Global Warming Potential of Smoked Trout Filet

AgroTech

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1 CONTENT

2 ABSTRACT

2.1 Goal and Scope

The current analysis and report follows the ISO 14044:2006 guidelines (ISO, 2006). The aim of this study was to identify products/processes with a major contribution to the global warming potential of one package of 125 g smoked trout, cultivated in Danish aquaculture, fed with industrial fish food (Biomar), and processed at *DanForel*. The process is supervised by *Dansk Akvakultur*. The functional unit of the study was one package of 125 g smoked trout delivered at gate (i.e. *Lidl* distribution centre in Germany).

2.2 Background and Methods

The present life cycle assessment is based on consequential modelling as discussed in the Danish consensus project (Hansen, 2004). The global warming potential is calculated according to the Intergovernmental Panel on Climate Change (IPCC) 2007, using a 100 year time span (IPCC, 2007). Capital goods (e.g. roads and maintenance) are included in the major part of the background data (i.e. data for processes that are not part of the immediate product chain such as production of electricity, packaging etc.). Impacts from land transformation were excluded.

In this analysis the cradle to gate principle is used, i.e. neither complete life cycle including waste management nor consideration of biogenic carbon dioxide is applied.

The waste product of trout production (aquaculture fish waste) is used as fertiliser, and for generation of biogas, while the fish by-products from processing are used as mink fodder. If no trout were produced, alternative sources for fertilisers, biogas, and mink fodder, needs to be found. Production of smoked trout therefore creates a decrease in the production of fertilisers, biogas sources and other mink fodder sources. The system is therefore expanded to include fertiliser, fodder and biogas. The lower system boundary is hence production of the different ingredients to the fish feed, and the upper system boundary is the gate in Germany.

2.3 Results

The global warming potential of one package of 125 g smoked trout is estimated to 496 g CO_2 equivalents (the 95% confidence interval spans from 460 to 547 g CO_2-equivalents). This estimate does not include the contribution from transforming non-arable land to arable land; estimated to 2 g CO_2 equivalents per 125 g package smoked trout Nor does it reflect methodological uncertainties - see also section 7.2.

These results are somewhat lower than suggested by other LCA studies of farmed fish (see section 7.3).

There was used 185 g trout feed per 125 g package smoked trout. Feedstuffs accounts for 62% of the total global warming potential (GWP), including all processes (also the positive contribution of fodder substitution), and is thus the strongest contributor to the total GWP. The second most important contributor to GWP is energy in form of electricity and gas consumption with 27%. Fish meal and rape oil are the strongest contributors to fish feed (34% and 35% of the net GWP from feedstuffs).

In summary, like any other LCA of a complex product, the reported LCA contains uncertainties due to the fact that it models a very complex world. It is seen that the estimated global warming potential is sensitive to the choice of model (i.e. marginal suppliers). The model-related variance reflects uncertainties of the LCA, whereas the empirical related variance, for the background products/processes also reflects how large the room for improvement is.

3 GOAL AND SCOPE

3.1 Focus

The current analysis and report follows the ISO 14044:2006 guidelines (ISO, 2006). The study was performed within the scope of the performance contract of AgroTech A/S as GTS institute and the Danish Ministry of Science. Within this contract AgroTech A/S agreed with *Dansk Akvakultur* (DA) to analyse the global warming potential (GWP) of smoked trout filet as part of a full life cycle analysis (ISO, 2006). The aims of this study was thus to (1) quantify the global warming potential (GWP) of one package smoked trout filet delivered at the gate in Germany and (2) to identify products/processes with a major contribution to GWP of the separate parts of the production chain of the trout filet.

The focus of the report is only to identify the main sources of global warming potential of packed smoked trout filet; other environmental impacts are not covered in this report.

The results of this study are for use within DA. The results are not to be used as a comparative assertion (ISO, 2006), but used as a guideline to pinpoint possibilities of reducing GWP in Danish aquaculture systems based on the case study *farmed smoked trout filet*. The intended audience are producers of any part of the production chain of smoked trout filet, and consultants related to Danish aquaculture.

