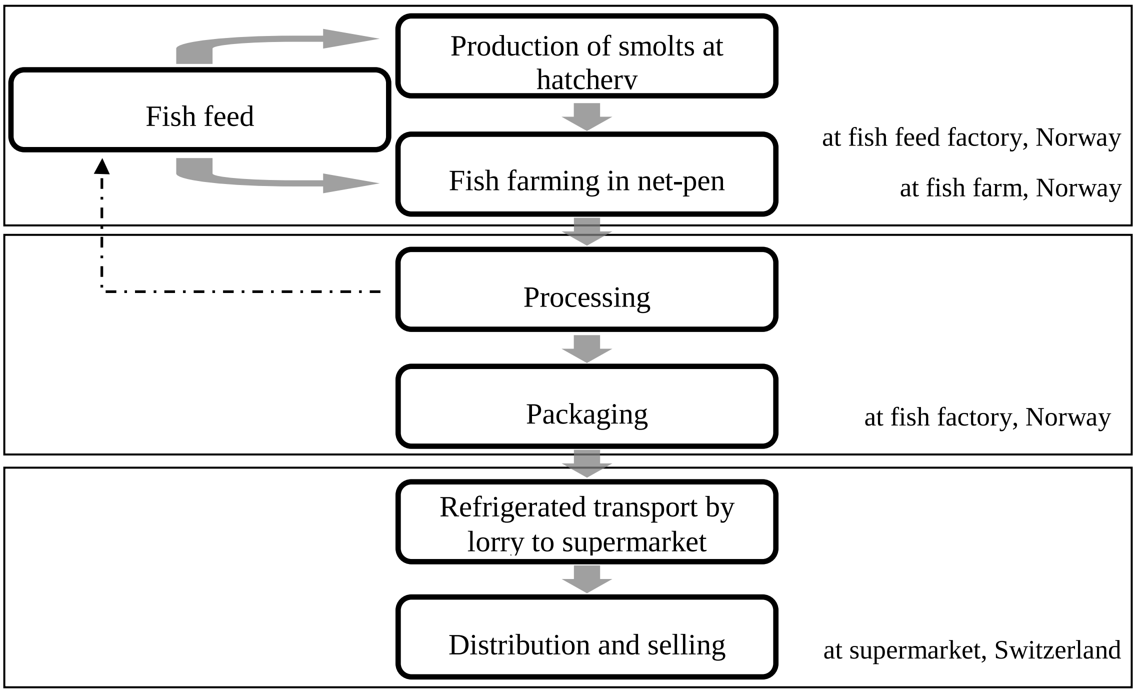

Fig. 2.2 Process chart for the production of smoked salmon ready to buy in supermarkets in Switzerland

2.4 Scenarios Investigated

2.4.1 High sea fish

Although a fishery has normally got one or several target species (i.e. codfish, mackerel or herring) which is the main purpose of the fishing activity, a number of by-catch species are also landed and sold (i.e. flatfish, Norway lobster, shrimp and industrial fish). While the latter are not the main driving force of the fisherman, they do have a commercial value. Thus they should account for some of the environmental impact caused by fishing activity. The fish is caught by gillnet or trawl net vessels with a gross tonnage of approximately 19 GT. According to Ziegler (2002), 47% of the cod catches from the Baltic Sea are caught by gillnets and 53% by trawl nets. For herring and mackerel datasets it was assumed that they were caught with trawl nets only. The fish were landed at a harbour located in Denmark. The fish are then processed and packaged (in cardboard or canned) at a nearby factory. From Denmark, the packaged frozen or canned fish is transported by lorry to supermarkets across Switzerland.

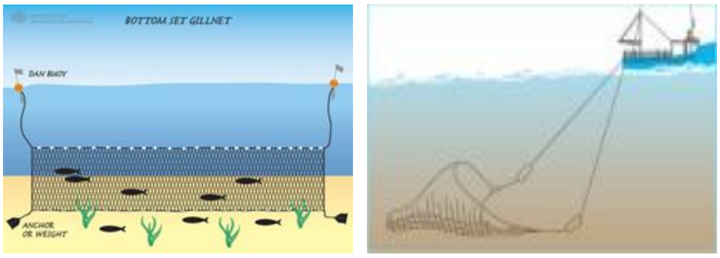

Fig. 2.3 The left illustration shows a gillnet[4] while the right illustration shows a trawl net[5]

2.4.2 Farmed Salmon

The first step of Salmon aquaculture which takes place at an on-shore hatchery is the production of smolts. A partial reuse system has been chosen out of several different technologies. A share of water that leaves the rearing unit is first treated and then reused. This reduces freshwater and energy needed. The fish feed used is made of industrial fish and agricultural products. Until harvesting, the salmons are kept in a floating net pen structures. In the processing stage, the salmons are slaughtered, gutted, filleted, brined and cold smoked. Finally, the smoked salmon is sliced, put on aluminium coated card-board and packed in plastic packages. Harvesting and pro-cessing take place in Norway. After processing, the salmon is transported by lorry to supermarkets across Switzerland.

Fig. 2.4 Floating net pen[5]

2.5 Allocation

In the fishing industry, several productions steps create multiple outputs. Examples are fishing where by-catch is caught and fish processing were fish waste is produced. By-catch and fish waste have got an economic value as they can be used for other products (e.g. fish meal and oil or pet food). To allo-cate environmental burdens, economic allocation is done. To lower uncertainty resulting from fluctuat-

[4] http://www.afma.gov.au/wp-content/uploads/2010/06/bottom_set_gillnet.jpg (29.04.20011)

[5] http://www.fish-4-ever.com/img/pic08_bottom_trawling.jpg (29.04.20011)

[5] http://blog.cleveland.com/world_impact/2008/11/large_Maine-Salmon_Farming_Meye.JPG (29.04.20011)

ing prices, average prices for fish meal and oil from 2004 to 2008 and average prices for fish products from 2000 to 2008 have been used (FAO 1998-2010). Prices used for allocation can be found in the annex (8.3).

2.6 Life Cycle Impact Assessment Methods

In this study two methods for the life cycle impact assessment (LCIA) namely the ecological scarcity method 2006 (Frischknecht et al. 2009) and the global warming potential (GWP or carbon footprint) (Solomon et al. 2007) are applied. For more details, see the annex 7.

3 Life Cycle Inventory Analysis

In the following section, the two analysed systems are described. Data has been obtained from literature study. The full life cycle inventory analysis is documented in a confidential annex. The annex and electronic XML data can be purchased from ESU-services on request.

3.1 High Sea fishing

3.1.1 Global overview

The trade of fish and fishery products has significantly increased in the last decades, reaching a worldwide volume of 102 billion US$ in 2008. At present about 80% of total fishery production is used for direct human consumption. The remaining 20% entirely from capture fisheries is destined for non-food products such as fish oil as well as direct feed in aquaculture and livestock. While demand continues to grow, capture fishery production has stabilized at approximately 90 Mt (OECD FAO Agricultural Outlook 2009)[6].

