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Environmental Assessment of a Swedish, frozen cod product with a life-cycle perspective
A data report

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Sammanfattning

Rapporten är en gemensam dataredovisning för två vetenskapliga arbeten som genomförts inom ramen för ett doktorandprojekt på SIK. Projektet handlar om miljöanalys av fisk- och skaldjursprodukter med ett livscykelperspektiv. Datainventeringsmetodik och –resultat är detaljerat beskrivna i denna rapport, medan introduktion och diskussion är mycket korta. Rapporten kan läsas separat eller tillsammans med de vetenskapliga publikationerna ifrån projektet, där mer vikt har lagts vid att diskutera resultaten i relation till andra studier. Den första studien är en modell över bränsleanvändning och avgasutsläpp från fiskebåtar i det svenska torskfisket. Den andra studien är en Livscykelanalys (LCA) för ett fryst torskblock. I denna användes data från den förra studien, kompletterat med en inventering för andra delar av livscykeln och andra miljöeffektkategorier.

Syftet med att göra detta arbete var att presentera data för resursanvändning och miljöpåverkan av ett marint livsmedel under hela sin livscykel samt att inkludera fiskets specifika miljöeffekter i inventering och miljöpåverkansbedömning.

Bland resultaten kan nämnas att fisket var den fas i livscykeln som bidrog mest till miljöpåverkan och att de viktigaste förbättringsmöjligheterna därför finns i denna fas. Bottentrålning visade sig vara ett mycket energikrävande sätt att producera mat på, som kräver betydligt mer energi än garnfiske. Kvantitativa data på produktkvalitet vid fiske med de två metoderna fanns ej att tillgå, varför det helt enkelt antogs att kvaliteten var lika, men detta skulle kunna ha stor betydelse för slutresultatet.. Det viktigaste förbättringsförslaget är att bara fiska hållbart utnyttjade fiskbestånd, detta minskar dels den negativa effekten på bestånd av överfiske men även miljöbelastningen per kg landad fångst, eftersom mängden resurser som krävs är direkt relaterat till fiskeansträngningen som krävs för att få en viss mängd fångst. Valet av fiskemetod och sättet man kör fiskebåten på visade sig också vara viktiga faktorer. Användningen av modern motor- och bränsleteknik skulle minska mängden avgaser kraftigt. På grund av fiskets stora betydelse för resultaten är den viktigaste miljöåtgärden efter landning att bibehålla hög kvalitet och minimera produktsvinn under hela kedjan från hamnen till konsumenten.

Summary

The present report is a summary of two separate studies that have been performed within a Ph.D. project at SIK concerning Environmental Assessment of seafood products with a life-cycle perspective. Data inventory methodology and results are thoroughly described in this report, while introduction and discussion are more brief. The report can be read separately or together with the scientific publications resulting from this work, where more emphasis was put on discussion of results in relation to other work performed in the field, but where data are not presented in detail. The first study concerns a model on the fuel consumption and emissions from Swedish cod fishery and the second is a Life Cycle Assessment (LCA) for a frozen cod product in which data from the first study was used, supplemented with an inventory for other life-cycle phases and environmental impact categories.

The purpose of both studies was to present data for the resource use and environmental impact during the entire life-cycle of a seafood product and to include fishery-specific environmental aspects in the assessment.

Main results include that fishery is the life-cycle phase contributing most to the environmental impact and that, therefore, the main improvement options can be found in this phase. Demersal trawling was in the present study shown to be a highly energy-consuming way of producing food in Sweden, requiring more energy than gillnet fishing. However, no quantitative information on the resulting product quality was available, why it was simply assumed that quality was the same for the two fishing methods. The most important improvement option is to fish sustainably managed stocks, this reduces both the negative stock impact of over-fishing and the environmental impact per kg of catch landed, as the input of resources is directly related to the fishing effort needed to obtain a certain amount of catch. The choice of fishing method and way the fishing vessel is operated was also shown to influence results considerably. The use of modern engine and fuel technology would decrease emissions significantly. Due to the dominance of fishery in the results, the most important environmental issue after landing of the catch was to maintain high quality and minimise product losses in the product chain from the harbour to the consumer.

Keywords: LCA, fishery, environmental effects, by-catches, discards, seafloor

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1. INTRODUCTION

1.1 Seafood production

Seafood is a source of protein of increasing importance in the world. In many developing countries more than half of the human intake of protein comes from seafood (Anon. 1997). In the industrialised part of the world, the seafood market is constantly increasing and the main limitation for the seafood industry today is the availability of raw material. Today, world fisheries and aquaculture together produce around 100 million tons of fish and crayfish, squid and mussels (FAO 1997). The limits of wild production of the oceans have been reached for most species caught commercially and the proportion of seafood being provided by aquaculture is increasing. The type of aquaculture growing most rapidly, however, is heavily dependent on capture fisheries for feed production and in this perspective it is of greatest importance to increase the knowledge about the environmental impact caused by capture fisheries.

Fishery causes environmental impact, just like other types of food production. The demand for product-oriented studies of the environmental impact of seafood products has increased thanks to growing awareness about environmental issues among consumers. Major obstacles to performing such studies have been the lack of data and methodology to include fishery-specific types of environmental impact such as impact on the seafloor, impact of the large-scale outtake of biomass and discarding and gaseous emissions from fishing vessels. It is, therefore, important to find methods to quantify these kinds of impacts and assess their environmental effects.

1.2 Environmental problems connected to commercial fishing

The environmental effects of fishery include direct effects on the stocks and production of the target species. As fisheries often cannot be directed towards a single species, by-catch species which are landed and sold, are also affected. Some species are caught, but later discarded, together with damaged, low-value or undersized specimens of commercial species. Other fishery effects are changes in biological, physical and chemical conditions on the seafloor due to the use of towing gear, toxic effects due to release of active substances from anti-fouling paints and effects of emissions from combustion of diesel fuel. Some of the environmental aspects of fishery are introduced briefly below.

The target species, by-catch and discard

A fishery normally has one or several target species, which is the main purpose of the fishing activity. A number of by-catch species are generally also landed and sold. They are not the main driving force of the fisherman, but have a commercial value and are therefore regarded as by-products that should account for some of the environmental impact caused by the fishery. The extraction of a considerable part of the biomass of target and by-catch species affects the standing stock size, rate of production and age and size composition of the stock. It also has more indirect effects on the rest of the marine ecosystem (Hjerne 2001).

Discard, on the contrary, is the part of the catch, which is unwanted and normally thrown overboard. Discards consist of both undersized and damaged specimens of the target species and species with a low commercial value. When quotas are limiting, commercial sizes of the target species may be discarded, a phenomenon called upgrading. The discarded individuals do usually not survive the treatment of being caught, taken onboard and then thrown back into the sea and therefore this loss of resource has to be accounted for as an environmental impact. Globally this loss represents around 27% of total catches (Alverson 1994). Discarding is a widely recognised resource management problem in fisheries. Seafood nowadays has to be regarded as a limited resource, although renewable, since the limits for production of most of the commercially exploited species have been reached and we cannot control production the way we can for other food types. The discard of under-sized, commercial species is therefore a waste of a limited resource since it could have been fished one or a few years later when it has reached a greater size. The discard and the offal from the landed catch is in part consumed by seabirds and marine animals. Locally, discarding can contribute to eutrophication if it is done close to the coast or in areas with slow water exchange, even though fishery overall leads to a net removal of nutrients from the sea.

The seafloor

Although internationally there are studies on the environmental impact on the benthos of mobile fishing gear, local or regional data for the effects of different types of gear are rarely available. The knowledge about the natural variation in benthic communities is typically low, even in the most studied areas like the southern parts of the North Sea (Lindeboom 1998). In the Baltic Sea, so far no studies on the seafloor impact of trawling have been performed. The natural conditions in the Baltic Sea are unique and because of its brackish water environment, biodiversity, as well as benthic biomass, is low (Kautsky 2000). Low salinity creates a stressing environment both for freshwater and marine species. The ocean is semi-enclosed and influx of high-saline water, depending on oceanographic conditions, is irregular. Therefore, the occurrence of oxygen-depleted seafloors in the Baltic is not a new phenomenon, but rather a result of its natural conditions and around 1/3 of the seafloor in the Baltic Proper is devoid of higher life because of regular oxygen deficiency (Kautsky 2000). The water-column of the Baltic is stratified by a permanent halocline[1] at between 60-80 m depth and the seafloor areas suffering from oxygen-depletion are generally located below this depth.

The impact of a passing trawl can be expected to differ considerably between a sediment, where the oxygen-content of the bottom water allows the existence of higher life forms, and an often or regularly oxygen-depleted sediment. An oxygen-depleted sediment is colonised by sulphur- or nitrogen-reducing bacteria instead of higher life forms. Therefore, the biological impact of trawling such sediments is low, while a “chemical” impact might be significant (Krost 1993). The re-suspension and turbation caused by the passing trawl may release organic (and toxic) material that had been buried in the sediment and the increase in nutrients might accelerate eutrophication and oxygen-depletion processes even further. In Baltic sediments where the bottom water contains oxygen over a certain minimum level, however, a benthic community exists and this community can be expected to be impacted by passing trawls. The effects of this disturbance depends both on the frequency and the dispersion of it in an area.

1.4 Purpose

The purpose of the research project was to quantify these highly different environmental aspects of fishery and put them together into a model with other aspects, such as energy consumption during the entire life-cycle of a seafood product from the sea to the table. This can give a new perspective on the overall environmental impact of seafood products. Policy-makers, consumers and seafood companies require this kind of information today. Environmental assessment through LCA is therefore expected to have the potential of being a valuable tool for assessing the environmental impact of current practices and of planned changes in the seafood production chain.

[1] The water in oceans is normally stratified into two layers with different salinity and/or temperature and therefore density. The boundary between these layers is called the halocline

Aims of this report are:

- To present in detail the methodology used and the resulting inventory data set used for the performance of an LCA for a seafood product as well as results of the LCA
- To demonstrate how fishery-specific types of environmental impact can be included in the inventory and impact assessment

The present report contains the data used for an environmental assessment of a consumer-package of frozen cod fillets, originating in the cod fishery in the Baltic Sea (Ziegler 2001). The importance of different phases in the life cycle for the different environmental impact categories is demonstrated by characterising emissions where an accepted methodology is available. Fishery-specific types of environmental impact are included in the inventory of the LCA and the differences between the two most common fishing methods in Swedish cod fisheries in the Baltic, trawling and gillnet fishery, are described. For environmental impacts that could currently not be characterised, qualitative impact assessment was made.

2. GOAL AND SCOPE

2.1 System boundaries

In the present study the "outer boundary" of the system is production of gear, anti-fouling agents, diesel fuel and packaging material (Fig.1), which were all included in the study. Material for gear production was included as the amounts were significant, while the material and energy needed for construction of the fishing vessel was excluded based on previous findings that this is negligible with regard to the long life-time of a fishing vessel (Aanondsen 2001). The product was followed from fishery through a processing plant where it is filleted, frozen and packaged and then transported via a wholesaler and a retailer to the consumer where it is stored, prepared and consumed. Transportation between the different steps was included, as was wastewater treatment within the industry and waste treatment of the packaging material. The life cycle ends after the municipal sewage treatment plant.

