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GHG Emissions in aquatic production systems and marine fisheries

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1. Introduction

In 2012, a total of 148 million tonnes of fish was supplied to the world by aquaculture and capture fisheries, of which 128 million tonnes of fish was used as food for people (FAO, 2012). Fish and fish products are an important source of protein and micronutrients in nutrition. These products accounted in 2009 for 16,6% of the world's population intake of animal protein and 6,5% of all protein consumed (FAO, 2012a). Therefore, it is an important global food source for many people.

Available knowledge on the emissions of greenhouse gases (GHG) released from aquaculture systems and capture fisheries is rather limited. In 2012, FAO organized an expert workshop on greenhouse gas emissions strategies and methods in seafood (FAO, 2012b). The conclusion of this workshop is that no sound estimation of global GHG emissions can be made as only few data and assessments are available for mainly large scale fish production (gadoids and salmonids) at company level in developed countries. Higher level assessments at industry group, national and global level requires generic approaches and filling of the data gap concerning GHG emissions related to fish production in Asia and Africa.

From available studies and comparisons the image easily arises that commercial fisheries are heavily dependent upon the combustion of fossil fuels and as such contribute to increased atmospheric concentrations of greenhouse gases. It was estimated that fishing burns 1.2% of the fossil fuel used globally each year (Tyedmers et al. , 2005). The FAO (2012a) states that estimates show that 620 litres of fuel is used per tonne of landed fish. Estimations show that the global fishing fleet consumes about 41 million tonnes of fuel per annum, which generates 130 million tonnes of CO2. It must be mentioned that fuel consumption varies according to the gear used, fishing practice and distance to the fishing ground. In addition, Life Cycle Analysis (LCA) show that energy consumption and GHG emissions occur as well during processing, cooling, packaging and transport.

The latter also plays a role in aquaculture (Bunting & Pretty, 2007). Besides, available studies show for example that in the production of farmed salmon marked differences in the nature and quantity of material/energy resource use and associated emissions per unit production across regions can be found.

In this paper we will look at aquatic production systems and marine fisheries, determine which knowledge already exists, which problems need to be addressed and which challenges and knowledge gaps are there to be overcome.

2. GHG released from aquatic production systems

2.1 Aquaculture emissions

Several studies have been performed on the GHG-emission of aquaculture systems. Most published articles (mainly as a part of Life Cycle Assessment data: LCA) included only energy use or global warming potential of large farms in their LCA. To assess the impact on global warming of the production of a specific product most studies quantified emissions of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Carbon dioxide is mainly released during the combustion of fossil fuels to power machinery, during fishing (for feed use) or industrial processes. Methane is inadvertently released during fossil fuel extraction and refining. Besides, methane formation occurs in an anaerobic environment, mainly in mud layers in intensive ponds. In many cases, the fish are tossing the soil, so an anaerobic environment does not exist, however, in pangasius cultivation this is different. There seems to occur an anaerobic mud layer. Nitrous oxide is released during microbial transformation of nitrogen in the soil or in manure (i.e. nitrification of NH3 into NO3$^-$ and incomplete denitrification of NO3$^-$ into N2) as well as during nitrate fertiliser production for feed ingredients (Burg van den, 2012).

Table 1 gives an overview of different aquaculture systems and the total fossil energy use in Mega Joule per kilogram of fillet, the Global Warming Potential (in CO2) (GWP) per kilogram of fillet, the Energy use and GWP, the eutrophication (NO3) potential and acidification (SO2) potential.

Table 1. Total fossil energy use, Global Warming Potential, Eutrophication and Acidification of different types of Aquaculture (Burg van Den, 2012; Pelletier, 2012; Aubin, 2009; Iribarren, 2010; LCA DK Food).

Type of aquaculture	Energy use (MJ/kg of fillet)	GWP (kg CO$_2$-eq/kg of fillet)	Eutrophication (kg of NO$_3$ -eq/kg of fillet)	Acidification (kg of SO$_2$-eq/kg of fillet)
Tilapia in lake systems	15	1.5	0.57	0.031
Salmon in Norway	21	1.8	0.41	0.023
salmon in Chili	28	2.3	0.82	0.036
Salmon in UK	N/A	3.3	N/A	N/A
Pangasius pond based vietnam	N/A	4.7	N/A	N/A
Trout RAS flow through system	N/A	2.7	N/A	N/A
Trout RAS France	N/A	1.6-2.0	N/A	N/A
Seabass RAS cages	N/A	3.6	N/A	N/A
Turbot RAS recirce	N/A	6.0	N/A	N/A
Mussel culture raft system	N/A	2.6	N/A	N/A
captured mussels	N/A	0.04	N/A	N/A
Filleting of salmon	2.8 MJ of electricity	0.15	N/A	N/A
Freezing of salmon	0.5 MJ of electricity	0.03	N/A	N/A
Processing (incl. freezing) of pangasius in vietnam	4.9 MJ of electricity	0.93	N/A	N/A

Table 1 covers mostly industrial aquaculture systems. Besides, table 1 covers information on the processing of farmed fish, which is mostly done when fish is meant for export. Furthermore, emissions from transport should be taken into account (table 2). Processing and transportation emissions of small farms for the local market will thus be different from fish produced for export (Kluts, 2012).