3.1.2 High Sea Fishing in Denmark

In this study it is assumed that the high sea fishing activities occur on the Northeast Atlantic Sea. The fish is landed at a harbor located in Denmark and processed to fillets and packaged at a nearby fish factory. The major part of production is exported. The EU is the most important market for Danish fishery products. The value of Danish exports of fish and fishery products was 18.6 billion DKK in 2001. The value of Danish imports, which are dominated by unprocessed fish, were 11.3 billion DKK.

There are basically three types of fisheries in Denmark:

- The industrial fishery for fishmeal and fish oil; mainly for sandeel, Norway pout, blue whiting and sprat in the North Sea, sprat in the Skagerrak/Kattegat, and sprat in the Baltic Sea
- The pelagic fishery for human consumption; mainly herring and mackerel stored in tanks and landed whole
- The demersal fishery for white fish (cod, hake, haddock, whiting, saithe), flatfish (sole, plaice, flounder etc), lobster and deep water prawns

In this study, the focus is on codfish (representing the demersal fishery) and on herring and mackerel (representing the pelagic fishery). The final product is determined by the processing of the caught fish at a fish factory that is located close to the harbour. Fuel consumption has been derived from (Thrane 2004a). In case of codfish, it is assumed that the fillet is frozen and packaged into LDPE laminated cardboard boxes, whereas herring and mackerel fillets are processed and canned. In the processing stage, the fish is gutted, de-headed, filleted and packed. Literature study showed a variety of figures for energy use, waste water loads and losses from filleting and trimming (Cardinal et al. 2001, COWI 2000, Silvenius & Grönroos 2003, Thrane 2004a, Winther et al. 2009 and Ziegler 2002). As processing inputs and outputs differ significantly according to the efficiency of the technology used for processing, an average performance has been assumed. The fish to fillet factor, which is the edible share of weight, differs among species. The fish to fillet factors for the species analysed is 0.41 (codfish), 0.46 (herring) and 0.53 (mackerel). Fish waste is used for fish feed. From Denmark cod is brought to Switzerland by refrigerated transport in a lorry. Transport of canned mackerel and herring

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[6] http://books.google.ch/books?id=l-ScEVN-GEUC&pg=PA45&dq=oecd+environmental+outlook+2009+fish&hl=de&ei=vSvlTMOrLY7Mswaom4HDCw&sa=X&oi=book_result&ct=result&resnum=3&ved=0CDQQ6AEwAg#v=onepage&q=oecd%20environmental%20outlook%202009%20fish&f=false (18.11. 2010)

does not need any refrigeration. In the supermarket, cod is kept in a freezer unit whereas the canned mackerel and herring are stored on the supermarket's shelves.

Previous LCA studies on codfish include the data report Environmental Assessment of a Swedish, frozen cod product with a Life-Cycle Perspective by Ziegler (2002) as well as a research article published in the Journal of Industrial Ecology by Thrane (2004b) titled "Environmental impacts of Danish fish products". Latter also provided some significant data on mackerel and herring fishery. In personal contact, Ian Vazquez-Rowe provided some background data on mackerel, which he originally gathered for his report "Life Cycle Assessment of Horse Mackerel Fisheries in Galicia (NW Spain)" (Vazquez 2010).

3.2 Salmon aquaculture

3.2.1 Global overview

Aquaculture is a fast growing sector in the global fish industry as it offers possibilities to accommodate increasing consumer's demand for fish products: From 1970 to 2006, the aquaculture production increased significantly from 3.9% to 36.0% (weight) of global fish production. Growing rates are even higher than global population's growth rate. The per capita production increased eleven fold from 0.7 kg in 1970 to 7.8 kg in 2006. The leading producers of farmed salmon are Chile and Norway with 31% and 33% respectively of worldwide production. (FAO 2008)

3.2.2 Salmon aquaculture in Norway

As mentioned above, Norway is the leading country in producing farmed salmon. The main species is Atlantic salmon (*salmon salar*). Before being transferred to the offshore net-pen, smolts are raised in hatcheries. In 2008, there were 224 concessions for smolt production facilities in Norway (FHL 2008). In this study, it is assumed that smolts are produced at a land-based hatchery using a partial water re-use system. Other technologies can be found in (Colt 2008).

After smoltification, a physiological transformation, salmons are able to live in salt water; salmons are transferred to a marine net-pen. At that stage, the salmon weights approx. 60-90g (Colt 2008). Salmons spend between 14 and 25 months in the net-pen before harvesting. At that time, they have gained a weight of 2-5.5 kg. In this study, a growth time of 20 month is assumed (Tyedmers 2000). The net-pen structure usually consists of several cages located around 100 m off-shore or in fjords for sheltering from storms (Tyedmers 2000). The cages are made of a steel structure and a net. During operation electricity, anti-foiling paint and the operation of a fishing boat is required. According to the Norwegian Fiskeri - og havbruksnærings landsforening (Norwegian Seafood Federation), 884 concessions for salmon aquaculture were granted in 2008 (FHL 2008).

It is assumed that the same feed is used in the hatchery and the net-pen. As mentioned by Pelletier (2009), the feed conversion ratio (FCR) and feed composition differ for different salmon species and regions: Salmons raised in Norway have got a FCR of ~1.1 whereas Salmons from aquacultures in the UK (~1.33), Canada (~1.31) and Chile (~1.5) have got higher FCRs. The analysed Norwegian feed consists of 41.90% of vegetal products (e.g. oils and meals) and 58.10% of fishery products (fish meal and oil). A detailed composition of fish feed in different countries can be found in (Pelletier et al. 2009). Due to the lack of inventory data for several fishery products, industrial fish products from fishing processes, modelled for high sea fish and from salmon processing, are used. This is only a rough assumption which should be improved as feed input is a major determinant of environmental impacts. Ecoinvent v.2.2 data has been used for vegetal products.

In the processing stage, the fish is gutted, de-headed, filleted, brined and smoked. For an explanation of energy requirements, see 3.1.2 and literature mentioned therein. The fish to fillet factor is 0.49. Finally, the salmon is packed, refrigerated transported and distributed to supermarkets across Switzerland.