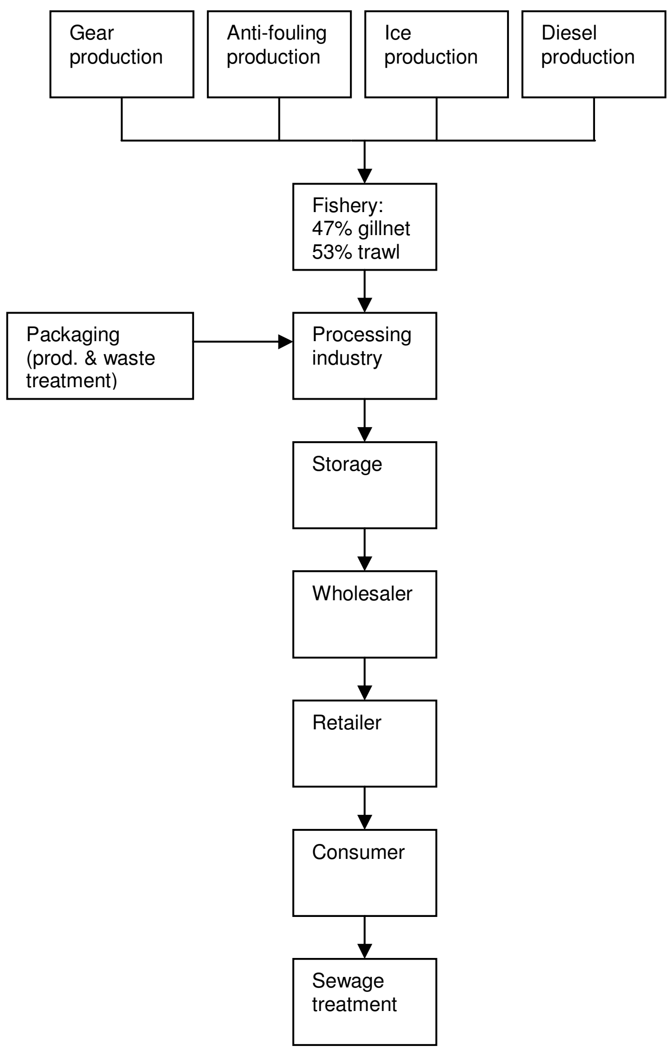

Fig. 1 *The studied system. Transportation between the different phases and fuel and electricity production is not shown but was included in the model.*

2.2 Functional unit

The functional unit is a consumer **package of 400g of frozen cod fillets** reaching the household, fished by Swedish fishermen in general and processed by a major seafood company. It was chosen because it is an easily understandable unit and a common seafood product in Sweden and is referred to as the product, a cod block or the FU. We chose to study the Baltic fishery in general, rather than the specific vessels supplying the processing industry with fish, in order to make the results more generally applicable.

2.3 System description

2.3.1 The fishery

Cod (*Gadus morhua*) fishery in the North Atlantic has a long history (Kurlansky 1999). Even though major stocks in the north-western Atlantic have already been depleted, in the north-eastern Atlantic, cod fishery continues to be an important livelihood in many coastal regions though decreasing during the last decade. The Baltic cod represents over 80% of the total Swedish cod catches, whereas Swedish catches only constitute around 20% of the total cod fishery in the Baltic. In the Baltic Sea, two genetically different stocks exist, which are both currently fished outside safe biological limits (Anon. 2000a). Cod is, though, still the commercially most important species in Swedish fishery and, in the form of frozen fillets blocks, it is one of the most common seafood products consumed in Swedish homes. During 1999 Swedish fishermen landed about 21000 tons of cod with a first-hand value of 300 million SEK (around 30 million USD) (Anon. 2000b). Around 47% of the Swedish cod catches from the Baltic are caught by gillnets and 53% by benthic and pelagic trawls (1999), with a trend towards a slowly increasing proportion of landings by trawl in the most recent years.

2.3.2 Life-cycle after fishery

Cod processed to frozen fillets normally originates in the Baltic fisheries, while fresh cod sold in Sweden is generally fished along the Swedish west coast[2] (i.e. in the Kattegat and Skagerrak). Since the product followed in the present LCA is a processed and frozen block of cod, we used data for Baltic fishery. Three scenarios of Baltic fishery were included; gillnet and trawl fishery and a weighted mixture of the two (47% gillnet and 53% trawl), reflecting the Swedish fishery of today in the Baltic. The product was then followed through a major processing industry, producing the market-dominating brands of consumer-packed frozen cod blocks[3]. The industry is situated on the island of Bornholm in Denmark and around 4000 tons of gutted cod are processed per year[4]. The processing industry produces around 30% of the consumer-packed frozen cod fillets consumed in Sweden. The product is transported first by lorry to the port on Bornholm, Rønne (30 km) and from there by ferry to Ystad in Sweden (68 km). From Ystad, the cod blocks are taken by lorry to storage in Helsingborg (117 km) from where they are transported to all major wholesalers in Sweden. Of the total product volume, 30% goes to wholesalers in Stockholm, 20% to Malmö, 20% to Göteborg, 15% to Växjö and 15% to a wholesaler in Umeå. The product is stored at the wholesaler and then transported to retail stores all over the country. From the retail store, the product is generally transported by car or bicycle to the household (Orremo 1999), where the consumer stores it in the freezer before preparation. It was assumed that the fish is prepared in the oven and that the household wastewater is connected to municipal sewage treatment. It has also been assumed that no product waste occurs after the processing industry.

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[2] This difference is due to a curious complication: Even though the cod from the Baltic and west coast are un-separable in blind tests, the west-coast-cod is said to hold higher quality and it achieves up to 35% higher prices than the Baltic cod.

[3] Findus/Frionor hold 42% of the total volume of consumer-packed 400g cod blocks sold in Sweden

[4] corresponding to about 70% of Findus/Frionors sales of the product

3. METHODS

3.1 Data inventory methodology

3.1.1 Fuel consumption and emissions

Catches, gears, engine and vessel types in Swedish cod fishery

All data described in this section were obtained from the fishery statistics and the vessel register at the Swedish National Board of Fisheries (NBF). An overview over the structure of the emission study (Ziegler 2002) is given in Fig. 2. The data from the fishery statistics concerns all cod landings reported to the NBF in 1999 and includes information about the amount landed, the harbour of landing, the gear used, the geographic position where the gear was put into the sea and the size of the vessel (box 1. in Fig.2). Data from the vessel register was given in the form of engine size, type and age of vessel and reported cod catches for each vessel in 1999 (box 2. in Fig.2). The data material is presented in summary in Tables 1-3.

Table 1 *Amount of cod fished with different gear types in 1999 in the seas surrounding Sweden (kg)*

Fishing Gear	Kattegat	Skagerrak	Baltic	*Total*
Benthic trawls	2 015 700	1 503 710	6 939 153	10 458 562
Semi-pelagic trawls	-	580	1 382 046	1 382 626
Gillnet	127 642	66 670	7 830 840	8 025 152
Other	230 921	342 149	496 183	1 069 252
Total	2 374 263	1 913 109	16 648 221	20 935 593

Table 2 *Catches during 1999 by engine size classes*

Engine size class (hp)	Engine power (kW)	Catches (kg)
0-100	0-74	4190872
100-200	74-147	2000478
200-350	147-257	2831350
350-450	257-331	2433411
450-700	331-515	3724917
>700	>515	5754567

Table 3 *Catches during 1999 by engine age classes*

Decade of engine installation	Number of vessels	Catches (kg)
<1969	75	2017394
1970-1979	206	5145206
1980-1989	294	6973615
1990-1999	89	4302044
Unknown	190	2497334

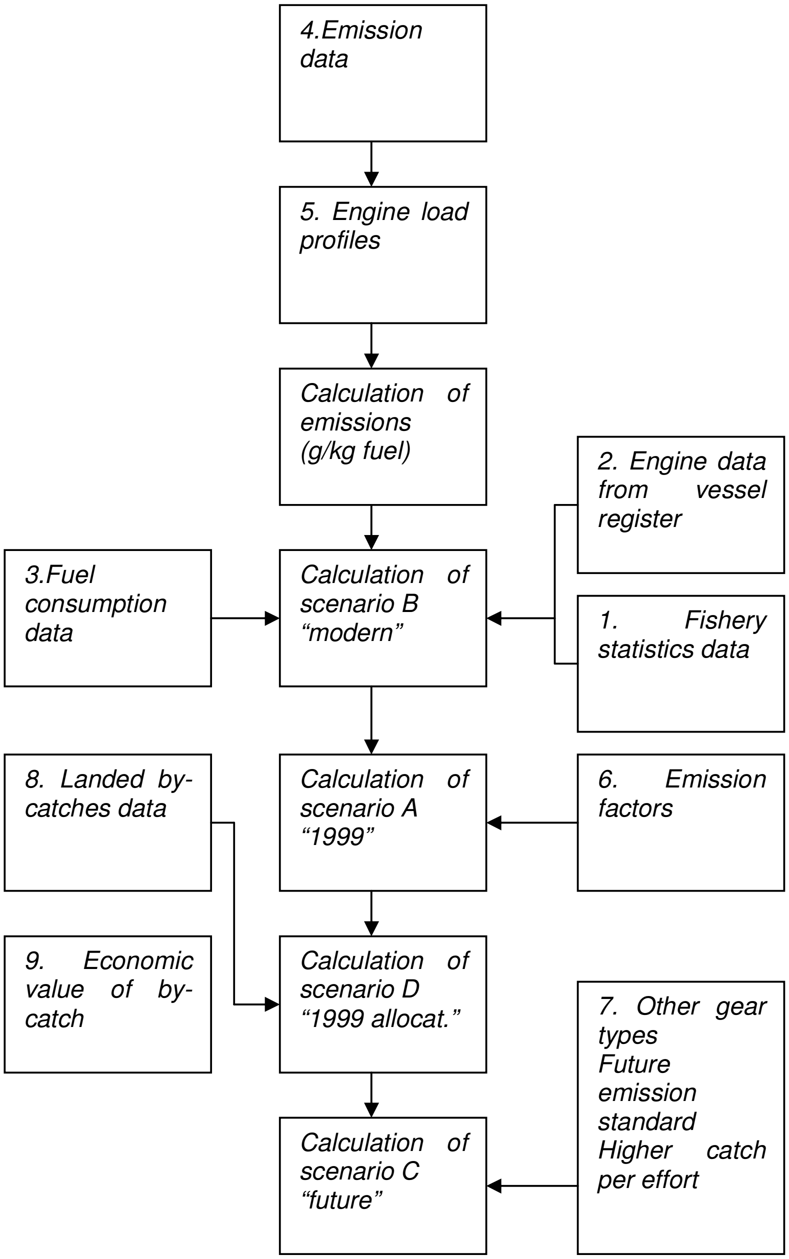

Fig. 2 *Overview over how the study was performed. Numbered boxes indicate data used as input in the calculations, boxes without numbers indicate calculation steps and the four calculated scenarios. The allocated scenario (D) is based on scenario A ("1999") and the future scenario (C) is based on scenario B ("modern engines").*

Fuel consumption and engine load profiles for different fishing methods

Fuel consumption in the studied cod fisheries was determined by sending out a questionnaire to randomly selected fishermen from different parts of the country which, according to the vessel register, use cod specific gear. It included questions about the fuel consumption of their vessel during different modes of operation, the total fuel consumption and catches of different species during 1997-99. The fishermen also answered what type and size of engine is installed on their vessel. Since some of the fishermen no longer used cod gear, only some could be used in this study. Data is therefore based on the answers from seven cod trawling fishermen and six cod gillnet fishermen. The result of the questionnaire regarding fuel consumption was that for cod fishing with gillnets, 0.34 (SD: 0.26) liters of diesel were used per kg of cod landed, whereas for trawled cod the corresponding figure was 1.41 (SD: 0.72) l/kg (box 3. in Fig.2 and Fig. 3). The engine load profiles used for trawl and gillnet fishery respectively in a Norwegian study have been assumed to be valid also for Swedish fishery. According to this study, the load on the engine of a trawler is 90% for 20% of the time, 80% for 50% of the time and 30% for the remaining 30% of the time. The load on the engine of a gillnet vessel is 95% for 10% of the time, 80% for 30% of the time and 20% for the remaining 60% of the time (Meltzer 1991).

