Environmental performance of wild-caught North Sea whitefish

A comparison with aquaculture and animal husbandry using LCA

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Summary

Better market positioning of North Sea whitefish is required in order to secure a healthy sector in the future. Sustainability can be an important topic here, emphasising the qualities of North Sea fish in terms of people, planet and profit. The objective of this study is to examine various aspects of the environmental impact of wild-caught North Sea whitefish in comparison to imported aquaculture fish and meat. The core of this study is the life cycle assessment (LCA). The main findings from the LCA are that the environmental impact of wild-caught North Sea plaice and cod is comparable with that of salmon, tilapia and pangasius from aquaculture, the most important import fish. Although plaice and cod catching requires more energy than meat production, the global warming potential (GWP) is comparable due to lower non-CO_2 greenhouse gas emissions. Expected technological improvements offer possibilities for reducing the environmental impact of both wild-caught fishing and aquaculture.

Introduction

Information on sustainability is important

Since 2008, market prices for various wild-caught North Sea whitefish (mainly plaice and cod) have shown a sharp decrease, competing with relatively cheap imported whitefish products. Wild-caught North Sea whitefish also suffers from a bad image. In combination with declining prices and increased competition, this poses a serious threat to the Dutch fishing sector. Better market positioning of North Sea fish is required in order to secure a healthy sector in the future. Sustainability can be an important topic here, emphasising the qualities of North Sea fish in terms of people, planet and profit.

The Dutch cutter fishers recognise the importance of sustainability and works hard on innovations to improve the sustainability performance of the sector's products and production methods. Rapid developments are taking place in fishing techniques, such as the development of pulse trawl fishing. To maintain its economic viability and societal licence to produce, the sector invests in technologies that save fuel and reduce the impact on the environment. The sector is also engaged in the improvement of the management of the North Sea and its natural resources, in collaboration with government and social actors.

Society places great importance on the sustainable production of fish. Producers and marketers acknowledge this and seek to position products as "sustainable". This leads to heated debates about definitions of sustainability, clearly visible in debates on certification (Gulbrandsen 2009). Others speak of 'whitefish' war (Little et al. 2012). Claims on sustainability become part of the political and economic competition between different production systems. As stated by Mansfield (2011, 415), debates regarding the sustainability of aquaculture must now also be understood as both "an outcome of and an influence on changing political economic conditions".

At the heart of the controversy is the absence of a precise definition of sustainable produced fish. Different data and methodologies are used to make claims of sustainability. To improve the positioning of wild-caught whitefish, it is necessary to have scientifically solid information on the qualities of the most important North Sea species and to be able to compare these with competing products from aquaculture species or animal husbandry.

Research goal and questions

The objective of this study is to examine various aspects of the environmental impact of wild-caught North Sea whitefish in comparison to imported aquaculture fish and to meat. In particular, we aim to research whether or not claims on the environmental impact can be supported by scientific data. In this paper, we answer the following research questions:

1. How does environmental impact of plaice and cod compare with imported aquaculture?
2. How does the environmental impact of plaice and cod compare with animal products (pork, chicken, beef)?
3. How can expected improvements in fisheries reduce environmental impact?

Methodology

Overview

Given the lack of knowledge about environmental impact, a desk study was performed for some of the economically most important whitefish species. The desk study aimed to collect information on the performance of the North Sea species plaice and cod and to compare this with imported salmon, tilapia and pangasius from aquaculture. The focus was on energy use, global warming potential, acidification, eutrophication and land use. Subsequently, data from literature on the environmental impact of beef, pork and chicken was investigated and compared with that of wild-caught North Sea whitefish.

Life cycle assessment

The core of this study is the life cycle assessment (LCA). An LCA is a holistic method for evaluating the environmental impact during the entire life cycle of a product. LCA includes the use of resources (such as land or fossil fuels) and the emission of pollutants (such as ammonia or methane) (Guinée et al., 2002). The emission of pollutants contributes to categories of environmental impact such as global warming potential, the acidification and eutrophication of ecosystems, and human or terrestrial ecotoxicity. A carbon footprint is basically a single-issue LCA, focussing only on the emission of greenhouse gases through the life cycle of a product. In this paper, we use the notion of global warming potential (GWP) instead of a carbon footprint.

An LCA expresses the environmental impact of a defined system in relation to a functional unit, which is the main function of the system expressed in quantitative terms. The majority of LCA studies evaluate the production stages until the farm gate and leave out succeeding stages, such as processing, retail and household consumption. We recalculated the results of the different studies to cradle-to-farm-gate boundaries. The functional unit in our system, therefore, is one kg of fresh fillet accounting for the amount of live weight required to produce one kg of marketable product, excluding the processing and transport stages.

We have excluded the environmental impact in relation to infrastructure from our analysis. Infrastructure is often excluded from agricultural LCAs because the great deal of time it takes to include the infrastructure is not proportional to the relatively small environmental impact (Aubin et al., 2006; Vásquez et al., 2010).