4 Life Cycle Impact Assessment

4.1 Ecological Scarcity 2006 Method

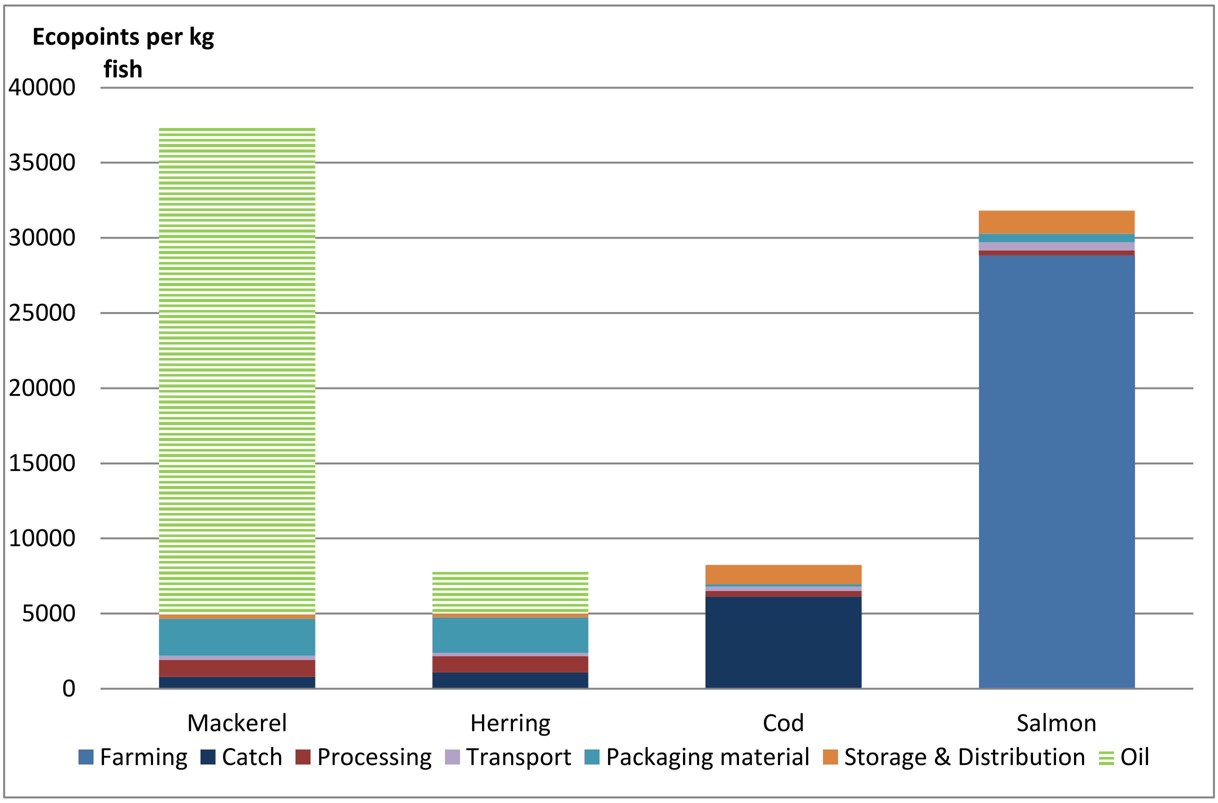

Fig. 4.1Fig. 4.1 shows eco-points of analysed fish products evaluated with the ecological scarcity 2006 method. The environmental impacts are shown for different steps along the production chain, which include the catch phase at sea, or farming, processing, packaging, transport as well as storage and distribution.

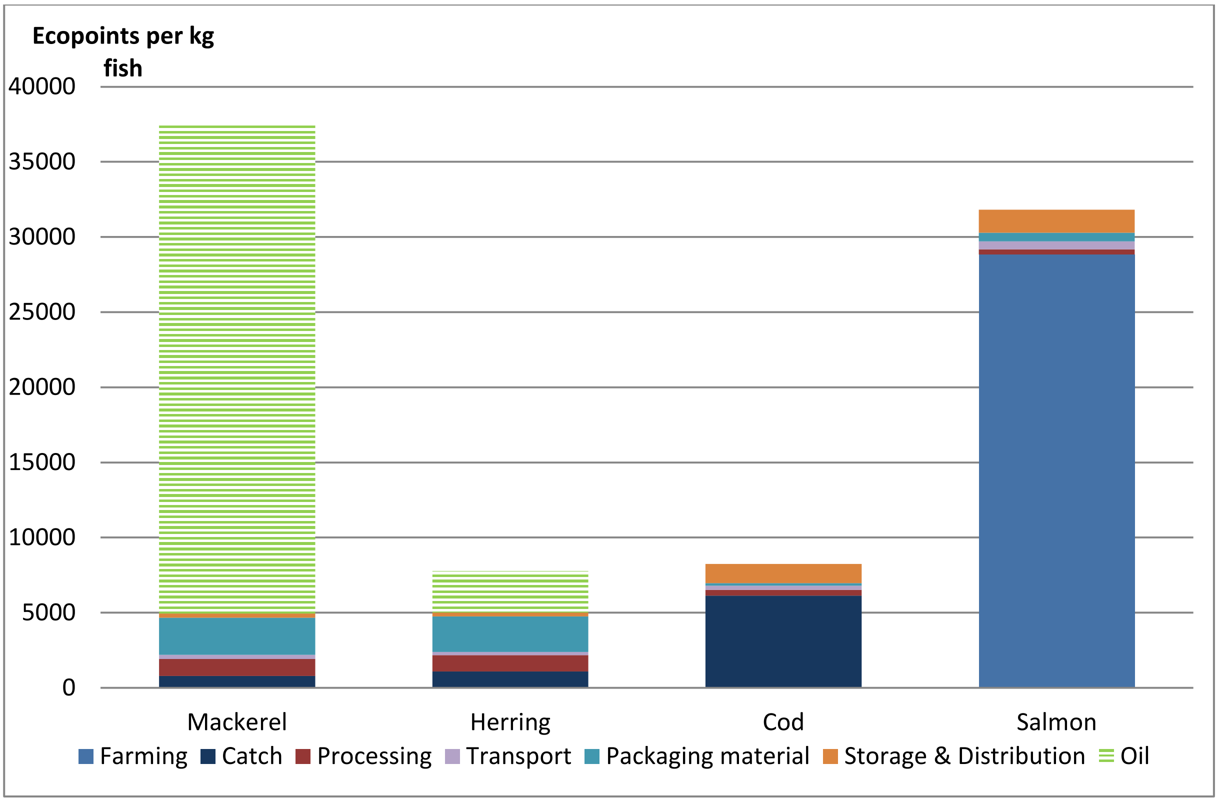

Fig. 4.1 Distribution of eco-points in regard to different life cycle stages

If not considering additive oil, mackerel and herring perform best with about 5000 eco-points respectively (more than 35000 and around 8000 eco-points, if oil is used). Codfish and salmon perform worse with approx. 8000 and more than 30000 eco-points. In case of codfish over 70% of the eco-points stem from the operation of diesel-fuelled fishing vessels. The second highest impacts come from storage and distribution. This is due to refrigerated transport. When comparing codfish to herring and mackerel, the most obvious differences are the impact of fishing operation and packaging material. For herring and mackerel, the impacts of the catching phase are considerable lower. This is caused by two reasons: Firstly, it is caused by lower fuel consumption per kg fish landed. The second reason is allocation: The assumed price for codfish is considerably higher than the price for herring or mackerel.

In case of mackerel and herring the highest share of impacts (around 50%), not considering oil, are caused by aluminium production for packing material. Transport has a lower impact, even though distance is the same as for codfish, but no refrigeration is needed. Storage of frozen codfish causes obviously higher impacts. However, lower impacts for transport and storage are compensated by higher impacts for processing. Processing of canned products requires more energy than the processing of deep frozen goods. This is due to a higher demand of energy for electricity and steam production. Steam is required for cooking and sterilizing. Approximately 11% (not considering oil) of eco-points come from these processes required for canning. The use of vegetable oil as an additional ingredient leads to significantly higher impacts for mackerel and herring. For mackerel, the use of high value virgin olive oil is assumed; for canned herring production, rape oil is used. The amount, type and quality of oil used is highly variable and therefore a source of high uncertainties. Olive oil causes high environmental impacts due to emissions into air and topsoil occurring in olive farming. High emissions for oil come from burning of prunings in open wood fires and the use of insecticides in olive plantation (Avraamides & Fatta 2006). The use of insecticides is responsible for 68% of olive oil's impacts.