Calculation of emissions

The standardised test procedures present data for the regulated carbon monoxide (CO), nitrogen oxides (NO_x) and hydrocarbon (HC) emissions, which all depend on the engine design. Calculating the carbon dioxide (CO_2) and sulphur oxide (SO_x) emissions is also of interest, but these values are linearly related to the amount of energy and sulphur in the fuel used, respectively, and are therefore more straight-forward to calculate. The fuel used is diesel oil of the lowest environmental class (EC 3). In the present study, the amounts of CO_2 produced are calculated as 3.17 kg/kg of fuel and the energy content is 42.8 MJ/kg fuel (Anon. 1999a). The amounts of SO_x are calculated as 0.7 g/kg fuel, based on the maximum allowed sulphur content of 350 ppm in the fuel (SPI 2001).

Emission data was made available by Volvo Penta, an engine manufacturing company producing the engines most commonly used on Swedish fishing vessels (Wallström 2001). Detailed emission data was given for engines typical for each of the size classes described in Table 2, except for the largest size class. For each engine, emission data was available for 4-8 combinations of loading torque and engine speed. The number of test modes was dependent on the test procedure used. For the TAMD 72 engine emission data was available, for example, for 0, 25, 50, 75 and 100% of the maximum load. It was tested according to the ISO 8178 E5 standard. Since it was not possible to obtain data for an engine >700 hp from Volvo Penta, this size class was assumed to be represented by the largest engine, i.e. the TAMD 163 (box 4. in Fig.2).

Typical engine loads in gillnet and trawl fishing were described earlier in this section. For each of the typical loads, emissions were calculated from the available test data using linear interpolation between each of the load combinations described in the standard according to which it was tested. These figures were then weighted together, using the percentage of time at each level of engine load as weighting factors for the two fishing methods studied (box 5. in Fig.2). Table 4 presents the calculated emissions when each of the engines are operated at load conditions typical for trawling and gillnet fishing, respectively.

Table 4 *Emissions produced by modern marine diesel engines when performing different fishing operations (calculated values).*

		Emissions when trawling (g/kg fuel)			Emissions when gillnet fishing (g/kg fuel)		
Power (kW)	Type	HC	NO_x	CO	HC	NO_x	CO
74	TAMD31m	1.00[a]	34.5[a]	1.07[a]	1.08	33.7	1.27
170	TAMD63	2.36[a]	22.9[a]	3.22[a]	3.35	25.4	4.36
260	TAMD102a	0.99[a]	33.8[a]	1.73[a]	1.31	35.8	2.16
322	TAMD72	1.32	31.7	2.40	1.83[a]	34.2[a]	2.25[a]
404	TAMD163	0.92	37.6	1.85	1.13[a]	42.9[a]	2.55[a]

[a] the fishing method is not common on vessels with this engine size

The distribution of the catches on vessels with different engine size was described in Table 2. When calculating the average emissions per kg fish for the different fishing methods, this size distribution was used to weight together the emissions according to catches represented by each size class.

All emission data obtained are from tests of engines not older than 5 years. On average, these modern diesel engines produce lower emissions per kg of diesel used than older ones, mainly because of the introduction of after-cooling in engines. The distribution of the catches on vessels with engines of different age classes (Table 3) shows, however, that the amount of cod caught by vessels with older engines is considerable. In order to calculate representative values, it was therefore necessary to estimate the levels of emissions from older engines. Table 5 shows relative emissions from engines of different age classes when compared with engines produced after 1990, which corresponds to the time when the main part of the engines in Swedish fishing vessels were after-cooled. The values in the table have been provided by experts at Volvo Penta. The variations between engine types are, however, considerable and the values should be regarded as rough estimates (box 6. in Fig.2).

Table 5 *Relative amount of emissions from older engines when compared to the amounts produced by engines from the 1990s, estimated by experts at Volvo Penta (TAMD: Turbo After-cooled Marine Diesel, MD: Marine Diesel, TMD: Turbo Marine Diesel).*

		Emission factors compared to the age class 1989-2000		
Age class	Engine type	CO	NO_x	HC
1989-2000	TAMD	1.0	1.0	1.0
before1989	TMD and MD	2.8	2.4	2.7
before1989	TAMD	1.9	1.5	1.4

Table 6 *Proportion of engines without after-cooling installed in different decades.*

Decade of engine installation	Proportion of engines without after-cooling (%)
<1970	100
1970-1979	75.0
1980-1989	65.4
1990-1999	31.3

The distribution of the catches on vessels with engines of different ages was described in Table 3. For the calculations of emissions per kg fish for the different techniques, this distribution, together with the emission factors described in Table 5 and the relative proportion of engines without after-cooling (MD and TMD) during different decades, given in Table 6, were used to compensate for the larger amounts of emissions produced in fishery on vessels with older engines. For the fuel consumption and emission calculations, the following four scenarios were included:

Scenarios

A. Swedish cod fishery during 1999

The scenario comprises all cod fishery reported by Swedish fishermen and landed in Swedish harbours during 1999. Emission data for engines representing different size classes and ages are weighted with regard to their proportion of the total catches. Typical engine load profiles for trawling and gillnet fishing are used as well as data on fuel consumption, provided by fishermen.

B. Modern engine and fuel technology

The difference from the first scenario is that the emission factors for engine age are disregarded in order to look at the effect of installing modern, after-cooled engines in the entire fishing fleet. A 10% lower fuel consumption due to increase in fuel efficiency was assumed for all engines. The effect on sulphur oxide emissions of changing fuel from EC 3 to EC 1 is also calculated.

C. A future scenario for Swedish cod fishery

This scenario is an extension of the previous scenario (B) taking into account a number of additional changes that could take place in the Swedish cod fishery in the future (box 7. in Fig. 2). It is emphasised that this future scenario is only one of several possible ways the fishery might develop and that changes are very difficult to predict. The future perspective is 5-10 years. A change in the use of fishing gear was assumed; a slight increase in Danish seine and long-line fishery (5% of total landings, respectively) as well as pair-trawling (10% of total landings) connected to a decrease in single-trawling (still representing 40% of total landings). Gillnet fishing is assumed to account for the remaining 40% of total cod landings. Fuel consumption data for pair-trawling, Danish seine and long-lining were taken from literature and the emissions were calculated from the same engine emission data by using typical engine load profiles for these fishing methods. The engine load during pair-trawling was assumed to be similar to single trawling.

In addition, an estimate of change in fishing effort, based on the fact that the Swedish cod quota for 2002 is 30% lower than for 2001, was made. The assumption is that fishing effort targeting cod will decrease as much as the total landings under the new quota (30%) and since effort has been decreasing more (36%) than catches (26%) between 1999 and 2001 this leads to a higher catch per unit effort (CPUE) compared to 1999. The increase in CPUE due to this assumption would be 16% and such an increase would be connected to an equal decrease in fuel consumption per unit of catch (16%), because total fuel consumption is linearly correlated to fishing effort.

For all fishing methods except gillnetting and Danish seine (where much less time is spent steaming), it was also assumed that optimising speed can lead to a reduction of fuel consumption of 10% (Hassel 2001). Studying emission standard development for marine diesels in the EU and US, led to an estimated decrease of nitrogen oxide emissions of 50% in the future scenario, but no decrease in carbon monoxide and hydrocarbons since the emissions of these are already well under expected future limits (Wallström 2001).

D. Allocation strategies

The allocation scenario takes into account that there are more by-catches in the Skagerrak and Kattegat cod fisheries than in the Baltic. The difference is due to increasing salinity and biodiversity along a gradient from the Baltic to the North Sea. The same data for fuel consumption, engines and engine load and emission factors as in scenario A is used for the three areas. The only variable added is the amount of by-catches (box 8. in Fig.2). Data on the amounts of landed by-catches was gathered from the fishery statistics at the NBF. Mass and economical allocation was performed to demonstrate the effect on the results. For the economical allocation, average first-hand prices in 1999 were used for 28 commercial species (SFPO 2000), see Table 7 (box 9. in Fig.2) for the relative proportion of mass and economic value represented by by-catch in the investigated fisheries.

Table 7 *By-catches share of the mass and economic value of the catch (%) in different cod fisheries*

	Mass		Economic value	
Ocean	Trawl	Gillnet	Trawl	Gillnet
Baltic	1.5	1.2	0.75	0.44
Kattegat	20	15	39	14
Skagerrak	48	38	65	39
Weighted total	11	1.7	17	0.98

3.1.2 Seafloor use

The seafloor use was determined by analysing fishing effort data (measured as hours fished) with trawling gear from the official fishery statistics in a Geographical Information System (GIS). Trawl dimensions and typical speeds during trawling were then obtained from trawl manufacturers and fishermen and led to figures of impacted area per trawl hour. This area was then multiplied by the fishing effort and led to a total impacted area per landed catch. In order to separate the impact occurring in regularly oxygen-depleted sediments from impact taking place in areas with a macrobenthic community as described in section 1.2, a division of impact above and below the 80m depth isocline was made. It is emphasised that the impact of mobile fishing gear certainly leads to different kinds of biological effects depending on the type of sediment where it occurs, the frequency of the disturbance and also the specific type of gear in use. The calculated area is simply a measure of the area a trawl has to sweep to obtain a certain amount of catch and does not indicate anything about the biological effects.