3.2 Product

The product, trout filet, is a standard grocery food product used for lunch or dinner. The trout investigated in this study is a final customer good that is packed in protected atmosphere for long keeping in plastic, at *DanForel* and as such available for the consumer on the market or supermarket. The functional unit used in this study is 1 package of 125 g filet at the whole market distribution centre. However, values for 1 kg product are given on some places for comparison to other reports and products.

In the current analysis the production cycle is only analysed to the market supplier close to Kassel, Germany with a distance of 600 km from the production unit; i.e. no further GWP between grocery market distribution centre and the final destination (including waste products) was included in this study.

3.3 Data

Production data of the different parts of the production cycle where supplied by *BioMar* (fish feed producer), *Nielsby Dambrug* (trout farming, grow out) and *DanForel* (fish processing unit). When available, average data of the year 2008 were used for calculations. Data from different sources such as the Ecoinvent 2 database, literature sources, and personal communications with key persons where however involved, too (see *Inventory* section). When feasible the Ecoinvent 2 database was used and adjusted to the data and the specific product used. Some data does however appear with a large uncertainty; especially emissions of nitrous oxides, which is included in many agricultural processes, is very uncertain (Halberg et al., 2006).

3.4 Methods

3.4.1 Tools

The calculations are made using the PC tool SimaPro 7.1 (PRé-Consultants, 2008) together with LCA databases (e.g. Ecoinvent 2 and LCA Food DK) that contain data for specific background processes. For simplicity, processes in the databases are used without modifications, if nothing else is stated in the *Inventory* section.

3.4.2 LCIA

The chosen life cycle impact assessment method (LCIA) takes only the global warming potential into account, and is calculated according to IPCC 2007, using a 100 year time span (IPCC, 2007). Using IPCC 2007, 1 g N_2O and 1 g CH_4 correspond to 298 and 25 g CO_2, respectively. As a default the Ecoinvent 2 database includes biogenic CO_2 (carbon incorporated into plants/trees from the atmosphere). However, because the waste process is not included, the LCA reported here excludes biogenic CO_2 sources. Furthermore, GWP that arises due to land transformation is not included in this study. Therefore, biogenic CO_2, CO_2 in air as well as CO_2 from land use is set to a value of 0 CO_2 equivalents in the LCIA method for GWP (IPCC, 2007).

The GWP of the production facilities (building etc.) at the three production units (*Biomar*, *Nielsby Dambrug*, *DanFore*l) is not included, because it is expected to be of minor importance compared to the very large production of material (fish feed, fish etc.),

The investigations include processes from fish feed production, technical processes of the main three investigated production chain groups (fish feed, fish cultivation, fish processing), internal and external transports, and production of plastic foil for packaging, production of cardboard packaging boxes, plastic for wrapping, and more.

3.4.3 Consequential Approach

The LCA reported here is based on a consequential approach (Weidema, 2003). In many processes more than one product is produced (joint production). In such cases it is necessary to divide the environmental impact from the process between the products (the main product and by-products) (ISO, 2006). Using a consequential approach this is done by *system expansion*, where the impacts of the by-products are included in the analysis, rather than splitting the impacts due to e.g. weight or value of the different products (an attributional approach); for further details see Weidema (2003), Kørnøv et al, (2007) or Thomassen et al, (2008). However, for simplicity, data for the background processes used from existing databases as Ecoinvent 2 are used without modifications although the estimates might have been obtained by a non-consequential LCA approach, if nothing else is stated in the Inventory section; i.e. the background estimates might have been obtained by an attributional approach, where the GWP for by-products is allocated due to e.g. economical value of the products, rather than by system expansion.

3.4.4 System Boundaries

In the current analysis the lower boundary of the analysis is the production of the different ingredients to the fish feed as fish meal and soy meal as main substances. The upper boundary is the delivery of the fruits to the whole market. However, the production system cycle is expanded through including the consequences of substitution of fish waste to mink fodder (*DanForel*) or biogas (*Dambrug*) (see Table 1).