Many production processes yield more than one product. In the case of fisheries, filleting yields fillet and fish waste that can be used as feed and other products. In these situations, the environmental impact of the production system or process has to be allocated to the various outputs. There are three main allocation methods described in the ISO 14044 standard (ISO, 2006): economic allocation, physical allocation (e.g. mass or energy allocation) and system expansion. In the case of mass or energy allocation, the environmental impact of a production system or process is allocated to its multiple outputs based on their relative mass (or energy), whereas in economic allocation the basis is their relative economic value. LCA results based on different methods of allocation cannot be compared directly. In comparing wild-caught and aquaculture, we chose mass allocation because this was the most common allocation method used in the reviewed articles (see annex 1).

Comparing wild-caught whitefish and aquaculture

We found thirteen articles and two reviews in peer-reviewed scientific journals and scientific reports examining the environmental impact of individual fish products (see annex 1). These studies described the LCA results of products from fishery or aquaculture for one or more species and diverging production systems. Being interested in wild-caught plaice and cod versus farmed salmon, tilapia and pangasius (data is collected on striped catfish, Pangasiadom hypophthalmus), we focused on these species only (numbers 1-13 in annex 1). The Ellingsen and Aanondsen study (2006) was not included because they based their article on the data by Thrane (2006). We included the only LCA of a recirculation aquaculture system (RAS) (Ayer and Tyedmers, 2009), which evaluated char, to demonstrate the strengths and weaknesses of RAS.

Annex 1 shows that most articles reviewed included only energy use or global warming potential in their LCA. To assess the impact on global warming potential of the production of a specific product, the studies we reviewed quantified emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In all studies, CO_2, CH_4, and N_2O emissions were summed up based on their equivalence factor in terms of CO_2 equivalents (100-year time horizon): 1 for CO_2, 25 for CH_4, and 298 for N_2O. This enables a valid comparison of the global warming potential (GWP) across studies. Similarly, in all studies energy use related to production and use of fossil fuels was summarised based on MJ.

Not all studies addressed eutrophication and acidification; only a few studies assessed land use.

To enable a comparison of eutrophication (EP), acidification potential (AP) and land use of plaice and cod with salmon, tilapia and pangasius, we used the following approach:

1. We deduced technical parameters from the articles reviewed (1-13 in Table 2.1), such as feed conversion, diet composition, origin of feed ingredients, energy requirement for feed processing or fish farming, etc.

2. We predicted the global warming potential of the diet by combining knowledge on technical parameters with Ecoinvent data 2.2. Ecoinvent data 2.2 allowed us to compute the GWP for each feed ingredient. If recent yield data were not available in Ecoinvent 2.2, we used production data from FAO (http://faostat.fao.org/default.aspx) for the countries concerned, averaged for the period 2005 to 2007. In addition, the energy requirements for the production of fishmeal were based on Schau et al. (2009).

3. We validated our predictions of GWP per kg of fillet by comparing them with the original results as published by the authors (see Table 1). The difference between published GWP and calculated GWP averaged 7.2% (range from 1-18%).

4. We combined technical parameters about diet composition with Ecoinvent data to assess the EP, AP and land use of each feed ingredient.

5. To determine the EP and AP per kg of fish fillet, we also assessed emissions of eutrophying elements (nitrate [NO_3^-] to water, phosphate [PO_4^{3-}] to water, and ammonia [NH_3] to air) and acidifying elements (NH_3) at the aquaculture farm. For each farm, we computed a farm-gate nitrogen (N) and phosphorus (P) loss as the difference between the NP in feed and the NP retained in fish. Subsequently, we assumed that about 13% of this farm N loss was NH_3 emission, and 87% was lost as NO_3^- to water (Gross et al., 2000), where the farm P loss was assumed to fully leach as PO_4^{3-} to water.

6. To determine land use, we combined knowledge of technical parameters with Ecoinvent data 2.2. Ecoinvent data 2.2 allowed us to compute the land use for each feed ingredient. If recent yield data were not available in Ecoinvent 2.2, we used production data from FAO (http://faostat.fao.org/default.aspx) for the countries concerned, averaged for the period 2005 to 2007. Land use computation is only relevant for aquaculture.

To assess the EP along the entire life cycle, we added all emissions of nitrate (NO_3^-) to water, phosphate (PO_4^{3-}) to water, nitrogen oxide (NOx) to air, and ammonia (NH_3) to air, based on their equivalence factor in terms of nitrate: 1 for nitrate, 10.45 for phosphate, 1.35 for NOx and 3.64 for NH_3. To assess the AP, we added emissions of sulphur dioxide (SO2), NOx, and NH_3, based on their equivalence factor in terms of sulphur dioxide: 1 for SO_2, 0.7 for NOx and 1.88 for NH_3.

Table 1 **Comparison of GWP (kg of CO_2-eq/kg of fillet) as published in different articles with our own computations**

Diet	Published (P)	Our computation (O)	O/P (in %)
Salmon NO (6)	2,160	2,063	95.5
Salmon NO (7)	1,790	1,518	84.8
Salmon CI (8)	2,300	2,123	92.3
Salmon CA (9)	1,830	1,850	101.1
Tilapia Lake based ID (11)	1,520	1,249	82.2
Tilapia Pond based ID (12)	2,100	1,848	88.0
Pangasius VN (13)	4,743	4,576	96.5
Cod Fishing NO (1)	740	755	102.0

The procedure described above enabled a comparison of energy use and GWP among published studies about cod, plaice, salmon, tilapia and pangasius, as well as EP, AP and land use.