3.1.3 Discards

Discard data was taken from the data collected under the International Baltic Sea Sampling Programme (IBSSP), an EU-funded project collecting discard data for fisheries in the Baltic Sea. Data was given for the years 1999 and 2000 and for cod trawling and gillnet fishing in an aggregated form (sum of discards for a variety of species and sum of landed catches of a number of species for the hauls and sets done in one year) (Walther 2001). In order to separate a pure biological impact, when non-commercial species are discarded, from a combined biological and economical impact, when undersized or even marketable commercial species are discarded, two types of discards were distinguished, commercial and non-commercial, based on the availability of average prices at the producer organisation of Swedish fishermen (SFPO 2000). The amounts of commercial and non-commercial discard were included in the LCA as a resource flow. In order to assess the impact of this resource use, an expert in the field calculated how much the discarded, undersized cod (the main constituent of commercial discards) would mean in terms of future spawning biomass and future catches if left to grow in the sea instead of catching it while still premature (Sjöstrand 2001).

3.1.4 Fishing gear material and ice production

Amounts of ice needed per kg of catch on gillnet and trawling vessels were taken from a Finnish environmental study of coastal and open sea herring fisheries in the Baltic (Lillsunde 2001). A manufacturer of ice machines provided data for energy use in ice production (Blomgren 2001). Data on material use for gear production was taken from a trawl manufacturer and for gillnets from a few fishermen (which often make their own nets). They were asked what kind of and how much materials their gears contain and how long the life-time of the gear is. Data in the fishery statistics on typical annual cod landings by gillnet fishing and trawling vessels, respectively, gave the relation between amount of material used and landed catch.

3.1.5 Anti-fouling paints

In the questionnaire sent out to fishermen to obtain fuel consumption data, questions were also included on the use of anti-fouling agents. Type of paints and amounts used per year were reported. From the producer of one of the common brands, data was obtained on the content of toxic substances and release rate once applied on the hull. The producer also provided information on energy use and emissions during production as well as distribution routes of the anti-fouling product (Jotun 1998; Gjerdevik 2001).

3.1.6 Process industry, storage, wholesalers, retailers and transports

Data for production, resource use and emissions in the process industry was kindly provided by Nordfilet A/S and their main customer Findus AB for the year 2000 (Hansson 2001). The production does not vary a lot from year to year, the main production limitation is the availability of raw material (i.e. cod) fulfilling the quality criteria of the company. The process industry also provided information about which wholesalers buy their products and about the packaging material. The product is packed in 400g blocks in LDPE-laminated cardboard and as only secondary packaging material, LDPE is used. The road carrier, wholesalers and later retailers were then contacted about product turnover times and energy consumption during storage of the frozen product. In the retail store, the most energy-consuming activity is the exposure of the product in the store, why specific data for this exposure was collected from a manufacturer of open retail freezers. Information from a study on the environmental impact of retail stores in general was used to calculate the energy used for activities apart from freezing in the retail store. For transports, the road carrier provided information on the amount of additional energy used due to transportation of frozen products compared to non-frozen transports. Data for resource use and emissions during non-frozen transportation were taken from databases (CIT-Ekologik 2001c). Data and assumptions for the transport from the retailer to the household were based on literature (Orremo 1999). Economical allocation was performed for this transport, i.e. the environmental impact was split up between the different products we take home when we have been shopping on the basis of economic value.

3.1.7 Consumer and sewage treatment

For the household phase, storage in a freezer for 14 days and preparation in the oven was included. Data for energy consumption of the freezer was taken from an Environmental Product Declaration (EPD) for Electrolux freezer ER 8209C (Electrolux 2000). Data for preparation has been measured in the test kitchen at SIK and average data for the most energy-consuming mode of preparation (oven) was used (Thorsell Nilsson 2000).

The household was assumed to be connected to a municipal sewage treatment plant. Municipal sewage treatment was included in order to have the system boundary on the border between nature and the technosphere. The sewage treatment plant is where the product ends its life cycle through our society and the nutrients in it are recycled back into the sea. These emissions, although originating in the product and being returned to the sea, occasionally may contribute to coastal eutrophication due to the high concentrations emitted in coastal areas. Nutrient emissions were calculated from data on nutrient content of the product and average rates of reduction of nutrients in the plant (SEPA 1997). Average data for energy use for the treatment of sewage water was used as input in the sewage treatment plant (Dalermo 1996).

3.2 Impact assessment methodology

Environmental impact categories included in the LCA study were: Global Warming Potential (100 years), Acidification Potential, Nitrogen Eutrophication Potential and Phosphorous Eutrophication Potential, Aquatic Ecotoxicity and Photochemical Ozone Creation Potential. Due to the higher eutrophication potential of phosphorous in a nitrogen-limited marine environment, two category indicators were calculated for eutrophication, one for nitrogen-containing emissions and one for phosphorous-containing compounds to be evaluated separately. Ozone Depletion Potential was not included due to a lack of data on ozone-depleting refrigerants used for freezing and cooling. The refrigerants used in the life-cycle of the studied product are R404a (ODP: 0, GWP: 3750) and ammonia, NH_3, but no data on the use of these refrigerants was found (refilling was very uncommon), why this is a data gap. Impact assessment indexes were taken from a database (CIT-Ekologik 2000), except Eutrophication N and P (Wenzel 1997), Aquatic Ecotoxicity (Heijungs 1992a; Heijungs 1992b) and Eutrophication Potential (EPD) (Anon. 1999b). Resource use, seafloor use and biological extraction are categories of environmental impact that were not characterised, due to lack of data and/or characterisation methodology, but are discussed qualitatively in the discussion. The LCA was performed in LCA software LCAiT (CIT-Ekologik 2001a).

4. RESULTS

4.1 Inventory results

4.1.1 Fishery

Fuel consumption and emissions
Results of the questionnaire regarding fuel consumption are shown in Fig. 3, data was described in section 3.1.1 (page 12). Results from the emission calculations are presented in Tables 8-11.

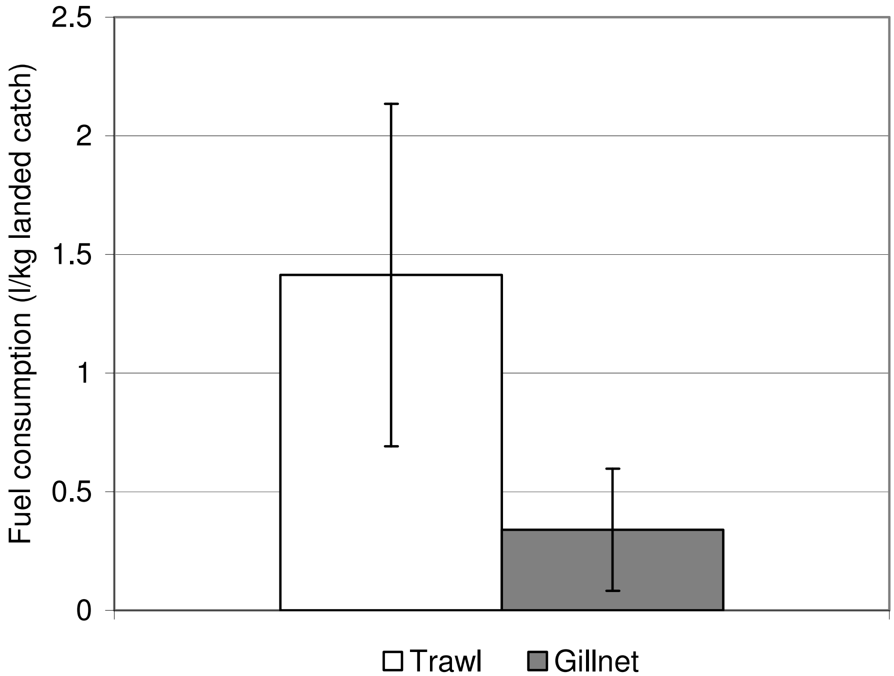

Fig. 3 *Fuel consumption reported by cod fishermen using trawls and gillnets (error bars show standard deviation)*

Table 8 *Emissions from Swedish cod fishery during 1999*

Fishing gear	Emissions (g/kg cod[b] landed)				
	HC	NO_x	CO	SO_x	CO_2
Trawling	2.69	87.4	4.56	0.83	3782
Gillnet fishing	1.04	18.3	1.48	0.20	912
Weighted total[a]	2.06	61.2	3.39	0.59	2691

[a]38% fished by gillnets and 62% trawled
[b]including by-catches, i.e. no allocation has been made

Table 9 *Emissions from Swedish cod fishery (including by-catches) if new engines were installed*

Fishing gear	Emissions (g/kg cod landed)				
	HC	NO_x	CO	SO_x	CO_2
Trawling	1.12	39.4	1.78	0.75	3404
Gillnet fishing	0.43	8.29	0.58	0.18	821
Weighted total[a]	0.86	27.6	1.32	0.53	2422

[a]38% fished by gillnets and 62% trawled

Table 10 *Emissions from Swedish cod fishery (including by-catches) in the future scenario*

	Emissions (g/kg cod landed)				
Fishing gear	HC	NO_x	CO	SO_x	CO_2
Trawling	0.84	14.7	1.33	0.56	2541
Gillnet fishing	0.36	3.48	0.48	0.15	689
Pair-trawling	0.59	10.3	0.93	0.39	1779
Danish seine	0.42	6.29	0.50	0.22	1014
Long-lining	0.72	10.9	0.92	0.39	1784
Weighted total[a]	0.60	9.17	0.89	0.35	1610

[a]40% fished by gillnets, 40% by trawls, 10% by pair trawls and 5% by Danish seine and long-lines, respectively

Table 11 *Mass and economical allocation performed on the data from scenario A*

		Emissions (g/kg cod landed)				
Fishery	Allocation	HC	NO_x	CO	SO_x	CO_2
Baltic[a]	Mass	1.89	54.2	3.07	0.53	2400
Baltic[a]	Economical	1.90	54.6	3.09	0.53	2418
Kattegat[a]	Mass	2.09	67.2	3.53	0.64	2911
Kattegat[a]	Economical	1.62	52.2	2.74	0.50	2261
Skagerrak[a]	Mass	1.38	44.5	2.33	0.42	1927
Skagerrak[a]	Economical	0.95	30.5	1.60	0.29	1322
Weighted total[b]	Mass	1.90	56.5	3.13	0.54	2484
Weighted total[b]	Economical	1.84	54.7	3.03	0.53	2404

[a]weighted total for both gear types (Baltic: 47% gillnet, 53% trawl, Kattegat: 5.4% gillnet, 94.6% trawl; Skagerrak: 3.5% gillnet, 96.5% trawl)

[b]38% gillnet and 62% trawled

Target species/ by-catch/ discard

Total international landings of cod from the Baltic were around 115000 tons in 1999. The greatest part was caught from the eastern stock (63%). Around 60% of the estimated total biomass of the eastern stock was fished in that year. Excluding the youngest year classes, the ratio between landings and spawning biomass was 0.98. Recruitment (i.e. the survival of juveniles to commercial size or maturity) has been low and fishing mortality (i.e. fishing pressure) high during a number of years and today the stock is considered to be in a critical condition. The western stock is also considered to be fished outside safe biological limits, here the removal of biomass was 70% and the ratio between landings and spawning biomass is over one, indicating that a large amount of smaller fish was taken. These figures support the conclusion reported earlier that cod fishery in the Baltic is at present not done on a sustainable basis.