The report was sent to external critical review for ISO quality assurance.

4 BACKGROUND OF LCA

A Life Cycle Assessment (LCA) is the assessment of environmental effects a product, or a service, has during its lifetime, in principle from cradle to grave. In some cases it may, however, be necessary to use system boundaries and analyse only a part of the life cycle. Such system boundaries are included because the faith of a given product is not always known when the product is sold, or the product is used as a part of other products.

A strength of the LCA approach is that processes in the fabrication of a product/ service, that have the highest environmental impacts, can be identified. Thereby, the LCA may help the producers to make decisions concerning where to take actions in order to reduce the environmental impact, for example by optimising energy consuming processes.

A LCA can contain a number of environmental impact categories, e.g. global warming, acidification, eutrophication, land use and photochemical smog. The different impact categories can be normalized and weighted to a single score, either monetary units or Quality Adjusted Life Years (QALYs). In this report only the global warming potential is covered and weighting of environmental impacts is therefore not necessary.

5 PROCESS DESCRIPTION

The processes involved in producing one package of 125 g smoked trout filet are illustrated in Figure 1 and 2. Figure 1 gives a global overview of the main product phases involved that is from fish feed production to packed and transported filets, where there are denoted unspecified in and outputs to the separate production processes. Figure 2 illustrated the three main phases of the production cycle in more detail: Fish feed production (I), fish farming (II), and Processing (including packing and transport) (III). It gives a more detailed overview of the three main production categories in the life cycle (from cradle to gate) of the smoked trout filet. Figure 2, however, only shows the major fluxes, for a detailed overview of the processes involved see the *Inventory* section. To support the understanding of the method using system expansion Table 1 gives an overview of the involved expansions.

Fish feed production (Figure 2, I) is modelled by the ingredients in the fish feed, and the energy used for the fish feed production Fish feed is transported to the fish farming unit at *Nielsby Dambrug*. Fish farming (Figure 2, II) is separated in the two sub-processes 'Smolt Production' and 'Trout Grow-Out'). Both sub-processes include usage of water, energy and fish feed, and the smolt production further uses mother fishes. Mother fishes and other wasted fish (Fish Waste; 4% of the production) from the two sub-processes is transformed into biogas in a biogas reactor. The produced biogas is modelled to reduce the demand for natural gas, and hence lead to a reduction in the net GWP of the product.

Processing of the fresh fish takes place at the third main station of the production cycle (Figure 2, III). Fresh fish is transported alive, including water from the farming

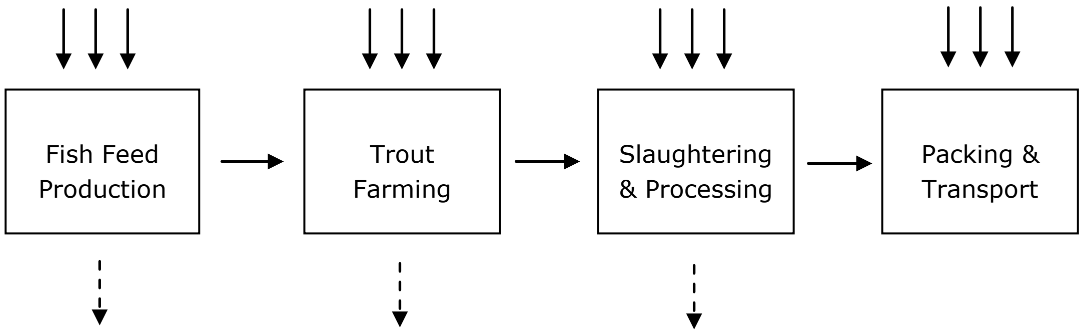

Figure 1. Main production flow diagram of production of packed trout filet. *Boxes illustrate processes, arrows illustrate inputs from outside (undefined) and transport from one process to another. From each process there may be waste, which is either sent to the water treatment plant or used as fodder (dashed arrows)*

unit, with trucks to the processing unit at *DanForel*. The fresh trout is kept in clean water basins for a short time and then transported via conveyor belts to the cutting unit (before cutting the fishes are killed by electricity shock).