Using our own data, we also computed the energy use, GWP, AP and EP of two Dutch fishery-systems: cod caught by flyshoot and plaice caught by twinrig. Data about fossil fuel use were based on the average statistics for 2010 (LEI, 2011), i.e. 0.84 litre of fuel for 1 kg of landed plaice by twinrig and 1.08 litre of fuel per kg of landed cod by flyshoot.

Comparing wild-caught whitefish to animal products

Data on the environmental impact of animal husbandry was taken from the publication by De Vries & De Boer (2010), who carried out a meta-analysis of the environmental impact of various products from the livestock farming sector. These results therefore relate to the global livestock sector. On the basis of the available data, the environmental impact of livestock farming is expressed below in two impact categories: fossil energy consumption and global warming potential. However, in this study, economic allocation is used. To enable a comparison with the LCA data on meat, we had to recalculate the environmental impact of fisheries from mass allocation to economic allocation. To recalculate, we used the figures presented in table 2 (personal communication with Jaczon). Note that this is the value of fillet for the first seller, not for retail. When comparing wild-caught whitefish and animal husbandry, we had to exclude foreign studies on fisheries because the data required to recalculate were not available.

Table 2	**Factors used to recalculate environmental impact of fisheries**
Indicator	**Factor**
% of fillet (plaice)	40%
% of fillet (cod)	45%
Value of fish waste	0.11
Value of plaice (fillet)	4.14
Value of cod (fillet)	7.09

Environmental impact of wild-caught compared with aquaculture

Energy use and global warming potential

Figure 1 shows the results for energy use per kg of fillet for the thirteen published systems included in our analysis (number 1-13 in Annex 1) and the two NL systems added. Energy use varied from 11 to 305 MJ per kg of fillet. Similarly, results for the GWP per kg of fillet are presented in Figure 2. The GWP varied from about 0.7 to 16.4 CO_2-eq per kg of fillet.

Figure 1 **Total fossil energy use of analysed systems (in MJ/kg of fillet)**

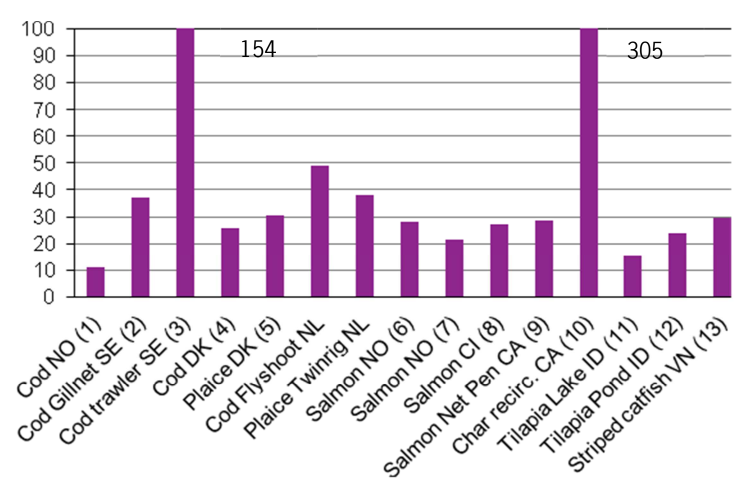
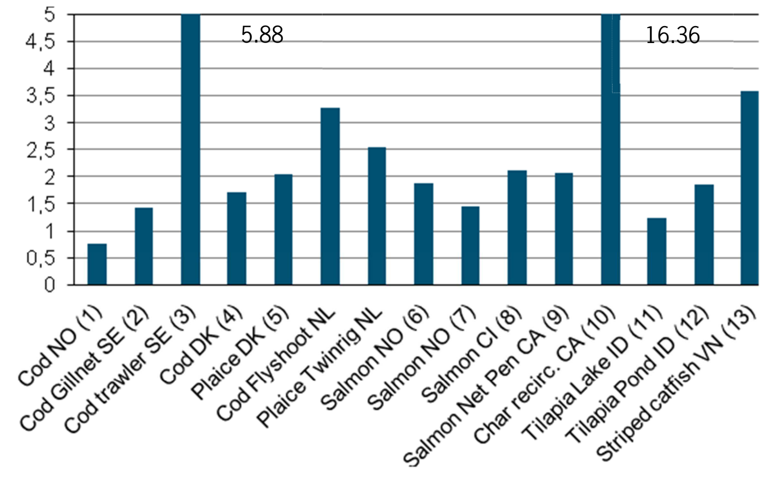


Figure 2 **Global Warming Potential of analysed systems (in kg of CO_2-eq/kg of fillet)**



A comparison of Figures 1 and 2 shows that the GWP is determined to a great extent by the use of fossil fuels (CO_2-emission). This is because current LCA studies did not include N_2O emissions on the fish farm, which implies a systematic underestimation of GWP per kg of farmed fish. Although the amount of N_2O emitted can be low, because of the high equivalence factor (298) the influence on the GWP can be substantial. The relative influence of this omission is difficult to assess without further research.