Landed by-catch was around 7 kg/ton cod landed for gillnet fisheries and 12 kg/ton cod landed for trawl fisheries (0.3 and 1.1% of economic value) during 1999. Main by-catch species in gillnet fishery were flounder (*Platichthys flesus*), sea trout (*Salmo trutta*) and vendace (*Coregonus albula*) and in trawl fishery flounder, plaice (*Pleuronectes platessa*) and turbot (*Psetta maxima*). Economic allocation between the different landed species was based on the economic value, this is explained in more detail in section 3.1.1 (scenario D and Table 7) and discussed briefly in section 5.1.2. The discards mainly consist of under-sized cod, flounder, turbot and bull-rout (*Myoxocephalus scorpius*) as presented in Table 12. A division into commercial and non-commercial discards is presented in Table 13. The division was based on the availability of average first-hand landing prices at the producer organisation of Swedish fishermen.

Table 12 *Main discard species (kg/ton cod landed, 1999)*

Species	Trawl	Gillnet
Flounder	26	22
Cod	49	18
Turbot	2.5	0.1
Bull-rout	0	6.6

Table 13 *Baltic discards divided into commercial and non-commercial species, 1999 (kg/ton cod landed)*

	Trawl	Gillnet
Commercial	78.5	41.3
Non-commercial	0.1	6.6
Total	78.6	47.9

Seafloor use

Assuming a typical single cod trawl is 55m between otter boards (double trawls 110m) and a trawling velocity of 2 knots (nautical miles per hour) gives an impacted seafloor area of 0.22 and 0.43 km^2 per trawl hour, respectively. Multiplying trawl effort data with these factors gave an average value of 1711 m^2 of impacted seafloor per kg of *trawled* cod, corresponding to a square of 42*42m. Dividing the fishing effort into above and below the 80m-depth-isocline and over-laying the fishery statistics data with the 80m-isocline in the GIS showed that 93% of the trawl effort occurs on sediments above 80 m, i.e. in areas with a benthic community, while 7% of the effort occurs on sediments below 80 m, i.e. in areas that are colonised mainly by sulphur- and nitrogen-reducing bacteria. Weighting of the total seafloor impact value by catches showed that 1593 m^2 of seafloor above 80m and 119 m^2 below 80 m are impacted per kg of *trawled* cod. Weighting according to the distribution between gillnet and trawl fisheries in the Baltic today and relating it to the FU gave a total impacted area of 706 m^2/FU (657 m^2 above 80 m and 49 m^2 below).

Anti-fouling paints

The production of the paint Jotun Super Tropic requires 14.9 MJ/kg of paint and causes an emission of 7.1g volatile organic compounds (VOCs) per kg of paint (Gjerdevik 2001). The paint is produced at the Jotun plant in Flixborough, UK and transported by cargo ships from Hull, UK to Oslo, Norway (1035 km) from where it is distributed by lorry to wholesalers and retailers in Scandinavia (this final lorry transport was disregarded, but generally the transports of supply materials used in fishery were negligible compared to the product transports, as stated in section 4.2.2).

Regarding the use of paint, the variation between vessels was high and no general difference could be distinguished between gillnet and trawling vessels. The use is, of course, related to the hull size and therefore to the vessel size and annual catches.

An overall average figure resulting from the questionnaire was used : 0.725g paint/kg fish landed (0.5ml/kg fish). The type of paint for which data was collected (Jotun Super Tropic) contains 26% (% weight) copper (I) oxide, which corresponds to 0.15 g copper ions (Cu^{2+}) per kg of fish landed, organic solvents, polyaromatic hydrocarbons (PAHs) and xylene (Jotun 1998). The type of paint was chosen because it is in the mid-range (26% CuO) of the paints occurring in the questionnaire (10-56% CuO). Tributyltin (TBT) is not an allowed anti-fouling substance in Swedish coastal waters.

Gear and Ice production

For the calculation of material used in the production of fishing gear, the following data and assumptions were used:

A gillnet is made of around 6 kg of nylon net and a rope made of 4 kg of LDPE and 8 kg of lead. Using 80 nets with a lifetime of 1.5 years means that 53 new nets have to be sewn each year, which is normally done by the fishermen themselves. The nylon net is worn out after this time, while the lead-containing rope is used for making new nets approximately three times (i.e. is used during 4.5 years). After that the lead normally ends up in waste treatment[5]. Data are average data based on interviews with a couple of Baltic fishermen. Catches for such an “average Baltic gillnet vessel” have been around 25000 kg per year for the last couple of years according to the Swedish fishery statistics.

Single trawls consist of a net of low density polyethylene (LDPE), weighing around 75 kg and two iron otter boards of around 450 kg each. Iron chains weighing around 350 kg connect the net to the otter boards. The life-time of the trawl net was by fishermen estimated at two years and the average catch of trawlers in the Baltic was 100000 kg a year in the data material. Otter boards are assumed to be used with a new LDPE-net 10 times, i.e. are used for fishing during 20 years. The resulting estimates of material use for gear production can be seen in Table14:

[5] Although it is a widely recognised problem that some gillnets are lost and continue to fish in the sea for a long time. The lead in the net can, in such cases, pose an environmental risk.

Table 14. *Material used for gear production (g/kg landed cod)*

Material	Gillnet	Trawl
LDPE	2.8	0.38
Nylon	13	-
Iron	-	0.63
Lead	5.8	-

Ice production

Ice is used to maintain the quality of fish after catch. In general, Swedish gillnet vessels in the Baltic take ice with them from land, while trawlers have an ice machine installed on board. Data on energy use for ice production was gathered from a producer of equipment (Blomgren 2001) and ice consumption from a recent study on herring fishery in the Baltic (Lillsunde 2001). An ice machine producing 750kg/day is a typical size used on trawlers and such a machine requires 96 kWh/ton ice. When onboard a trawler the machine and room for cold storage (also requiring around 3kW) is generally run by diesel fuel and this energy is included in the overall diesel consumption. We assumed that 170 kg ice/ton trawled fish is used, even though this varies with the season (Lillsunde 2001). When the trawler is in the harbour, energy is used in the form of electricity. It was assumed that 30% of the time for ice production is while the vessel is in the harbour. The room for cold storage was assumed to be run around 200 days a year (also 30% in harbour). Additional energy consumption as electricity on trawlers is hence estimated at 48 kWh/ton of cod.

Gillnet fishing vessels take the ice from a machine on land of a similar size as the one mentioned, either owned by themselves or together with other fishermen. The energy for the ice production comes from electricity and is therefore not included in the overall diesel fuel consumption, which explains some (although a minor part) of the difference in fuel consumption between the two fishing methods. It was assumed that a gillnet vessel uses 590 kg ice/ton fish landed (Lillsunde 2001) and hence, ice production in the case of gillnet fishery requires approximately 57 kWh electricity per ton of cod.

4.1.2 Process industry

The processing industry makes cod fillets out of gutted, whole, cod landed by both Swedish, Danish and Polish fishermen. However, as mentioned in section 2.2, data for Swedish fishermen in the Baltic in general was used rather than data for the specific vessels supplying the industry with fish, in order to make the results for the fishery more generally applicable. After filleting, freezing and packaging in the industry, where around 1% of the raw material is lost in wastewater as dissolved nutrients, the product is distributed in Sweden as described in section 2.3.2. Some fish mince is produced and frozen for transportation to fish finger production, together with separated larger parts of cod fillet representing 23% of the production value (14% of the mass), which are the main by-products. The parts of the cod, remaining after filleting, are frozen and sold to the pet food industry, as are solids from the industrial wastewater. The consumer-packed cod blocks represent 75% of the economic product value in the company, but only 38% of the product mass flow (i.e. the parts that go to pet food production represent 2 % of the value and 48% of the mass flow). The amount of gutted cod processed in 2000 was 4000 tons and it resulted in around 1700 kg frozen cod fillets being produced. As we wanted to follow the main product, which represents 75% of the economic value of the production to the company, 25% of the environmental impact in the process industry and earlier life cycle was allocated economically to the by-products. The total resource flow through the industry is given in table 15.

Table 15 *Flows through the cod processing industry (per year)*

Flow	Type of flow	Amount/year
Gutted cod	Input (raw material)	3878 tons
Primary package (LDPE-laminated cardboard)	Input (packaging material)	75 tons
Secondary package (LDPE film)	Input (packaging material)	6.4 tons
NH_3	Input (cooling agent)	450 kg
Water	Input (process water)	20969 m^3
Electricity	Input (energy)	1.43 GWh
Oil	Input (energy)	65 m^3
Cod blocks, consumer-package	Output (main product)	1675 tons
Blocks of cod parts and fish mince	Output (by-product)	190 tons
“Fish waste”	Output (by-product)	2013 tons
Nitrogen	Emission to water	2187 kg
Phosphorous	Emission to water	25.2 kg
COD	Emission to water	10332 kg
BOD_5	Emission to water	9100 kg

Environmental data for LDPE was taken from a database (CIT-Ekologik 2001b) and for cardboard production from the manufacturer (Anon. 2001). Waste treatment (85% incineration and 815% landfill) of the packaging material is included under packaging. Data for this was taken from a report (Sundqvist 1999).The wastewater from the industry is treated in a private sewage treatment plant owned by three seafood companies together. Nordfilet A/S contributes by 28% of the water flow to the plant and a weight allocation was made with regard to the emissions leaving the plant, assuming that the wastewater from the three companies has a similar content (Jorgensen 2001). The emissions allocated to the production at Nordfilet A/S are shown in the last four rows in table 15.

4.1.3 Storage, Wholesaler and Retailer

The product is stored in Helsingborg for about 30 days (Thelin 2001). Assuming a storage room requiring 0.3 W/dm^3 and filled to 50% is used (Rindhagen 2001), the energy required for storage is 0.110 kWh. Assuming the same type of storage room as during storage and a storage time of 7 days at the wholesaler (Gunnarsson 2001), energy consumption at the wholesaler is 0.026 kWh.

Specific energy consumption data from manufacturers of retail freezers (Rindhagen 2001) was combined with data from a study on retail stores to calculate for the energy used for other things than freezing (Carlson 2000). An assumption was that the retail freezer was 100% filled. The lowest value of energy represented by freezing (58% of total) was chosen as a “worst case” leading to an energy consumption at the retailer of 0.31 kWh (10 days of storage and 10 days of exposure in the store).

4.1.4 Transports

For truck and ferry transports, database data was used (CIT-Ekologik 2001c). Transportation from the industry to the wholesaler was assumed to be carried out by heavy trucks that are empty on the way back and after the wholesaler by medium trucks going back with 50% load. The average distance from the storage in Helsingborg to the wholesalers was 429km (storage time at the wholesaler is around 7 days) and from wholesaler to retailer 238km (Gunnarsson 2001; Thelin 2001).