A large part of the fish (head, bone, skin, intestines and quality sorting) is stripped of in the cutting process, and used for fodder; i.e. 49.5%. The fish waste from processing is thus substituting animal fodder (see section 6.7), and the avoided fodder production is included in the GWP calculation of the product.

The remaining 51.5% of the fish are the raw filets. In the further process, filets are salted in a salt solution, dried, and smoked at warm temperature (54 °C). The smoke is produced by burning wood, and the smoking driven by steam produced by a gas boiler. Additional 9% of the total fish weight is lost as evaporated water during the process.

Table 1: System expansion modules for the production of the 125 g packed fish filet. *Shown are the cases where system expansion is used with the three main modules fish feed, I, fish farming, II, and fish processing, III*

Substituted Product	Substitution	Module	Substitution Ratio
Fish waste	Biogas	II	1:1
Biogas	Natural gas	II	1:1
Fish waste	Fodder (Energy, SFU) Fodder (Protein)	III	4:1 8.3:1
Fodder[1] (Energy, SFU)	Barley Soya Meal Palm Oil	III	0.7:1 -3.3:1 13.5:1
Fodder[2] (Protein)	Barley Soya Meal Palm Oil	III	-0.26:1 0.32:1 -1.32:1

[1] Barley, soya meal and palm oil are substituted in one group for each unit SFU, see 'Fodder' under Inventory section
[2] Barley, soya meal and palm oil are substituted in one group for each kg protein, see 'Fodder' under Inventory section