These results show that environmental impacts of fish products are highly determined by impacts caused by fishing, packaging material and added ingredients. Impacts in fishing are dependent on fuel consumption per catch. Fuel consumption is in turn dependent on fishing method (e.g. gillnet fishing or trawling), technology (e.g. vessel and engine) and fish abundance. These factors may vary significantly in different regions. As fish abundance is highly variable in time, different results might be found for other time periods or years. Furthermore, it should be mentioned, that data from fishing used in this study is from 2004 and only from one country (Denmark). That's why it is not a complete picture of fish products sold in Switzerland.

The second type of product, analysed in this study, is fish from aquaculture. Environmental impacts of farmed salmon are considerably higher than those of caught wild fish. This is due to the significantly higher impacts caused by fish farming. Fig. 4.1 depicts that more than 90% of impacts stem from fish farming. Fig. 4.2 shows a distribution of impacts in the fish farming stage.

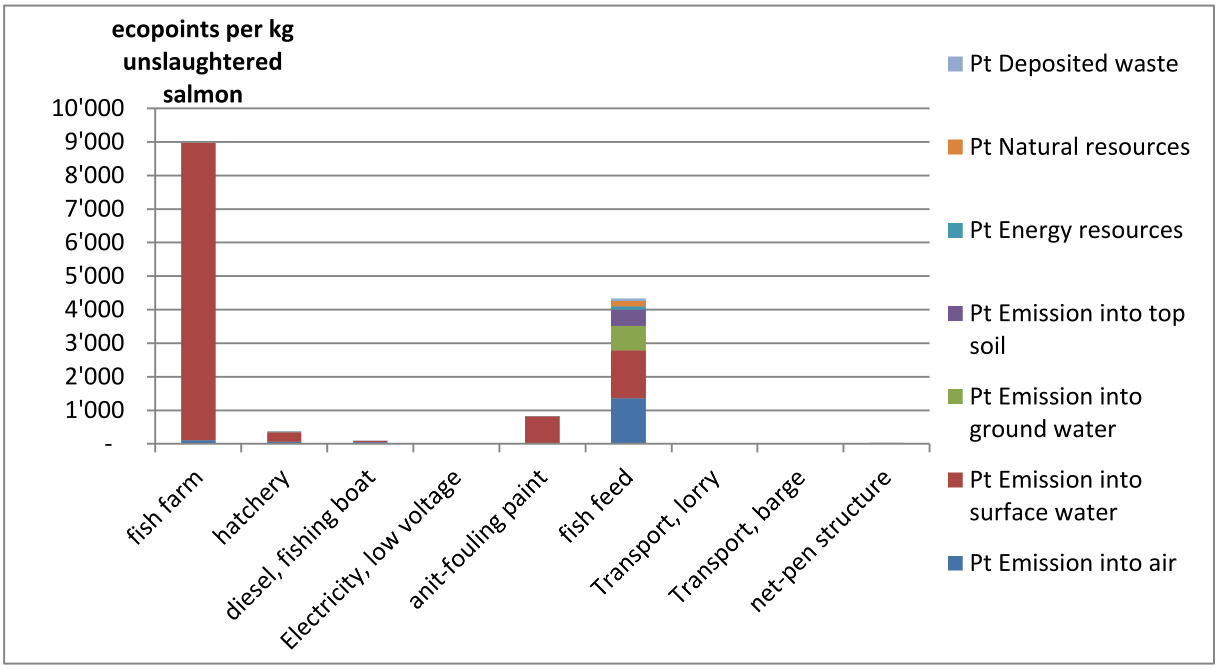

Fig. 4.2 Distribution of eco-points of fish farming

The results show that, during faming, direct emissions are emitted into surface water. These emissions are nitrogen and phosphorus compounds originating from nutrients contained in fish excretions. These emissions are dependent on nutrient uptake and efficiency of fish feeding. These impacts are that significant because nutrient emissions in fish farming cannot be used as manure for e.g. fodder production as it is the case in breeding animal husbandry. In the latter case, the use of dung as manure as a fertilizer considerable reduces the nutrient leachate to the environment. Furthermore, the use of copper oxide containing anti-fouling paint leads to emissions into surface water.

The second most eco-points at farming stage are causes by fish feed production. This is due to the use of fish meal and oil and energy requirements. By using fish wastes, environmental burdens from fishing and farming are allocated to fish feed. Other contributors are emissions from agricultural products. Infrastructure, smolt production and other processes only play minor roles. Other processes related to the production of smoked salmon amount to around 10% of eco-points. The largest share of these 10% is storage and distribution. This is due to the need of refrigerated storage. Other processing steps, such as smoking does not play a significant role. It should be mentioned that data availability for energy, wood requirements and emissions for smoking is sparse.

Another option for transportation is air freight. Transporting the fish product via air fright from Denmark or Norway to Switzerland would increase eco-points for transport fivefold.

4.2 Global Warming Potential 2007

The fish products analysed in this study cause approximately four to six kg CO_2 equivalent emissions per kg product (Fig. 4.3)