The home transport from the retailer was assumed to be made by car in around 60% of shopping occasions (Orremo 1999) and otherwise walking or by bicycle, without environmental impact. Swedish consumers spend on average SEK 208 in the supermarket per shopping occasion (Orremo 1999). The product price is around SEK 35 and economical allocation therefore means that around 17% of the environmental burdens resulting from the home transport should be allocated to the product. The average distance of this transport was assumed to be 7.8 km (Orremo 1999).

4.1.5 Consumer

In the consumer phase, two activities were included; storage in the freezer (14 days) and preparation of a meal in the oven.

A modern household freezer (Electrolux 8209 C) consumes 1.18 kWh/day and has a total volume of 290 dm^3 (Electrolux 2000). The total energy consumption of the freezer during 14 days is therefore 16.5 kWh. It was assumed that 50% of the volume, i.e. 145 dm^3, is used for storing products. The volume of a cod block is 0.5dm^3 and its weight is 0.42 kg.

Allocating the electricity consumption of the freezer based on the product mass and volume (Stadig 2001), gives an energy consumption due to the product of 0.142 kWh/kg

Data is available for less energy-demanding freezers than the one chosen. It was chosen as a “worst case” in order to see if this influenced results significantly.

An average value from measurements of energy consumption during preparation of a cod block (thawed) in the oven was 1.85 kWh/kg (Thorsell Nilsson 2000).

Preparation in the oven is the most energy-consuming way to prepare cod of the ways investigated (frying or boiling on stove or in the microwave is less energy-demanding). It was likewise chosen as a “worst case” to see if it influences the results and it is clear that, compared to the way the product is prepared in the household, it is not storing in the freezer that matters in the consumer phase.

4.1.6 Municipal sewage treatment

According to food nutrient content tables, cod meat contains 2.7 g nitrogen (N) and 190 mg phosphorous (P) per 100g edible meat (Anon. 1986). The performance of the sewage treatment used was 94% reduction of P water emissions and 54% reduction of N water emissions (of which 36% is emitted to air as N_2 and 18 % is found in the sludge). Energy consumption in this process was around 18 MJ/kg of N reduced. This efficiency represents a modern plant with supplementary removal of nitrogen, typical for large (>100000 person equivalents) plants situated along the Swedish coast (Dalermo 1996; SEPA 1997).

4.1.7 Overall uncharacterised life-cycle results

Resources

Primary resources used in the life-cycle of a frozen cod block are listed in Table 16. For an explanation of the impact of discard and target species extraction, see section 4.1.1.

Table 16. *The main primary resources used for production of a cod block (mixed fisheries), unit: g/FU, except seafloor: m^2/FU*

	Resource	Amount
Energy-containing	Crude oil	737
	Coal	32
	Natural gas	38
	Uranium in ore	0.03
Other	Bauxit	0.003
	Copper	0.13
	Iron	0.34
	Lead	2.1
	Commercial cod	1000
	Discarded biomass	50
	Seafloor (m^2)	706

Energy

The use of secondary energy is shown in Fig. 4 and in Table 17, where the dominance of fishery is clearly demonstrated. Fishery is responsible for 72% of the total energy consumption during the products' life-cycle, which was 36 MJ/FU. Trawling required almost four times as much fuel as gillnet fishing. The types of energy used are shown in Fig. 5. The reason why the bar for packaging is negative is due to the formation of district heat in waste incineration which replaces combustion of e.g. natural gas that would otherwise have been used to produce the corresponding amount of district heat.

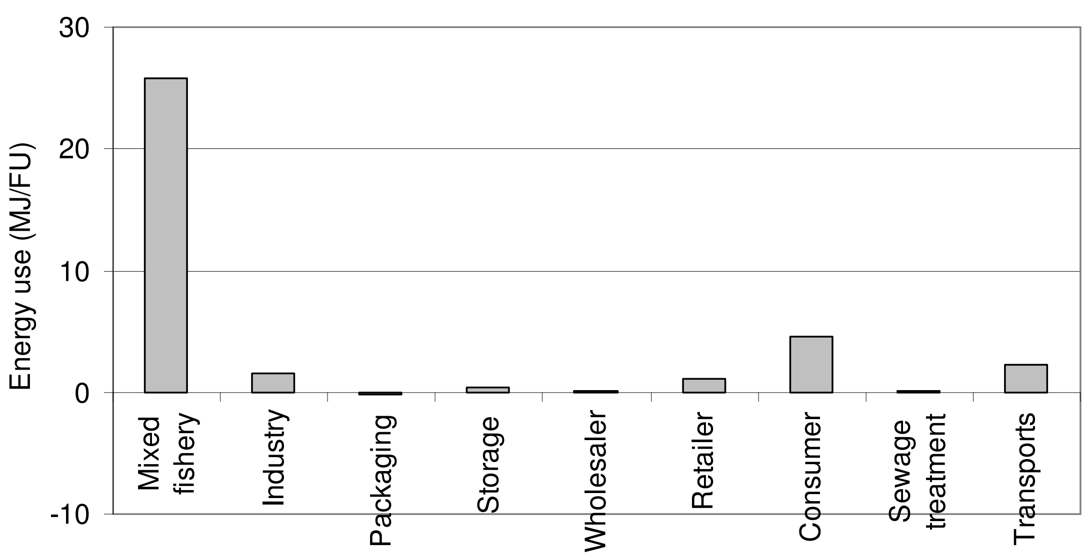

Fig. 4 *Use of secondary energy during the life-cycle of the product*

***Table 17**. Total consumption of secondary energy in the life-cycle phases of the studied product*

Life cycle phase	Total energy consumption (MJ/FU)
Mixed fishery	25.8
Process industry	1.5
Packaging	-0.14
Storage	0.40
Wholesaler	0.09
Retailer	1.1
Consumer	4.6
Sewage treatment	0.08
Transports	2.3

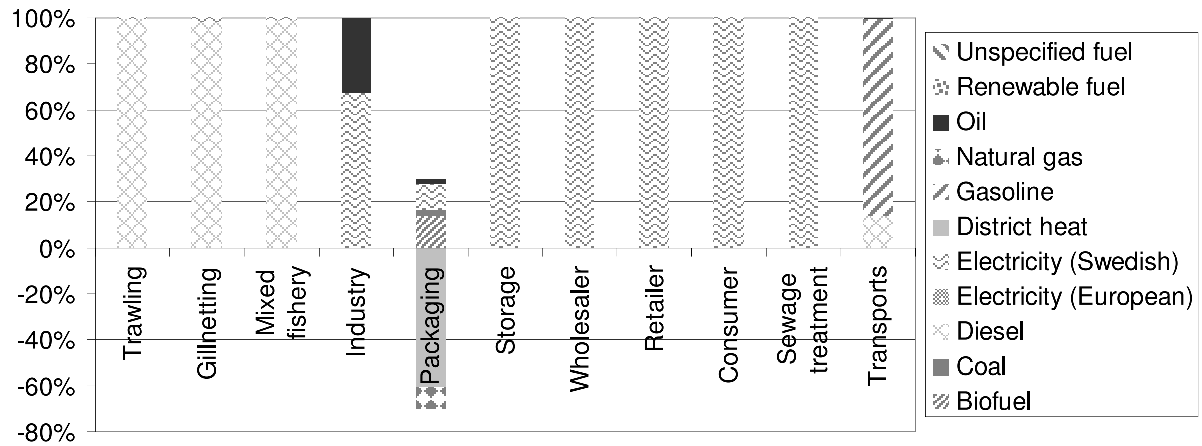

***Fig. 5** Types of energy used in the different life-cycle phases (for an explanation of the negative bar for packaging, see section 4.1.7-Energy)*

4.2 Impact assessment results

4.2.1 Overall life-cycle

Fishery is the phase of the life cycle dominating all investigated impact categories, except Phosphorous Eutrophication Potential, in which the process industry is the main contributor. Fishery includes gear, anti-fouling, ice and diesel production, but all these activities are negligible compared to the fuel combustion in fishery. It was assumed that fishery is a mix between gillnet and trawl fishery reflecting the Swedish fishery in the Baltic in 1999. For the impact categories dominated by fishery (i.e. all except EPP), it is most dominating in Aquatic Ecotoxicity (AE, 99.7%) and least dominating in Eutrophication Potential (EPepd, 70.1%), see Fig. 6.

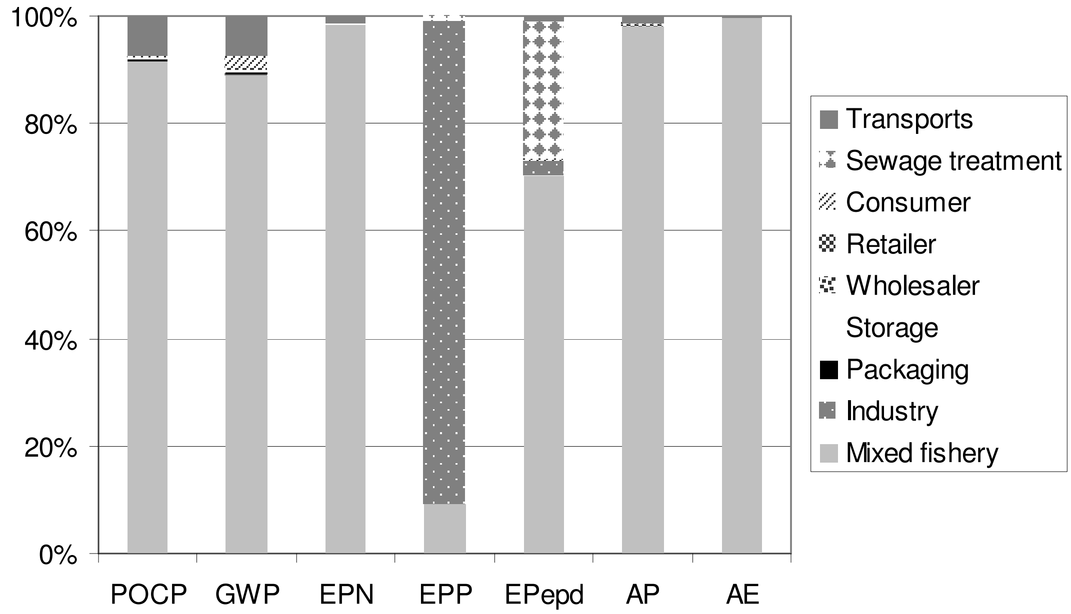

Fig 6. *Total impact assessment results for the environmental impact categories included.*

4.2.2 Global Warming Potential

Mixed cod fishery is responsible for 89% of the emitted CO_2-equivalents. The main part of this is due to fuel consumption on the fishing vessel and the most important contributors to GWP are carbon dioxide, nitrogen oxide and methane emissions. The three alternative fishery scenarios; pure gillnet, pure trawling and combined gillnet and trawl fisheries (Fig. 7) demonstrate a considerable difference between the fishing methods, mainly due to the difference in fuel consumption onboard. When fishery is excluded, transports and consumer are the most important phases for global warming (Fig. 8). The dominating transport is the home transport from the retailer to the household and the activity dominating in the consumer phase is the preparation of food rather than storage in the freezer. The transports summed are only the *product* transports, by truck, ferry and car; not transports of supply materials, which are included under each phase, e.g. fishery and packaging, but they are negligible compared to the product transports.