Table 2. Transport distances, energy and GWP for transport of 1 kg of fish products to Rotterdam (Burg van Den, 2012).

FROM	DISTANCE (KM)	TRANSPORT	ENERGY (MJ)	GWP (KG CO_2-EQ)
JAKARTA/INDONESIA	15.748	BOAT	2.63	0.17
HO CHI MIN/VIETNAM	16.444	BOAT	2.75	0.18
TRONDHEIM/NORWAY	1.307	TRUCK	2.38	0.14
ESBJERG/DENMARK	463	TRUCK	0.84	0.05
VANCOUVER/CANADA	16.422	BOAT	2.75	0.18
REYKJAVIK/ICELAND	2.042	PLANE	49.6	3.36

Comparison of GHG emission between aquaculture products and agricultural products shows that best agriculture practices for chicken and pork production have roughly similar emission values to aquaculture products. Pork has a GHG-emission of 3.9-10 and chicken of 3.7-6.9 kg CO2 eq/kg fillet (Burg van den, 2012).

On methane emissions, not much is known. However, a rough estimation can be made. In an anaerobic environment, carbon is converted into methane. Around 5% of the fish feed is converted into manure. For example: from 1 kg of fish feed, 50 gram is converted into settle able manure. 50% of the manure exists of carbon (25 gram), which is converted in an anaerobe environment into 33 gram CH4. The use of fish feed in the pangasius production is estimated at 2.1 million ton. This equals 70 million kg of CH4. There is no indication on the release of N2O.

2.2 Hotspots

2.2.1 Feed Conversion Ratio

For aquaculture production chains fish feed is typically the most dominant factor in GHG-emissions. For Atlantic salmon and Rainbow trout production feed accounts for, on average, 87% of total GHG emissions. The emissions are mainly determined by the amount of feed needed for the production of a kg of fish (Feed Conversion Ratio: FCR). FCR for tilapia are generally around 1.7; for aquaculture salmon between 1.1 and 1.5 (Pelletier, 2007; 2010), and currently still decreasing (currently approximately 1). In recirculation farms FCRs of 0.8 have been reported for African Catfish (d'OrbCastel, 2009).

Reductions of GHG-emissions can be achieved by influencing the FCR. However, this requires a change in diet and earlier harvesting (resulting in smaller fish). If the assumption is made that a better FCR results in less requirement of the same feed, the environmental impact would consequently decrease, although not linearly. The potential impact is found to be both positive and negative; for different feed ingredient mixes [1] some studies showed substantial improvement by using non-conventional feeds while others showed little improvement or even increases in emissions. All of these studies indicate that a major driver of the performance of fish feeds is the fisheries from which meal and oil are sourced. Selection of fish meal and oil species based on environmental performance may be a method to improve GHG emissions of many aquaculture-derived products (Parker, 2012).

2.2.2 Energy use

For recirculation systems (RAS) next to feed, energy use is the primary hotspot for GHG-emissions. RAS need energy to run aeration systems, regulate temperatures and circulate water. In for example turbot production energy use makes up ~60% of the emissions. Energy inefficient systems (such as RAS and to a lesser extent race ways) may from this perspective best be situated in clean energy environments.

[1] (Bosma, 2011; Boissy, 2011; Pelletier, 2007; Cao, 2011; Ellingsen, 2006; Grönroos, 2006; Papatryphon, 2004; Samuel-Fitwi, 2011)

2.3 Solutions

Many changes in the aquaculture production chain may result in lower carbon emissions. Solutions for improvement of the aquaculture GHG-emissions lie in:

- Development of more efficient feed composition to improve the FCR
- Optimisation of production systems and species-system interactions to reduce energy use
- Shift to renewable energy sources
- Improve management on farms decreases emissions (mainly developing countries)
- GHG-emissions and environmental performance of sectors should be implemented in certification programs for adequate improvement strategies
- The use of breeding principles may result in more efficient protein conversion to reduce GHG-emissions