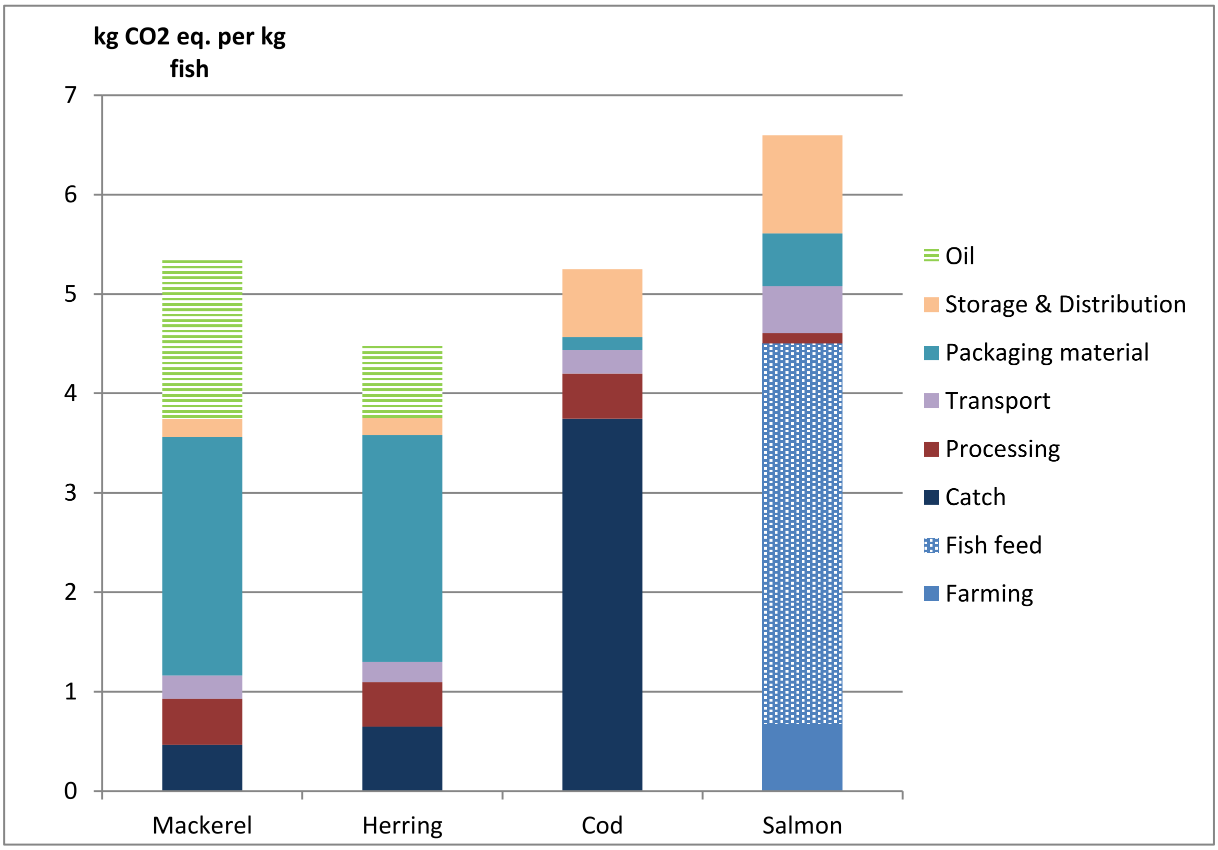

Fig. 4.3 Global warming potential of analysed fish products (kg CO_2-eq per kg)

The lowest impacts are caused by herring and mackerel with 3.7 kg CO_2 eq. emissions, without the use of additive oil; 54 and 4.5 kg CO_2 eq. Emissions, respectively, with oil. The results show that packaging material has a high influence on CO_2 equivalent emissions: Aluminium cans, used for herring and mackerel perform worse than plastic foil used for codfish and salmon. The results for cod (5.3 kg CO_2 eq. emissions) show that the fishing stage can play an important role, in case fuel consumption is high. Fuel consumption and its emissions are a hotspot in fishing industry as it offers high possibilities for improvements. One fact that affects the performance of mackerel positively is the high fish to fillet factor.

Highest emissions (6.6 kg CO_2 eq.) are caused by Salmon .Around 58% of these emissions stem from fish feed production. Salmon has got the highest impacts for transport due to a longer distance and refrigeration. Because of cleaner energy supply, processing of farmed salmon in Norway emits less CO_2 equivalent emissions than processing in a Danish factory. This fact shows that it matters, where fish is processed. A similar conclusion can be found in (Winther et al. 2009).

Fig. 4.4 shows the contribution of carbon dioxide, methane and dinitrogen oxide to GWP. The highest contributions to GWP come from carbon dioxide emissions. These emissions mainly stem from diesel use in fishing boat operation and fish feed production. Due to high impacts of fish feed and secondary dinitrogen oxide emissions formed from nitrogen compounds, farmed salmon is more environmentally harmful than high sea fish products. So far there seems not to be any clear scientific knowledge about the influence of added nitrogen on the natural oceanic nitrogen cycle and therefore of the formation of dinitrogen oxide. Due to the lack of useful information, standard emissions factors from IPCC for dinitrogen formation in agriculture have been used (De Klein et al. 2006).

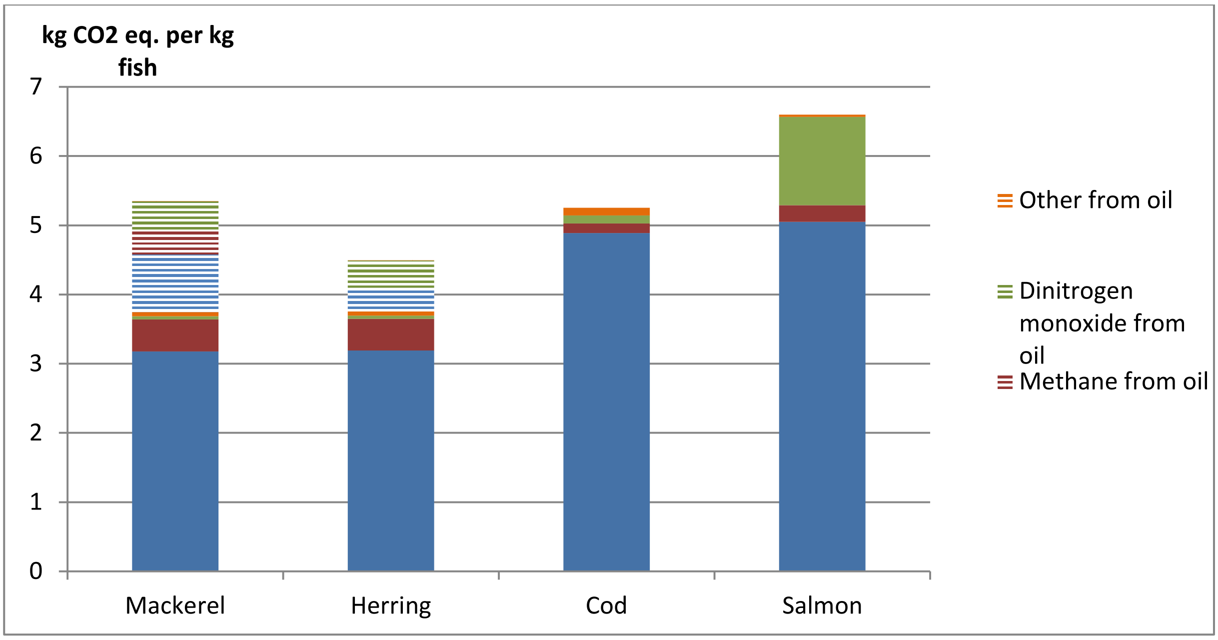

Fig. 4.4 Greenhouse gas emissions of analysed fish products

Tab. 4.1 gives a comparison of results for GWP of different studies. In most cases, GWP of landed fish had to be compared as different products were analysed (e.g. frozen or pickled, not canned herring). Landed codfish shows the highest discrepancy in results. Differences in results are caused by different data (different fisheries under study) and allocation.

Tab. 4.1 Comparison of different studies (kg CO_2-eq/kg)

	Own calculations	Winther et al. 2009 (NO)	Ziegler 2002 (SE)	Ayer & Tyedmers 2008 (CA)	Pelletier et al. 2009 (NO)
Cod, at harbour	1.78	1.6	2.45	-	-
Mackerel, at harbour	0.32	0.4	-	-	-
Herring, at harbour	0.47	0.4	-	-	-
Cod, at supermarket	5.25	-	5.83	-	-
Salmon, at fish farm	2.05	2	-	2.07	1.79

4.3 Comparison between Fish and Meat

Because the environmental impact of fish has not been quantified so far in the ESU database; sometimes it was assumed to be similar to that of meat (Jungbluth 2000).In the following, the validity of this assumption is tested by comparing cod, herring, mackerel and salmon to poultry, pork, lamb, beef and veal.