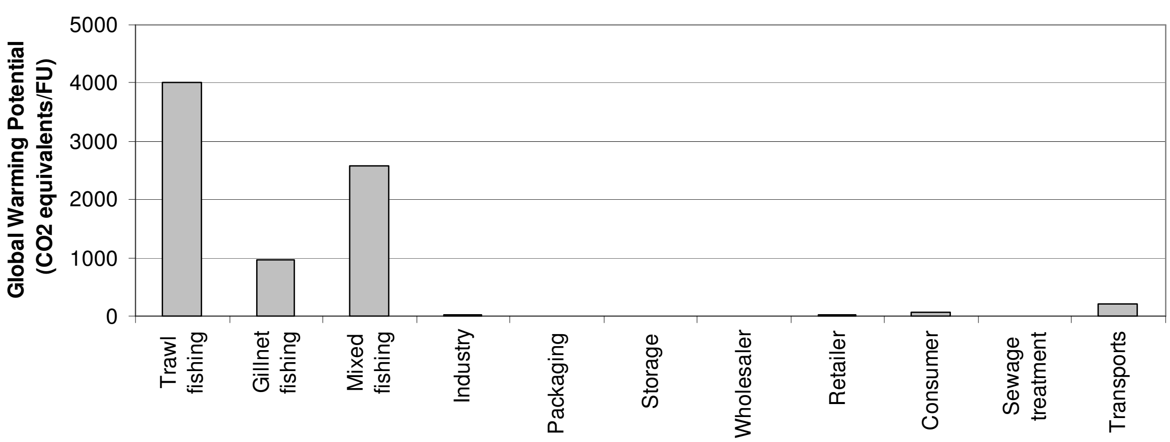

Fig. 7 *Results of characterisation of emissions contributing to global warming. Trawl fishing, Gillnet fishing and Mixed fishing are three alternative ways of fishing.*

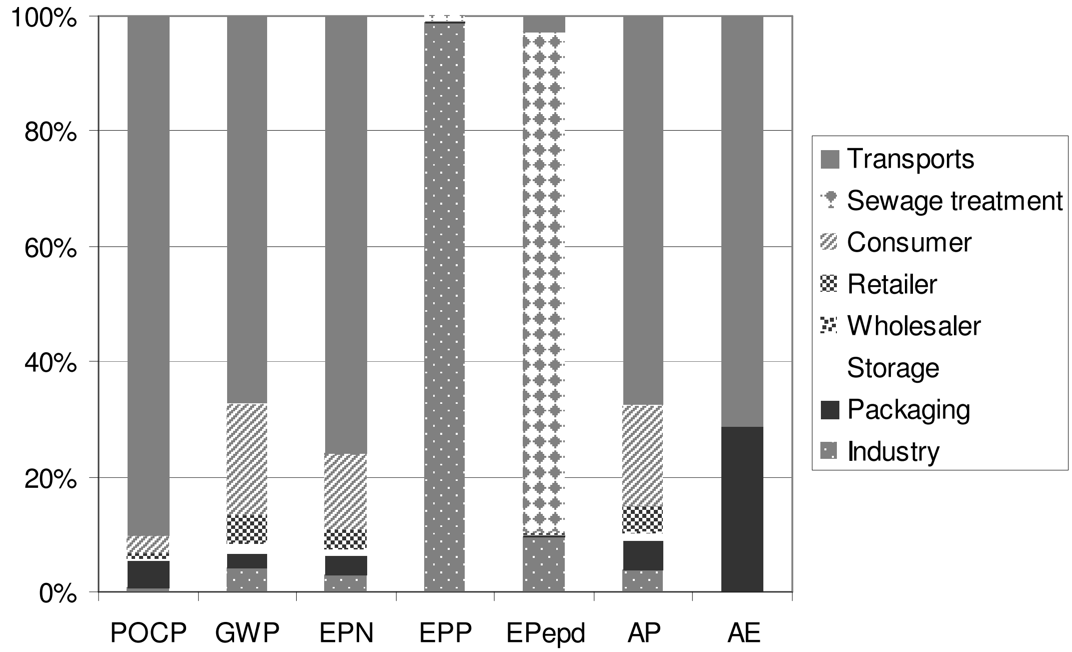

Fig. 8 *Total impact assessment results when fishery is excluded*

4.2.3 Eutrophication Potential (EPD, N, P)

The overall Eutrophication Potential (EPD, including both nitrogen- and phosphorous-containing emissions) is, again, dominated by fishery (70%, see Fig. 6). Fishery is followed by sewage treatment. Characterisation of nitrogen-containing emissions (EPN) shows that fishery through NO_x emission from fuel combustion is dominating completely, followed by transports. In the characterisation of phosphorous-containing emissions (EPP), it is clear that the process industry is responsible for the main part of these emissions (90%), followed by fishery (see Fig. 6).

4.2.4 Acidification Potential

Fishery and transports are the only activities that result in visible bars for acidification in Fig. 6. The difference in acidification potential between the alternative ways of fishing is considerable (Fig. 9), mainly due to the much higher levels of emissions of nitrogen oxides in trawl fisheries. A 97%-decrease in sulphur content of the fuel would not result in a significant decrease in acidification potential, which also shows that nitrogen oxides are dominant in the characterisation results.

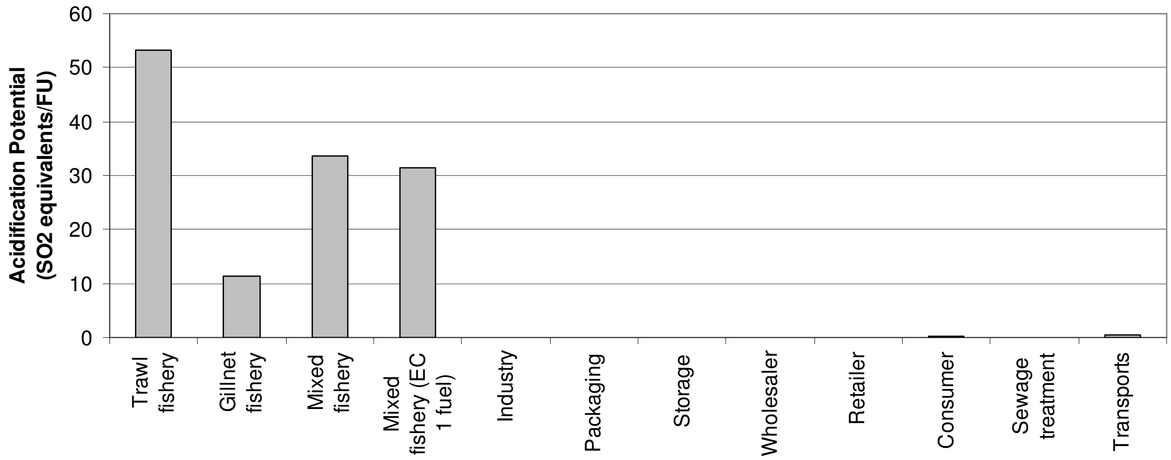

Fig. 9 *Acidification Potential with four different fishery scenarios: pure trawl and pure gillnet fishing, mixed trawl and gillnet fishing and mixed fishing using modern type of diesel (EC 1).*

4.2.5 Aquatic Ecotoxicity

Aquatic Ecotoxicity is completely dominated by the intentional use of copper as anti-fouling agent and it overshadows toxic substances released in diesel and gasoline production and combustion rating transports as the second most important source of toxic substances (the dominance of fishery and transports can be seen in Figs. 6 and 8).

4.2.6 Photochemical Ozone Creation Potential

The main contributors to POCP are volatile organic compounds (VOCs), hydrocarbon and carbon monoxide emissions. All of them origin in diesel and gasoline combustion and the latter is also formed in electricity production (Figs. 6 and 8).

5. DISCUSSION

5.1 Results

5.1.1 Emission study

Fuel consumption
One of the most important results of the present study was that the fuel consumption in the investigated fishery was high and that there was a great difference between the two fishing methods trawling and gillnet fishing, see sections 3.1.1 and 4.1.1. The underlying data material supporting this result is not complete, but rather a small, random sample. Nevertheless, the results are similar to those that have been found in previous studies that have been performed at different times for different cod fisheries in several countries, see references in Ziegler & Hansson (*in press*). Moreover, the variation in fuel consumption within gear type was relatively limited, which is why the difference between gear types could be shown to be statistically significant (Ziegler 2002). However, it would definitely be very useful if fuel consumption data were more readily available and not having to ask fishermen for such information. It would probably be a relatively simple task to introduce registration of fuel use for fishing vessels. Such data would be very useful in environmental assessments of seafood and in order to improve the environmental performance of fisheries in the future.

Emissions
The emission study showed that engine load and engine age are important factors for resulting emission levels. The low average engine load during gillnet fishing leads to higher emissions of nitrogen oxides, carbon monoxide and hydrocarbons *in g per g fuel*. The higher fuel consumption in trawl fisheries compared to gillnet fisheries, results in overall higher emissions *in g per kg of catch landed* for trawlers. A gradual exchange to modern engine technology could decrease those emissions by around 55-60%. However, the emission factors used for older engines are based on the few measurements available from that time and may therefore not be entirely accurate. Sulphur dioxide and carbon dioxide emissions are directly related to the fuel consumption and sulphur content of the fuel and can therefore only be decreased either by changing the fuel type to one with a lower sulphur content or decreasing fuel consumption, which is discussed in section 5.4.

5.1.2 LCA study

Overall
The LCA showed that, from an environmental point of view, fishery is the most important phase in the life-cycle of the investigated product. Emissions from fuel combustion dominate the characterised results of the LCA. In the fishery, a number of additional types of environmental impact occur which were quantified, such as seafloor use and discarding. Because of the dominance of the fishery, the most important issue after landing is to maintain high quality and minimise product losses. The resource use and environmental impact caused during the fishery to obtain the part of the catch that ends up as product loss have to be added to the part that is actually consumed and the size of the losses have a major impact on the overall results.

The LCA was performed specifically for Baltic cod, but in the emission study a scenario was included describing the effect of allocating between the highly different catches in the seas around Sweden (the Baltic Sea, the Skagerrak and the Kattegat). In fisheries with several high-value target species, such as the combined cod and Norway lobster fishery along the Swedish west coast, the choice of allocation method was shown to have a major impact on the results, whereas for the Baltic cod fishery, where the by-catches are low and have low economic value, the choice of allocation method did not influence results significantly (Ziegler 2002).