The GWP of pangasius is relatively high compared to the energy use of this system. This is caused by the fact that the feed in this system contains about 20% rice products. The paddy fields, where the rice is cultivated, emit about 1,270 kg CH_4 ha-1 yr-1 (IPCC, 2006).

Cod fishing with a trawler (3) resulted in a higher GWP and energy use per kg of wild-caught fish than cod fishing with a gillnet or flyshoot (2). The Swedish study that explored cod trawler fishing, however, used relatively old data (1999). Current trawler equipment might be more efficient, which might reduce the observed difference. Differences in available fish stocks also influence the results. Cod and plaice fishing in the Netherlands resulted in a relatively higher energy use (and related GWP) as compared to Norway or Denmark. It should be noted that Dutch fishers generally do not specifically fish for cod. This takes place incidentally but it can be done more energy efficient.

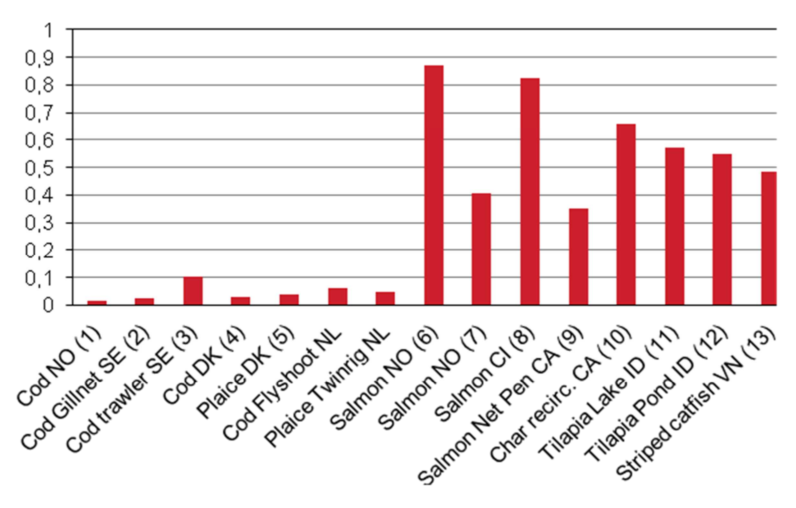
Energy use (and the related GWP) in aquaculture was highest for char recirculation systems (i.e. 305 MJ/kg of fillet). This is not due to the species, but is partly inherent in recirculation aquaculture systems (RAS). RAS energy requirements are high because the water is filtered and recycled. New water is added to the system only to make up for splash-out and evaporation, and for the water used to flush out waste materials. However, RAS energy requirements have improved over the last couple of years and will continue to improve (Martins, 2010).

Based on current cradle-to-farm gate LCAs, we cannot conclude that wild-caught fish has a higher or lower energy use or GWP per kg of fillet than farmed fish. There were large differences among individual fishing techniques and aquacultural systems, and in itself this offers potential for improvement. We also noticed that the current LCAs of farmed fish did not include N_2O emissions on the fish farm, which might have resulted in an underestimation of GWP per kg of fillet.

Eutrophication and acidification potential

Figure 3 shows the EP per kg of fillet for the thirteen published systems included in our analyses (numbers 1-13 in Table 2.1) and the two NL systems added.

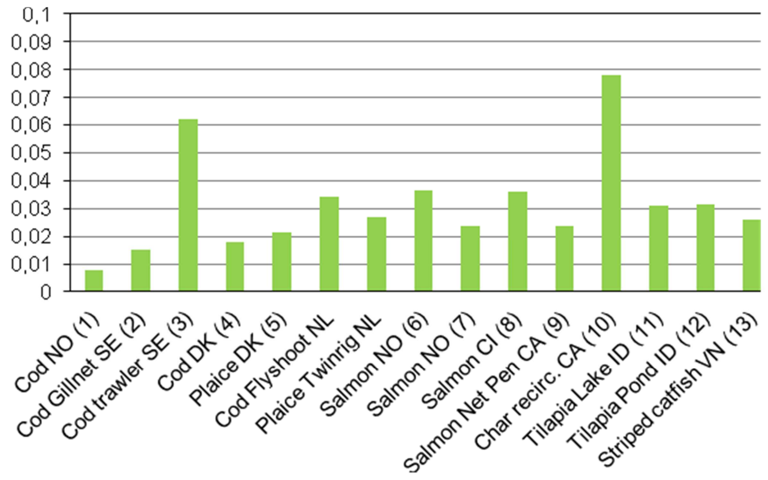
Figure 3 **Eutrophication potential of analysed systems (in kg of NO_3--eq/kg of fillet)**



The EP of wild-caught fish is very low compared to the EP of farmed fish. The EP in aquaculture results from emissions of NH_3 and leaching of NO_3^- during the cultivation of feed ingredients and during fish farming. Except for RASs, on average 86% (range 79%-93%) of the EP in aquaculture originated from on-farm emissions of NH_3 and leaching of NO_3^-. In RASs, however, the emission of NH_3 is almost zero (Schneider et al., 2007).

Figure 4 shows the AP per kg of fillet for the thirteen published systems included in our analyses (numbers 1-13 in Table 2.1) and the two NL systems added.