4.3.1 Eco Scarcity 2006

In Fig. 4.5, fish and meat are compared with the ecological scarcity 2006 method. The absolute single score of high sea fish is between 6000 and 8000 eco-points, which is 2 to 4 times lower than the single score of one kilogram of meat which ranges between 13’000 eco points (poultry) and 33’000 eco points (veal). Compared to meat products, farmed salmon is on the high end of range. As mentioned in 4.1, this is due to the emissions of nutrients and copper oxide to the ocean.

It has to be noted that environmental impacts of fish can vary considerably depending on the type of fish: There also some types of fish, such as lobster for which eco-points are as high as 75'000 points per kg landed at harbor.

The reason why veal has got higher impacts than beef may seem peculiar at first thought, but can be explained due to the economic allocation that has been used: The price of veal meat is higher than the one of beef. Beef is also produced in co-production with milk which leads to lower environmental impacts. Calves raised solely for the purpose of meat production thus exhibit higher environmental impacts.

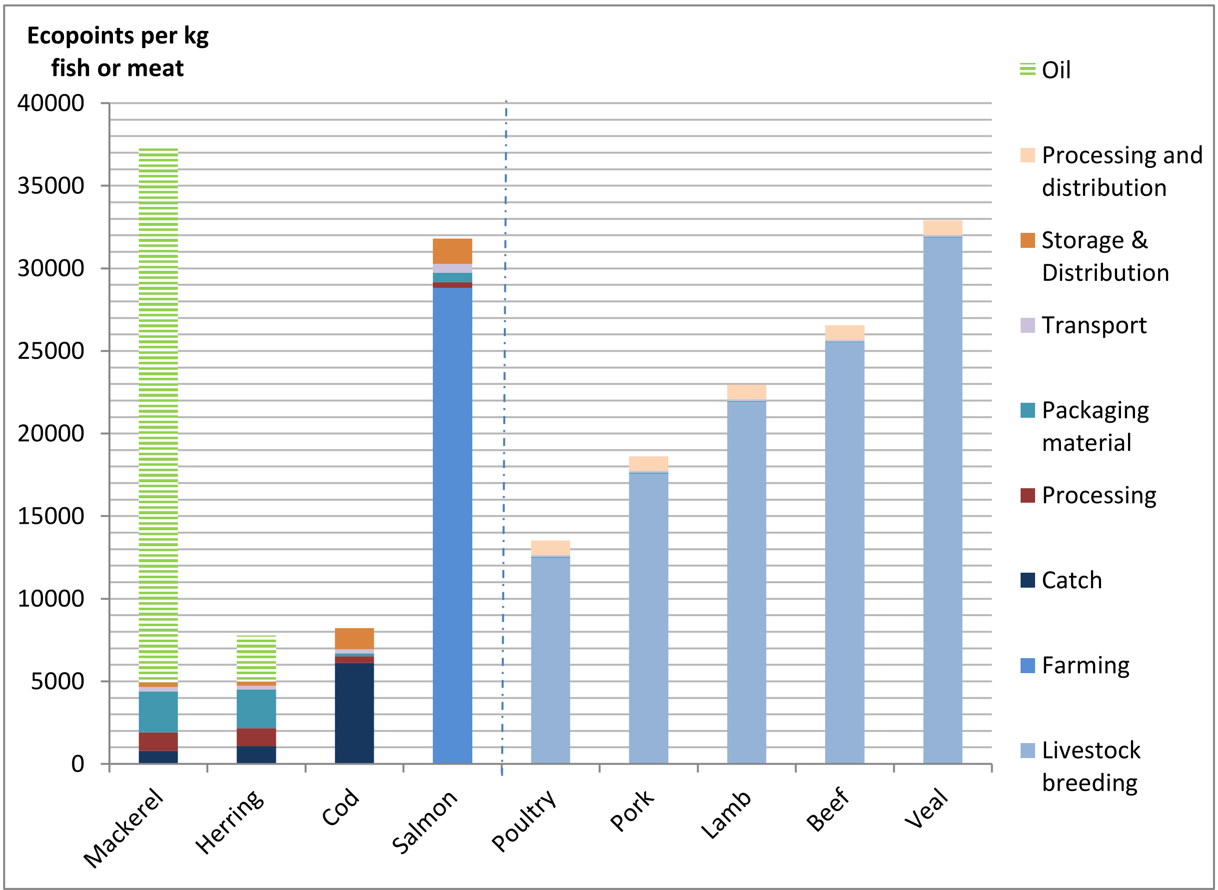

Fig. 4.5 Comparison of fish and meat – eco Scarcity 2006

In Fig. 4.6**,** fish and meat are compared with regard to the sphere where emissions occur. In this figure you see how and to what extent the various meat and fish sorts impact different environmental compartments. For meat products, the majority of emissions are emitted into air, whereas a larger share of emissions from fishery products is emitted into surface water. These eco-points stem from anti-fouling paint that is used. The same type of paint is used to a smaller extent in fish farming.

However, it should be noted that specific environmental impacts of fishery such as disturbance of natural habitats on sea ground or overuse of natural stocks are so far not covered by common LCIA methods. For a full environmental assessment it is necessary to better take into account such impacts. For example, the impact of a bottom trawl fishing vessel can differ considerably between sediments, where the oxygen content of the bottom water allows the existence of higher life forms. The swirled up sediment caused by the passing trawl may release organic (potentially toxic) material that had been buried. Furthermore, an increase in nutrients might accelerate eutrophication and oxygen-depletion processes even further (Ziegler 2002).The second significant environmental impact that remains unaddressed by the life cycle assessment is overfishing and the severe consequences it poses to marine ecosystems. For example, Atlantic cod only matures at six to nine years. Due to overfishing, a high percentage of the catches are not able to reproduce before being caught which leads to unsustainable fishing stocks (Ziegler 2003). The category "natural resources" does not take biologic resource use into account.

Furthermore, as already mentioned in 4.2, the influence of additional phosphorus and nitrogen compounds on the formation of secondary dinitrogen oxide remains unclear. Further scientific research is required to better the understanding of underlying processes of the oceanic nitrogen and phosphorus cycles and to estimate environmental impacts and greenhouse gas formation from nutrient contamination.

Another risk, originating from aquacultures is escaping fish. Damages to ecosystems caused by escaped fishes are not evaluated in this study as there is no method to quantify impacts. See Naylor (2005) for further details on these damages.