2.4 Challenges and knowledge gaps

In many studies of aquaculture GHG-emissions focus on use of fossil fuels (CO2-emission) and do not include NO2 emissions on the fish farm, which implies a systematic underestimation of Global Warming Potential per kg of farmed fish. In addition studies in general make use of non-validated “soft” data and general data base information on inputs and outputs. For validation purposes there is a requirement for field studies, and experimental data in production systems (eg. NOx in Recirculation systems). Moreover most cultured species that have been assessed have only been the focus of one to two studies, and in some cases these studies have reported markedly different results. Additionally, those studies that have focused on non-salmonid species have generally only presented results for one type of farm system, leaving a great degree of uncertainty as to other potentially less emission-intensive methods of culturing fish. Systems that require additional attention include farms for carp, tilapia and other globally significant species. Having a broader range of species studied would allow for more comparison between substitutable products, as well as a better understanding of the relative performance of salmonid products when compared to other major fish protein sources (Parker 2012).

In addition, not much is known on methane formation in aquaculture. The information given in this paper is only an initial coarse estimation.

Besides, more information must be gathered around the transport and post-harvest emissions. Some general data can be found in literature, however, these losses are case study specific. On emissions from coolants, no information has been found. Yet, this should be included in the scheme as well. Enabling a reduction of the carbon footprint per kg of protein by for example reducing post-harvest losses and improved protein yield from fisheries products is a challenge. Also introducing a standardised certification scheme for GHG-emissions in the production chain from farmer to consumer could assist in reducing GHG-emissions. Facilitating GHG-labelling could be aided by making data on aquaculture production publically available. Especially fisheries data on fishmeal and fish oil are often not available in open access datasets.

No literature has been found on the differences in emissions of industrial and smallholder farming systems. Studies must be carried out to find out these differences.

Finally, aquaculture has more environmental impacts then only GHG emissions. When talking about environmental impacts as a whole, other environmental impacts such as land use, acidification and ecotoxicity should be considered as well.

3. GHG emissions in marine fisheries

3.1 Fishery emissions

Depending on the nature of the fisheries, main GHG-emissions stem from the use of fossil fuel to propel the fishing vessel. In addition fisheries contribute significantly to the emissions of greenhouse gases during transport (emissions to air (truck and ocean freight) and refrigeration), processing (energy emissions e.g. refrigeration) and storing of fish (energy emissions e.g. refrigeration).Table 3 presents for 7 European fisheries systems and two processing systems the total fossil energy use in Mega Joule per kilogram of fillet, the Global Warming Potential (in CO2) (GWP) per kilogram of fillet, the Energy use and GWP, the eutrophication (NO3) potential and acidification (SO2) potential. Direct N2O and CH4 emissions do not play a role in fisheries. Table 2 shows energy and GWP for the transport of 1 kg of fish product to Rotterdam.

Table 3. Total fossil energy use, Global Warming Potential, Eutrophication and Acidification of different types of fisheries (Burg van Den, 2012).

Type of fishery	Energy use (MJ/kg of fillet)	GWP (kg CO_2-eq/kg of fillet)	Eutrophication (kg of NO_3 -eq/kg of fillet)	Acidification (kg of SO_2-eq/kg of fillet)
Cod Norway	11	0.70	0.01	0.008
Cod Gillnet Sweden	37	1.45	0.02	0.015
Cod Trawler Sweden	154	5.90	0.10	0.061
Cod Denmark	26	1.65	0.03	0.018
Plaice Denmark	31	2.05	0.04	0.021
Cod Flyshoot NL	49	3.25	0.07	0.034
Plaice Twinrig NL	38	2.55	0.05	0.027
Processing (including freezing) of plaice	2.6 MJ electricity 1.5 MJ heat	0.10		
Processing (including freezing) of cod	3.8 MJ electricity 2.3 MJ heat	0.15		

An Icelandic study (Guttormsdóttir, 2009) compared the environmental impacts of the production of frozen processed Icelandic cod for two different fisheries. Producing 1 kilogram processed bottom trawler cod, the fishing vessel combusted 1.1 litre of fuel and rendered 5.14 kg CO2 equivalents. This GWP corresponds to the GWP found for the Swedish Cod Trawler (Table 3). For 1 kg of processed long line cod, the fishing vessel combusted 0.36 litres of fuel and produced a GWP of 1.58 kg CO2 equivalents. Tyedmers (2005) estimated that based on data from more than 250 distinct fisheries or fleet subsets, based in 20 countries, for the year 2000 the global marine fishing fleet burned almost 50 million l of fuel (average of 620 l of oil per ton of fish) resulting in 130 million tons of CO2 emitted into the atmosphere (average of 1,7 tons of CO2 per ton of landed product). According to FAO the average ratio of fuel to carbon dioxide emissions for capture fisheries has been estimated at about 3 teragrams of CO2 per million tonnes of fuel used. The authors make a special note on the particularly high emissions per kilogram aquatic product that are transported by air (8.5 kg of CO2 per 1 kg of transported fish).