Figure 4 **Acidification potential of analysed systems (in kg of SO_2-eq/kg of fillet)**

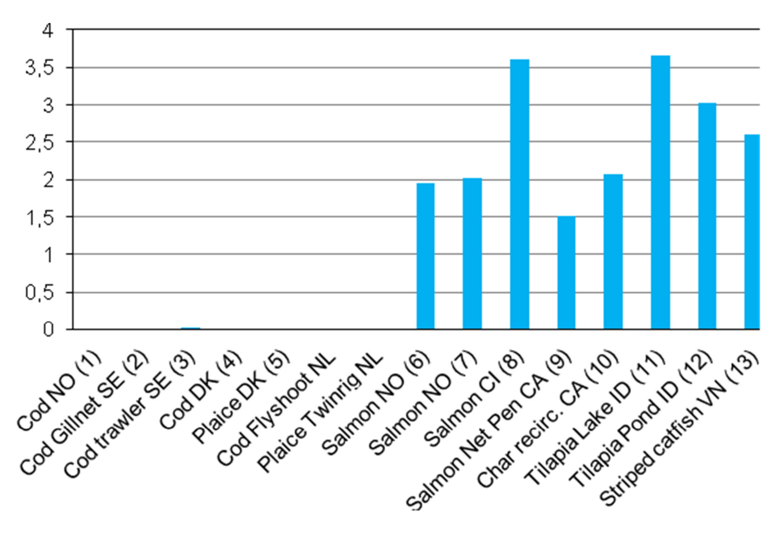


The AP mainly resulted from two aspects: (1) emissions of SO_2 related to the burning of fossil fuel, and (2) ammonia emissions during fish farming. In the aquaculture systems (except for RASs), on average 51% (range 33%-64%) of the AP originates from the ammonia losses from the pond. Based on a cradle-to-farm gate analysis, we cannot conclude that wild-caught fish has a higher or lower AP per kg of fillet than farmed fish. There were differences among individual fishing techniques and among the aquaculture systems.

Land use

Figure 5 shows the land use per kg of fillet for the thirteen published systems included in our analyses (numbers 1-13 in Table 2.1) and the two NL systems added.

Figure 5 **Land use of analysed systems (in m^2/kg of fillet)**



The land use attributed to caught fishing is land used for the production of fuels. In aquaculture a substantial amount of land is required to cultivate feed ingredients. Differences in land use among different studies can be explained by differences in diet composition and feed conversion rate (kg of feed/kg of fish fillet). Diets with a higher proportion of fishmeal or fish oil have a lower land use. In addition, a higher feed conversion will increase the land requirement per kg of fillet (11 vs 12).

Conclusions

The following conclusions can be drawn from the LCA analysis:

- Current LCA results do not show a significant difference (p=0.80) in energy use or global warming potential per kg of plaice and cod or salmon, tilapia and pangasius. Although there is some difference in the mean values, there is a great deal of variance in the data, resulting in insignificance.
- The average GWP of aquaculture (excluding one extremely high measurement) is 2.03. This equals the use of 0.67 l fuel per kg of landed fish. Current figures for fule consumption of fishery in the Netherlands are 0.84 l/kg for plaice and 1.08 l/kg for cod.
- The GWP of pangasius is strongly influenced by the amount of rice products included in the feed.
- Current estimates of the GWP of farmed salmon, tilapia and pagasius might be underestimated, because on-farm emissions of N_2O (greenhouse gas with a significant impact) are not included.
- The eutrophication potential of wild-caught cod or plaice is lower than the eutrophication potential of farmed salmon or tilapia (p<0.0001).
- Current LCA results do not show a significant difference in acidification potential per kg of wild-caught cod and plaice or farmed salmon or tilapia (p=0.33).

- The land use is significant in aquaculture. This land is used to cultivate feed ingredients ($p<0.0001$).
- The land use for wild-caught fishing only includes land used for the extraction and production of energy. Figures are very low. Wild-caught fishing often has an impact on the ecosystems in the sea. The biodiversity is influenced by disruptions to the seabed and by the exploitation of fish resources (both target fish and by-catch and discards). It is difficult to quantify this and weigh it against other impact categories (Thrane, 2004).

Environmental impact of wild-caught compared with animal husbandry

Energy consumption and global warming potential

Approximately 43 MJ of energy was required for the production of one kilogram of beef (De Vries and de Boer, 2010). That is more than double the amount of energy consumed for the production of a kilogram of pork or chicken. Energy consumed in the livestock sector is used for matters including: the production and transport of animal feed and the production and use of fuels (diesel, gas) and electricity at the farm (Thomassen et al., 2009).

The global warming potential (GWP) for three products from animal husbandry sector, measured in CO_2-equivalents per kilogram of the product, are highest for beef production (14 to 32 CO_2-eq) followed by pork (3.9 – 10 kg CO_2-eq) and chicken (3.7 – 6.9 kg CO_2-eq). Global warming potential resulting from livestock farming could be a consequence of emissions released by manure and emissions caused by the transportation of feed, amongst other things (Thomassen et al., 2009).

Production of beef requires the most land: between 27 and 49 m^2 land per kilogram of meat. The amount of land used for the production of pork (8.9-12.1 m2 of land per kilogram of meat) and chicken (8.1-9.9 m^2 of land per kilogram of meat) is considerably less (De Vries en de Boer, 2010).