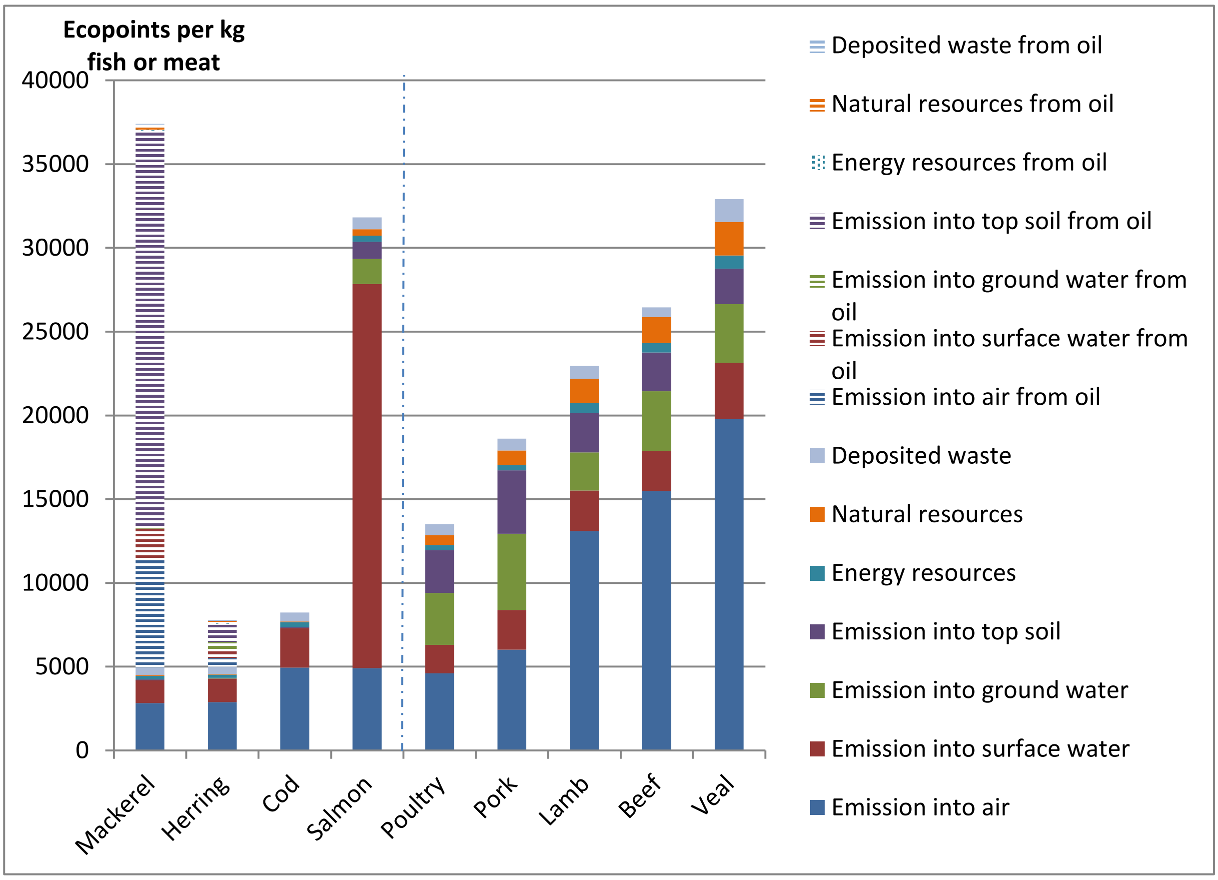

Fig. 4.6 Comparison of fish and meat – eco scarcity 2006

4.3.2 Global Warming Potential 2007

In Fig. 4.7 fish and meat are compared with regard to global warming potential. The GWP of one kilogram of fish is between four and seven kg CO_2 equivalents, whereas it is twice as much for beef or veal, which have a GWP of 16 kg and 22 kg of CO_2 equivalents, respectively. This large difference is caused by the significant amount of methane that cattle produce when digesting. Since nearly no methane emissions occur during the life cycle of fish, the impact on the environment is overall less. Dinitrogen oxide emissions of meat products stem from the use of fertilizers; those of farmed salmon from secondary dinitrogen oxide emissions from nutrients originating from digested fish feed.

However, poultry and pork have a GWP,which is in the same range as the analysed high sea fish products. Using different packing material for mackerel and herring would reduce their GWP. Nevertheless, results are highly dependent on prices, as economic allocation is used.

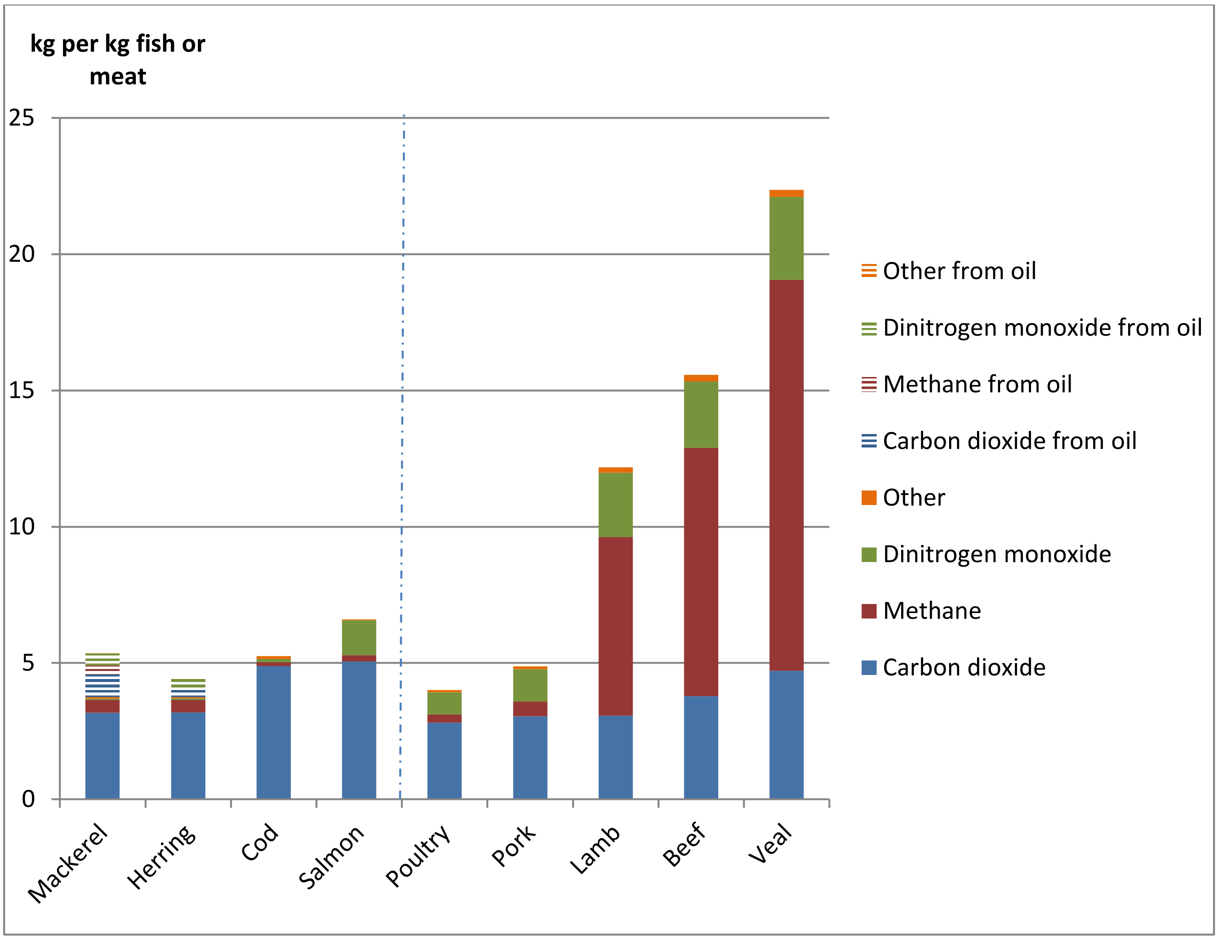

Fig. 4.7 Comparison of greenhouse gas emissions

5 Recommendations

5.1 Policy Recommendations

From the evaluated results it becomes obvious that the main area for improving the environmental impact of fishing lies in the catch phase and in particular in the operation of the fishing vessel. While the political solution so far has been to support investments in new engines, Thrane (2004b) argues that more efficient engines are likely to cause an increase in fishing activity, which in turn results in less fish. Less fish leads to another increase in fishing activity. A positive feedback loop evolves.