The results mentioned above can be compared with the energy consumption for pork, chicken en beef. De Vries & De Boer (2010) carried out an analysis of the environmental impact of various products from the farming sector and concluded that the energy use for plaice and cod are higher than for chicken, pork or beef. The GWP of plaice and cod are in the same range as pork and chicken.

3.2 Hotspots

3.2.1 Fuel usage

The main challenge in the reduction of GHG-emissions in marine capture fisheries lies in the reduction of use of fossil fuels for vessel propulsion. On the one hand this can be sought in the development and deployment of more fuel efficient propulsion systems (engine, transmission, propellers). On the other hand it can be sought in the development of fishing techniques that are less fuel intensive. As a result of the high levels of fuel prices over the last decade both developments have gained momentum.

3.2.2 Production chain

Reduction of GHG-emissions in the production chain can be targeted by increasing the efficiency of protein production in the processing chain (reduction of waste, produce from waste). In addition in the entire chain of processing, packaging and transport GHG reductions can be sought. Especially transport can take up a significant part of GHG production both in overall transport movements as in more efficient storage and delivery processes.

3.3 Solutions

Obviously a major solution can be found in increased fuel efficiency in the fisheries operation. Fuel reduction technologies show a direct reduction of energy consumption and GWP.

In addition fisheries management can play a significant role. The FAO report of 2009 states that good fisheries management can substantially improve fuel efficiency for the fisheries sector as a whole, by preventing overcapacity and excess effort, as they lead to lower catches per unit of effort and therefore lower fuel efficiency. Also when management measures lead to increased fish stocks a positive effect on the environmental performance will be a reduction in fuel needed to catch equal amounts of fish (Burg, van den, 2012).

In addition, changes in fuel mix like transitioning towards the use of sustainable fuels or biofuels could also reduce the use of fossil fuels and could have a positive effect on the environmental performance.
Guttormsdóttir (2009) proposes finding a substitution for fossil fuels such as hydrogen (burns without CO2 production), sun power, wind power and hydropower. Guttormsdottir (2009) calculated the hypothetical carbon footprint of a long liner vessel and a trawling vessel with hydrogen as an energy carrier. It was calculated that for bottom trawled cod the CO2 footprint would be 1.72 kg CO2 equivalence (73% reduction compared to fossil fuel), and for long lined cod 0.4 kg CO2 equivalents (85% reduction).

3.4 Challenges and knowledge gaps

As in the aquaculture analysis a main issue is the availability of reliable data to do a full GHG-emission of fishery operations. Most of the existing literature regarding GHG emissions from seafood supply chains focuses on a limited number of species (Atlantic cod, Atlantic salmon, rainbow trout), mostly located in European waters, caught by European fishermen and sold in Europe. Lack of GHG emission data on non-cod species fisheries prohibits understanding on the relative performance of those fisheries and the range of emission intensities within them (Parker 2012).

A very important challenge is to include the entire production chain into the analysis and hence in the attempt to reduce GHG-emissions. The processing, packaging, transport, sale, consumption and waste management stages are not always included in seafood LCAs. Parker (2012) states that these additional stages would be useful in placing earlier stages in context. This may be particularly important for products that are a) transported fresh by air; b) processed into value-added ingredients; or c) cooked for consumption.

The fishery types mentioned in table 3 are large-scale fisheries in Europe. Small-scale fisheries however, make a large part of the total marine captures fisheries (FAO, 2012). The emissions of this fishery are not comparable to the large-scale fisheries, therefore, studies should be carried out to get an insight in the emissions of small-scale fishers.

Industry produces a substantial amount of data that may not be publicly available. Data sharing initiatives and cooperative research engagements could overcome this obstacle. A proper insight in the GHG-emissions in all stages of the production chain, linked to for example a GHG-emissions certification scheme could allow proper monitoring an devaluation of GHG reduction efforts. To allow in this a level playing field an important step lies in improving the comparability of different data for example by reporting in common units (e.g. one kg fillet transported to market). While this would not remove the barriers caused by the use of different methodological choices, it would provide greater ease of access to industry practitioners interested in the relative performance of different products. It may be useful for studies to report results both in terms of this comparison-ready functional unit and a functional unit that extends into other life cycle stages which differ between systems, thus providing complete results for the system at hand and also providing a basis of comparison with other studies.

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