Table 5 compares the results of the LCA of plaice and cod with the results of the LCA of beef, pork and chicken. Note that the data on plaice and cod is recalculated from mass allocation to economic allocation (see methodology)

Table 5	**Comparing energy use and GWP of plaice, cod, pork, chicken and beef**	
	Energy use (MJ/kg of fillet)	**GWP (kg of CO_2-eq/kg of fillet)**
Cod flyshoot (NL)	106	7.2
Plaice twinrig (NL)	91	6
Pork	18-45	3.9-10
Chicken	15-29	3.7-6.9
Beef	34-52	14-32

The following conclusions can be drawn from this overview:

- The energy use for plaice and cod is higher than the energy use for pork, chicken or beef.
- The global warming potential of plaice and cod is in the same range as that of pork and chicken. Beef has a higher GWP. This difference can be explained by the non-CO_2 greenhouse gas emissions from animals and manure.

Expected improvements to environmental performance

In this section, we look at some of the predicted developments in the fisheries sector. Our objective is to analyse how innovations in fishing and fish-farming methods can affect the life cycle impact of wild-caught fishing and aquaculture. Various studies analyse the potential of long-term changes are taken into account and the scenarios are compared by reference to macro-economic, social, and governance criteria (Hoefnagel et al., 2011). In this study, we focus on the short-term changes and analyse how these might change the LCA of wild-caught fishing in the near future. Given the complexity of life cycle assessments, the cross-relations between the sorts of environmental impact, and the lack of validated data, we cannot accurately recalculate the LCA with these innovations in mind. We can, however, argue how innovations would change the impact, focussing on the direction of change (higher or lower impact) and the magnitude (small, medium, large). We present a schematic overview of the impact of various improvements at the end of this section (Table 6).

Increasing fish stock

Fish stocks constantly change under the influence of several factors, including climate change, changes in ecosystems, and changing fishery conditions. In the LCA, technical parameters for energy use, global warming, acidification and eutrophication were deducted from scientific papers published between 2003 and 2011. The total population size does not include information on the age distribution within the population. This also influences the revenues of fishermen: when populations are relatively young, revenues are lower. Why are increasing fish stocks important for the LCA of wild-caught fishing? Larger stocks mean that fishermen spend less time and fewer resources to catch equal amounts of fish. Consequently, the energy use per kg of fillet decreases.

Technical improvements

Fuel use constitutes one of the greatest expenses for wild fisheries. It is predicted that fuel prices will increase in the future, a result of increased competition for fossil fuels and depleting resources (International Energy Agency, 2011). Given the impact of fuel prices on income, fishers seek ways to improve the fuel efficiency of their fleets. One of the Fisheries Knowledge Networks ('Slim ondernemen in de Platvisserij', ‘Clever Entrepreneurship in Flatfishing’) examined options for reducing fuel use for beam trawlers in greater detail. The results of this study are published in the leaflet Hoezo dure gasolie? (“What do you mean, expensive gas oil?”) (Kenniskring Slim Ondernemen in de Platvisserij, 2009).

Fuel use is largely determined by the method used for fishing. The beam trawl method requires a great deal of energy and the use of alternative methods results in much lower fuel consumption. It is estimated that the use of a SumWing can result in savings of 10-20%. An average beam trawler (a vessel measuring around 40 metres) can save up to 300 tonnes of fuel by using SumWings and still catch equal amounts (Taal et al., 2010). The use of the pulse trawl method is expected to reduce fuel consumption even more: a shift to pulse trawling can, with the current state of technology, reduce energy use by 45 to 60% (ompared to beam trawlers in 2008), depending on the type of vessel and engine (Kenniskringen Puls en Sumwing and Slim Ondernemen in de Platvisserij, 2009).

Fuel consumption can also be reduced by taking relatively easy measures that require little or no investments. Examples of such measures include using lighter nets, reducing speed while fishing, and using cruise control and fuel consumption instruments. Each of these measures can result in a reduction in fuel use of 1-5%.

For wild-caught fishing, fuel consumption is linearly related to the environmental indicators GWP, eutrophication and acidification. A 20% reduction of fuel consumption means that GWP, eutrophication and acidification are all reduced by 20%.

Changes in the fuel mix

The use of sustainable fuels, or biofuels, is another way to reduce CO_2 emissions and fuel use by fishers. Fossil fuels are used at present, and replacing them with alternative fuels could reduce the GWP of fisheries. The use of biofuels leads to a net reduction of a number of emissions, particularly carbon dioxide emissions, as CO_2 is extracted from the air when natural resources are grown.

There are two methods for the production of biofuels. The first, and currently most common, option is to produce biofuels from plant materials derived from plants such as oil palms, Jatropha and sugar cane. The second option is to use animal products for the production of aquatic biofuels (FAO, 2011). This option is currently being researched by various institutes and corporations, as it would make it possible to produce biofuels from what is currently redundant catch. This production could be carried out on shore or even on board.

Although CO_2 is emitted by the combustion of these fuels, it is common to attribute no GWP to these fuels. The reason for this is that CO_2 is captured during the production of these fuels. If biofuels are produced from plant material, land use increases. The use of alternative fuel sources derived from plant material means higher impact on the EP and AP because use and production of these fuels have an impact on these indicators.