The catch quality resulting from fishery with different fishing methods has very rarely been quantified and documented. If, e.g., the resulting catch quality is different in gillnet compared to trawl fishing, meaning that in one case a greater part of the landed catch will end up as product loss than in the other; this would, as mentioned earlier, have a major impact on the overall results. Therefore, to quantify quality would be highly desirable in order to be able to account for quality differences in future environmental studies of seafood products.

5.2 Data uncertainty

The lack of data in the presented Life Cycle Inventory sometimes made it necessary to refer to personal communication, websites and unpublished literature. These sources of information have not been reviewed critically and their quality is therefore sometimes unknown.

The most important figures in this LCA are the fuel consumption and resulting emissions in the fishery, gasoline consumption in the transport from the retailer to the household, electricity use for preparation of the food at home, nutrient emissions from the sewage treatment plant (for the impact category Eutrophication Potential) as well as emissions of copper from anti-fouling paints (for the impact category Aquatic Ecotoxicity).

The data material on fuel consumption in fishery is limited and therefore subject to uncertainty. However, as stated earlier, the values are relatively similar to those reported for cod fisheries in other countries and the variation within gear types was limited. With regard to the importance of the data on fuel consumption for the final results of the LCA, however, it would be desirable to use more well-documented data. For the gasoline use, distance and allocation method for the home transport, literature data was used, which must be considered being the most representative data for Swedish conditions. Electricity used for preparation of cod in the oven was measured and an average value was used, why uncertainty of this figure is considered to be low. Nutrient emissions from the sewage treatment plant were taken from a recent study which can be considered to be updated with regard to modern sewage treatment technology, why the accuracy in this figure is considered to be high. Emissions of copper were calculated from the use of anti-fouling reported by fishermen in the questionnaire and this figure varied considerably between fishermen. Moreover, the type of paint and thereby, content of copper, varied and therefore the value used should be regarded more as an indication of the scale of copper emissions rather than a true value.

5.3 Impact assessment methodology

The application of characterisation methods for eutrophying emissions to the marine environment, e.g. Eutrophication Potential (EPD), can be subject for discussion (Anon. 1999b). These methods were developed to be applicable in all kinds of environments, but the impact of phosphate emissions is very different e.g. in lakes compared to the sea. The impact of phosphorous has a much higher impact index than nitrogen (e.g. phosphate: 46 , ammonia: 15 and nitrate: 6 g O_2 equivalents /g emitted, respectively) in this method, as well as in other characterisation methods for eutrophication. This may be a valid estimate in a phosphorous-limited environment, but in many oceans, including the main part of the Baltic Proper, the growth-limiting nutrient is nitrogen rather than phosphorous and hence, emissions of nitrogen compounds will have larger eutrophying potentials in that environment. Therefore, specific eutrophication potentials for nitrogen and phosphorous compounds were calculated. It can also be discussed whether the emission of nutrients from a sewage treatment plant, coming from the seafood itself, really can be called emissions. We followed the recommendation that the system boundary of an LCA should lay where the limit between the natural and the technical system is, in this case starting with fishery and ending with sewage treatment (ISO 1997). Sewage water is generally discharged in coastal areas, where water exchange is limited, and the eutrophying potential is higher than at open sea, why its inclusion might be more motivated. The application of copper-containing paints was the main cause of toxic emissions in the life-cycle of the studied product, followed by transports. However, the methodology for characterisation of toxic substances (Heijungs 1992a; Heijungs 1992b) is not complete and e.g. dioxins are, at present, not characterised why the dominance of copper in the results might be somewhat overestimated. The main part of the emissions of acidifying compounds at high sea will probably be deposited in the oceans. These emissions do not cause acidification, since the oceans constitute a giant carbonate-buffered solution. The development of geographical or environment-specific characterisation factors is necessary for several impact categories to achieve a more realistic picture of the environmental impact in marine environments. It should also be mentioned that the environmental impact caused by Swedish electricity production, i.e. the generation of nuclear waste and biodiversity effects in rivers used for hydropower generation, is not characterised due to lack of methods. Therefore, the use of electricity is, at present, favoured compared to fossil fuels, while production of electricity also causes a number of serious types of environmental impact.

5.4 Environmental risks in fishery

Even though loss of gear is rare, accidents happen and lost gear can pose both a biological and a chemical risk. Gillnets contain lead which in case of loss will remain on the seafloor for a long time, creating a potential environmental risk. Both lost gillnets and trawls can maintain a high fishing capacity and continue to ‘ghost-fish’ for a long time. Due to the lack of data on these issues, they were not included in the assessment.

Sometimes, solid waste is thrown overboard from fishing vessels, especially when vessels are out on longer fishing trips (Luetzen 1996). Fishing trips in the studied fisheries are generally short and all fishermen said that they bring their waste ashore, why solid waste was not included in the study.

The risk of accidental oil spills or spills of anti-fouling substances and other chemicals in fishery is considered to be low.

5.5 Improvement options

The LCA showed that fishery is the main contributor to a number of categories of environmental impact in the life cycle of the studied seafood product. Any measures decreasing the use of energy in fishery, will hence have a positive impact on the overall environmental performance of the product. Most important is to fish viable stocks with as high catch per unit effort (CPUE) as possible. The fishing effort (e.g. measured as hours fished) needed to obtain a certain amount of catch is directly related to the resources needed and environmental impact of the fishing activity (i.e. the “environmental effort”). Apart from decreasing fishing effort or closing areas or seasons for fishery, there are two main ways to improve sustainability in fisheries: Modifying fishing practices technically to become more resource-efficient and developing environmentally efficient fisheries for under-utilised species. The first alternative applies to the Baltic cod fishery and could e.g. consist in gear modifications, improved engine and fuel technology or education of fishermen in fuel-saving vessel operation. Even a limited increase in the use of passive fishing gear, connected to a decrease in the use of energy-intensive types of active gears, was in the emission study shown to influence the overall energy consumption considerably. The second alternative can be important in oceans where marine species exist which are currently under-utilised, such as the developing crab (*Cancer pagurus*) and whelk (*Buccinum undatum*) fisheries along the Swedish west coast. In the Baltic, however, no alternative species exist that today have a commercial value high enough to be the target species of a fishery.

Because of the environmental importance of fishery, the most important factor once the fish is landed is to use it in an optimal way. The environmental burden caused by product loss (e.g. losses in the industry or in the household) has to be added to the environmental impact of the product, and therefore, the most important measure in order to decrease the overall environmental impact of the product after landing can be to maintain high quality and decrease product losses.

If you have questions or comments after reading this report, you are welcome to contact me at:

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6. CONCLUSIONS

- The fishery is the most important phase in the life-cycle of the studied seafood product with regard to resource use and environmental impact

- The most important improvement option is only to fish viable stocks as the fishing effort (e.g. measured as hours fished) is directly related to the amount of resources needed to obtain the catch ("environmental effort")

- A considerable decrease in the energy consumption of the studied fishery could be achieved through a relatively moderate increase in the use of different kinds of passive fishing gear, fuel-saving vessel operation and exchange of fuel and engine technology

- After landing, the most important environmental issue is to maintain high quality and minimise product losses

- Energy consumption in Swedish cod fishery is around 36 MJ to land 1 kg of gutted cod (which was fished to approximately equal parts by trawls and gillnets)

- In mixed-target fisheries it is important to carefully consider system expansion or an allocation method to account for the landed (and sold) by-catches

- A quantitative or qualitative assessment of the sustainability of the use of wild biological resources should be included in an environmental study of a product made of such resources

- The seafloor use is an important issue when assessing the environmental impact of a fishery. Around 700 m^2 are swept by trawls in Swedish cod fishery to obtain 1 kg of gutted cod (= 400 g of cod fillet)

- Discarding in Baltic cod fisheries is relatively low, but is still a resource management problem since discards mainly consist of undersized cod and the cod stocks in the Baltic are currently outside safe biological limits, i.e. they are overfished. Around 50 g of biomass is discarded per functional unit (400g of cod fillet) of which 48 g are undersized cod.

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APPENDIX 1: Total characterisation results for each life-cycle phase and impact category (for explanation of impact categories, see report)

Impact category	Total	Unit (per FU)	Mixed fishery	Industry	Packaging	Storage	Wholesaler	Retailer	Consumer	Sewage treatment
POCP	3.04E+00	[g ethene equivalents]	2.78E+00	1.77E-03	1.21E-02	6.82E-04	1.67E-04	1.98E-03	8.18E-03	1.33E-04
GWP	2.91E+03	[g CO_2 equivalents]	2.58E+03	1.34E+01	7.81E+00	5.18E+00	1.27E+00	1.51E+01	6.23E+01	1.01E+00
EPN	1.38E+01	[g N equivalents]	1.35E+01	6.26E-03	7.72E-03	2.41E-03	5.93E-04	7.05E-03	2.91E-02	4.72E-04
EPP	5.63E-03	[g P equivalents]	5.22E-04	5.05E-03	7.93E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.56E-05
EPepd	3.84E+02	[g O_2 equivalents]	2.69E+02	1.10E+01	2.86E-01	4.70E-02	1.16E-02	1.37E-01	5.67E-01	9.94E+01
AP	3.44E+01	[g SO_2 equivalents]	3.36E+01	2.76E-02	3.61E-02	1.07E-02	2.61E-03	3.10E-02	1.28E-01	2.08E-03
AE	2.75E-01	[10^3 m^3 polluted water]	2.74E-01	1.76E-07	2.06E-04	6.80E-08	1.67E-08	1.98E-07	8.19E-07	1.33E-08
Total	3.34E+03		2.90E+03	2.44E+01	8.15E+00	5.24E+00	1.28E+00	1.53E+01	6.30E+01	1.00E+02

…continued:

Impact category	Total	Unit (per FU)	Trp Industry-Storage (ferry)	Trp Industry-Storage (truck)	Trp Storage-Wholesaler	Trp Wholesaler-Retailer	Trp. Retailer-Consumer	Sum of transports
POCP	3.04E+00	[g ethene equivalents]	9.97E-04	2.46E-03	7.17E-03	2.37E-02	1.96E-01	2.30E-01
GWP	2.91E+03	[g CO_2 equivalents]	1.23E+00	2.28E+00	6.67E+00	2.21E+01	1.86E+02	2.18E+02
EPN	1.38E+01	[g N equivalents]	6.53E-03	6.81E-03	1.99E-02	6.95E-02	6.78E-02	1.71E-01
EPP	5.63E-03	[g P equivalents]	2.99E-07	4.78E-07	1.39E-06	4.62E-06	0.00E+00	6.79E-06
EPepd	3.84E+02	[g O_2 equivalents]	1.30E-01	1.34E-01	3.90E-01	1.37E+00	1.28E+00	3.30E+00
AP	3.44E+01	[g SO_2 equivalents]	3.09E-02	1.78E-02	5.19E-02	1.81E-01	2.12E-01	4.94E-01
AE	2.75E-01	[10^3 m^3 polluted water]	1.93E-05	3.62E-05	1.06E-04	3.51E-04		5.13E-04
Total	3.34E+03		1.40E+00	2.44E+00	7.14E+00	2.37E+01	1.88E+02	2.22E+02