He recommends focusing on cleaner fishing techniques. He found out that gillnets and the Danish seines are considerably more fuel-efficient than bottom and beam trawls when used for the same target species. He therefore recommends supporting further development of passive and semi-active fishing methods, such as the Danish seine.

Further significant improvements can be made in packaging: The use of different packaging material can lead to a reduction of environmental impacts. To reduce impacts on biological resources, strict fishing quotas should be established and adhered to. In addition, sustainable management of fish stocks could reduce the amount of energy used per kg of landed fish as low catch rates are linked to high fuel consumption. High fuel prices might have a positive effect on fuel consumption, (Schau et al. 2002).

Aquaculture's environmental impacts can be lowered by a change in feed composition: The substitution of animal by-products by vegetal ingredients reduces total environmental impacts of fish feed. One should keep in mind that fish meal and oil are mainly by-products from other industries. Abandoning the use of these ingredients would reduce environmental impacts of fish feed, but it is not clear if this leads to an improvement on a larger scale: The available quantity (and environmental impacts) of these by-products is defined by the production of other products not by the demand created by fish feed production as the clear majority of fishing targets edible fish. It would not be any better to waste these by-products.

Another option is to improve feeding technique: The amount of feed needed per kg of salmon produced (FCR) varies significantly in different regions: From a FCR of 1.103 in Norway to 1.493 in Chile (Pelletier et al. 2009). In this study, an FCR of 1.103 was assumed as Norwegian farmed Salmon was analysed. In other regions, where the optimum is not reached, high potential for improvements are given.

Another risk created by aquacultures is escaping fish. Naylor (2005) explains adverse effects of escaping salmon on wild salmons. Therefore regulations need to be introduced to protect natural habitats.

In fish processing, improvements can be achieved by using energy and water efficient machinery (COWI 2000). Winther (2009) and own calculations proved that it matters where fish is processed as energy mixes and their environmental impacts vary in different countries.

5.2 Consumer Recommendations

From the consumer perspective, two recommendations can be made in regards to choices made at the supermarket: Firstly, when deciding between fish and meat, the analyses with the GWP method suggest that some types of fish from high-sea fishing are a less harmful choice for the environment than beef and veal. However, this cannot be generalized, as environmental impacts of some fish species are considerably higher. For some more expensive types of fish such as shrimps, flatfish or delicacies such as the Norway lobster, the GWP can rise above 30 kg CO_2-eq per kg of fish. This is due to economic allocation.

Aquaculture is sometimes praised as an environmental friendly alternative to high-sea fishing or land based animal husbandry. Calculations reveal that it is for salmon in the same range as high sea fish with regard to GWP. Its downside is eutrophication and disturbance of natural habitats. The use of vaccines and antibiotics worsens environmental impacts of farmed salmon. In regards to eco-points, salmon performs considerably worse than high sea fish and most meat products.

Thus, there's no clear cut answer to the question of whether an environmentally concerned consumer should rather buy meat or fish. The environmental impacts of fish are quite variable depending on the type of fish and fishery. From an environmental point of view a vegetarian diet is more preferable than eating fish and meat.

Finally, consumers should be aware that neither the eco-scarcity nor the GWP method adequately addresses the severe environmental consequences of overfishing or sea floor damage caused in particular by bottom trawl fishing vessels. For consumer advices one should consider e.g. recommendations by the WWF concerning types of fish which are so far not endangered by marine overfishing.[7]

5.3 Research Recommendations

Apart from consumer and policy recommendations some recommendations for further research can be given. This study shows that several aspects are not implemented in the LCA methodology so far. The most significant aspect concerning fishery is overfishing and the destruction and disturbance of natural habitats. Further development in LCA should address these problems as they resolve around the main problems towards a sustainable fishery. A starting point might be to check whether fishing quotas are adhered to or not (provided that current fishing quotas are considered as sufficient means of creating a sustainable fishery). Coping with seabed disturbance is another point that needs to be taken into account in more detail, especially when analysing trawling.

Another aspect that has been mentioned several times before is the formation of secondary dinitrogen oxide from nitrogen emissions into the ocean. So far there seems not to be much scientific knowledge about it.

Furthermore, the amount and influence of emitted anti-fouling paint is uncertain. The share of paint that flakes off the ship is hard to quantify and its fate and behaviour in the environment is highly uncertain.

[7] http://www.wwf.ch/de/tun/tipps_fur_den_alltag/essend/fisch/fischfuhrer/

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7 Annexe LCIA methods

7.1 Global Warming Potential 2007 (GWP)

All substances, which contribute to climate change, are included in the global warming potential (GWP) indicator according to IPCC (Solomon et al. 2007). The residence time of the substances in the atmosphere and the expected immission design are considered to determine the global warming potentials. The potential impact of the emission of one kilogram of a greenhouse gas is compared to the potential impact of the emission of one kilogram CO_2 resulting in kg CO_2-equivalents. The global warming potentials are determined applying different time horizons (20, 100 and 500 years). The short integration period of 20 years is relevant because a limitation of the gradient of change in temperature is required to secure the adaptation ability of terrestrial ecosystems. The long integration time of 500 years is about equivalent with the integration until infinity. This allows monitoring the overall change in temperature and thus the overall sea level rise, etc..

In this study a time horizon of 100 years is chosen, which is also used in the Kyoto protocol.

7.2 Ecological Scarcity 2006

The ecological scarcity method (Frischknecht et al. 2008) evaluates the inventory results on a distance to target principle. The calculation of the eco-factors is based on one hand on the actual emissions (actual flow) and on the other hand on Swiss environmental policy and legislation (critical flow). These goals are:

- Ideally mandatory or at least defined as goals by the competent authorities,
- formulated by a democratic or legitimised authority, and
- preferably aligned with sustainability.

The weighting is based on the goals of the Swiss environmental policy; global and local impact categories are translated to Swiss conditions, i.e. normalised. The method is applicable to other regions as well. Eco-factors were also developed for the Netherlands, Norway, Sweden (Nordic Council of Ministers 1995, Tab. A22 / A23), Belgium (SGP 1994) and Japan (Miyazaki et al. 2004).

The ecological scarcity method allows for an *optimisation within the framework of a country's environmental goals*.

The environmental and political relevance is essential for the choice of substances. The environmental policy does by far not define goals for all substances. Thus the list of eco-factors is limited. This particularly applies to substances with low or unknown environmental relevance in Switzerland and Europe (e.g. sulphate emissions in water bodies).