Improved Feed Conversion Ratio

The environmental impact of aquaculture is influenced by the feed conversion rate (FCR) describing how much feed is required to produce a fixed amount of fish. Improving the feed conversion rate is one way to reduce the total environmental impact of aquaculture. In the literature used for the LCA (see Annex 1), the FCR for tilapia are circa 1.7. The FCR for aquaculture salmon is reported to vary between 1.1 and 1.5 (Pelletier et al., 2009). A great deal of research focuses on what feed conversion rate can be achieved. This would mean an immediate improvement in the economic and ecological performance of aquaculture. For tilapia, it is expected that FCR can be reduced to 1.2. This requires a change in diet and earlier harvesting (meaning smaller fish). For salmon, feed conversion rates close to 1 are now reported. If we assume hypothetically that a better FCR means that less of the same feed is required, the environmental impact would logically decrease, albeit not linearly. The total environmental impact is also influenced by the energy used during production. If diets change, which is almost inevitable, net effects on the environment are more difficult to assess.

Alternative feed resources

Changes in diet in aquaculture is another way to reduce the life cycle environmental impact. The net benefits of such changes are not easily assessed. A change in diet will almost certainly affect the FCR and growth of fish. Therefore, we only give some indications on how changing diets might affect LCA.

From an examination of the literature on sustainable aquaculture and certification schemes for sustainable aquaculture, it appears that a reduction of the percentage fish oil is desirable. If we look at the LCA data, a reduction of fish oil use appears less favourable as it increases land use, eutrophication and acidification.

If we increase the amount of fish oil to a hypothetical 100%, the following picture emerges. Obviously, land use is reduced to nearly zero. Life cycle contributions to the EP and AP are also reduced, but energy use and GWP increase (more energy required to catch feed).

Overview

We have described various options for reducing the environmental impact of both wild-caught fishing and aquaculture. Table 6 summarises how these developments and innovations affect the life cycle environmental impact.

Table 6 **Summary of effects on outcome of LCA**

			Energy use	**GWP**	**EP**	**AP**	**Land use**
Wild-caught	Increased fish stock		↓	↓	↓	↓	=
	Reduced fuel consumption		↓	↓	↓	↓	=
	Alternative fuels	Plant-based	=	↓	↑	↑	↑
		Fish-based	=	↓	=	=	=
Aqua-culture	Improved FCR		↓	↓	↓	↓	↓
	Alternative feed sources	Plant-based	↓	↓	↑	↑	↑
		Fish-based	↑	↑	↓	↓	↓

Current developments in both fishing technology and fisheries management will most probably result in a significant reduction of the environmental impact of wild-caught whitefish and aquaculture.

- Increasing fish stock can reduce the environmental impact of fisheries

- All technologies that reduce fuel use have a direct positive impact on the LCA.
- A shift to biofuels comes with pros and cons. There is no easy win.

Effects of improvements in aquaculture do not seem to be as straightforward as in fisheries. Some of the changes, such as a shift to using biofuels in the diet of aquaculture, come with pros and cons. Changing to plant-based feed or fuel results in greater land-use. The alternatives (use of fish oil for feed and use of biofuels) use more energy and have a higher GWP.

Conclusion

Current LCA results do not show a significant difference ($p=0.80$) in energy use or global warming potential per kg of wild-caught cod and plaice or farmed salmon, tilapia and pangasius. Although there is some difference in the mean values, there is a great deal of variance in the data, resulting in insignificance.

The eutrophication potential of wild-caught cod or plaice is lower than the eutrophication potential of farmed salmon or tilapia ($p<0.0001$). Current LCA results do not show a significant difference in acidification potential per kg of wild caught cod and plaice or farmed salmon or tilapia ($p=0.33$).

The land use is significant in aquaculture ($p<0.0001$). This land is used to cultivate feed ingredients. The land use for wild-caught fishing only includes the land used for the extraction and production of energy. Figures are very low. Wild-caught fishing often has an impact on the ecosystems in the sea. The biodiversity is influenced by disruptions to the seabed and by the exploitation of fish resources (both target fish and by-catch and discards). It is difficult to quantify this and weigh it against other impact categories (Thrane 2004).

Comparing the environmental impact of plaice and cod with the environmental impact of animal husbandry, it is concluded that fossil energy use for plaice and cod is higher than the fossil energy use for pork, chicken and beef. However, global warming potential of plaice and cod is in the same range as that of pork and chicken. Beef has a higher GWP. This difference can be explained by the non-CO_2 greenhouse gas emissions from animals and manure.

Expected technological improvements offer possibilities for reducing the environmental impact of both wild-caught fishing and aquaculture. Current developments in both fishing technology and fisheries management will most probably result in a significant reduction of the environmental impact of wild-caught whitefish in the coming years. All technologies that reduce fuel use have a direct positive impact on the LCA. Other changes, such as a shift to biofuels or changes in the diet of aquaculture, all come with pros and cons. There is no easy win.

Discussion

This desk study concerning the environmental impact of North Sea plaice and cod is the first of its kind. A systematic analysis of environmental impact, enabling comparison with other fish or meat, was not available. We have presented the conclusion of our comparison but we wish to formulate the following points of discussion. Regarding the methodology used, it should be emphasised that:

- We tried to include sole in the LCA but no proper information was available.
- The LCA is merely part of a broader analysis of environmental impact. An integrated comparison of the environmental impact of plaice, cod, salmon, tilapia and pangasius also requires insight into the impact on ecosystems. Currently, there is no suitable information available for including such impact in the LCA.
- Current estimates of the GWP of farmed salmon, tilapia and pangasius might be underestimated, because on-farm emissions of N_2O (greenhouse gas with a significant impact) are not included.
- Under current conditions, the life cycle assessment does not include the energy used while building the vessel. In LCA analyses, it is common practice to omit this impact, as it constitutes less than 10% of the total energy use. Reducing fuel consumption means that the relative weight of energy use during construction increases. This may mean that to obtain a methodologically sound LCA, energy should be included in the future as well.
- Given the limitations of a desk study, it was also impossible to collect more information on the acidification and eutrophication potential of pork and chicken.

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Annex 1 **Characteristics of 15 studies on the life cycle assessment of fish products originating from fisheries and aquaculture**

					Environmental issues considered					Nr in study
	Reference	**Country and system**	**Species**	**Allocation**	**energy use**	**global warming**	**eutrophi-cation**	**acidification**	**land use**	
Fisheries	Winther *et al.* (2009)	NO-country average	Cod	mass	+	+				1
	Winther *et al.* (2009)	NO-country average	Saithe	mass	+	+				
	Winther *et al.* (2009)	NO-country average	Haddock	mass	+	+				
	Winther *et al.* (2009)	NO-country average	Herring	mass	+	+				
	Winther *et al.* (2009)	NO-country average	Mackerel	mass	+	+				
	Ziegler and Hanson (2003)	SE-gillnet	Cod	mass/econ	+					2
	Ziegler and Hanson (2003)	SE-trawler	Cod	mass/econ	+					3
	Thrane (2006)	DK-country average	Cod	System expansion		+		+		4
	Thrane (2006)	DK-country average	Flatfish (Plaice)	System expansion		+		+		5
	Ellingsen and Aanondsen (2006)	NO-trawler	Cod	mass [2]	+					
	Vásquez *et al.* (2010)	ES-bottom trawler	Horse Mackerel	mass/econ		+	+			
	Vásquez *et al.* (2010)	ES-purse Seiner	Horse Mackerel	mass/econ		+	+			
	Iribarren *et al.* (2011)	ES- trawler	Horse Mackerel	economic		+				
	Iribarren *et al.* (2011)	ES-seiner	Horse Mackerel	economic		+				
	Iribarren *et al.* (2011)	ES-trawler	Mackerel	economic		+				
	Iribarren *et al.* (2011)	ES-seiner	Mackerel	economic		+				
	Iribarren *et al.* (2011)	ES-trawler	Hake	economic		+				
Aquaculture	Winther *et al.* (2009)	NO	Salmon	mass	+	+				6
	Pelletier *et al.* (2009)	NO-Country average	Salmon	energy	+	+	+	+		7
	Pelletier *et al.* (2009)	UK-Country average	Salmon	energy	+	+	+	+		
	Pelletier *et al.* (2009)	CA-Country average	Salmon	energy	+	+	+	+		
	Pelletier *et al.* (2009)	CI-Country average	Salmon	energy	+	+	+	+		8
	Roque d'Orbcastel *et al.* (2009)	FI-flow through	Trout	system expansion	+	+	+	+	+	
	Roque d'Orbcastel *et al.* (2009)	FI-Recirculation	Trout	system expansion	+	+	+	+	+	
	Ayer and Tyedmers (2009)	CA-Marine Net pen	Salmon	energy [1]	+	+	+	+		9
	Ayer and Tyedmers (2009)	CA-Marine floating bag	Salmon	energy [1]	+	+	+	+		
	Ayer and Tyedmers (2009)	CA-Flow flow through	Salmon	energy [1]	+	+	+	+		
	Ayer and Tyedmers (2009)	CA-Recirculation	Char	energy [1]	+	+	+	+		10
	Aubin *et al.* (2006)	FR-Recirculation	Turbot	economic	+	+	+	+		
	Aubin *et al.* (2009)	GR-Sea cages	Sea-bass	economic	+	+	+	+		
	Ellingsen and Aanondsen (2006)	NO	Salmon	economic	+					

	Grönroos *et al*. (2006)	FI-Net cages	Trout	mass	+	+	+	+		
	Pelletier and Tyedmers (2010)	ID-Lake-based	Tilapia	energy	+	+	+	+		11
	Pelletier and Tyedmers (2010)	ID-Pond-based	Tilapia	energy	+	+	+	+		12
	Bosma *et al*. (2011)	VN	Pangasius (Striped Catfish)	Mass	+	+	+	+		13
	DK=Denmark, NL=The Netherlands; NO=Norway; GR= Greece; CA=Canada; CI=Chile; ES= Spain; FR=France; UK=United Kingdom; ID = Indonesia; FI=Finland; SE=Sweden. [1] For feed energy allocation, for output (if necessary) system expansion. [2] For fishery mass allocation, for others economic allocation.									