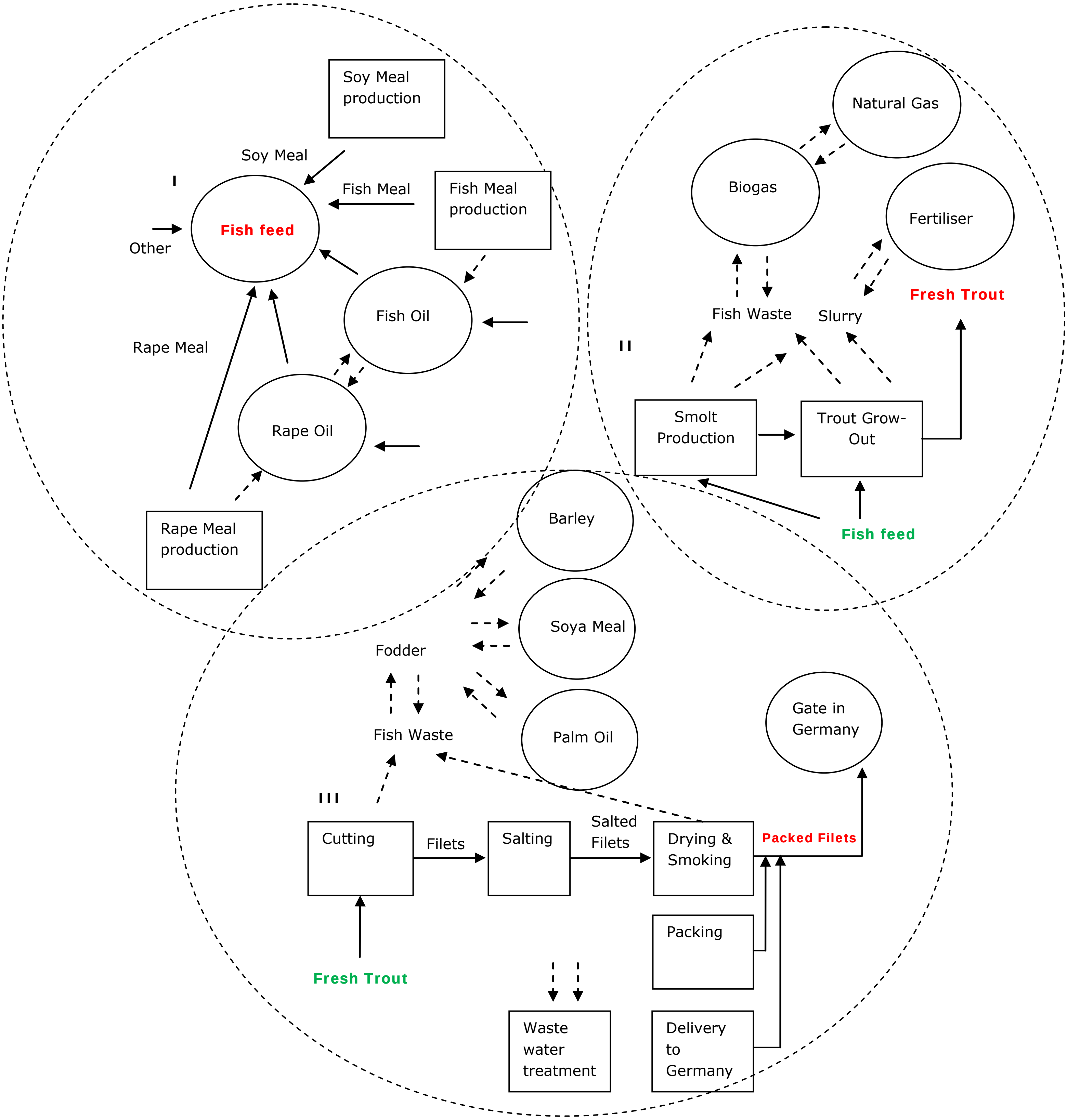

Figure 2. Process diagram of production of packed trout filet. *The three main processes involved in production of smoked trout filet with fish feed production (I), trout cultivation and grow-out (II), and processing and packaging of the filets (III. The bold red characters indicate the main production unit that is transported to the next process; the bold green characters indicate the input from the earlier process. Boxes illustrate processes, arrows illustrate transport from one process to another, one broken arrow indicates by-products or waste, two opposite broken arrows indicate substitution by system expansion, and ellipses illustrate markets for products. Energy and internal transport are implicit available for each process. From each process there may be additional wastes, which is either sent to water treatment.*

6 INVENTORY

In the consequential LCA approach the marginal product is used to model the environmental impacts. Theoretically resources can be replaced and the increased use of a certain restricted resource will result in the usage of another product that can be used instead. However, a restricted resource that is necessary for a certain product (e.g. fish feed must contain certain oil types and cannot use palm oil instead), is used as the marginal sub-product.

6.1 Fish Feed

Fish feed was modelled according to the feed-recipe attained from the producer (BioMar). Fish meal consists mainly of oil and protein sources.

The reviewer of the current report suggested modelling all protein sources as soya and all oils as palm oil (see Appendix). This is, however, a strong simplification of the reality that would lead to a too abstract view on the real system fluxes. For fish production certain oil types and protein sources are usually necessary (and thus the marginal) as they are needed for attaining certain fish quality parameters (e.g. certain fat acids). The same product quality can thus not be produced with alternative products and therefore no other marginal produce can be identified. We therefore used certain marginal oils and protein sources as described below. However, the effect of alternative marginal's as suggested by the reviewer were calculated with using soy meal as only protein source[3] and palm oil as only oil source[4] .

In the current analysis fish feed was thereby modelled as a mix of fishmeal (32.78%[5] + 6.72% blood meal[6]; see *Fish meal*), fish oil (12.07%; see *Fish oil*), wheat (12.83%; see *Wheat*), rape meal (9.7%; see *Rape meal*), peas and pea protein (see *Peas*), soy meal (see *Soy meal*) and Soy beans (2.21% soy beans + 1.29% soya flour; see *Soy beans*), and water (see *Water*). There was used 0.024 kWh electricity for fish feed per functional unit (FU) (see *Electricity*). The used feed efficiency was 0.9 kg fish feed for growing out 1 kg fresh fish.

6.2 Fish Meal

Fish meal was used as marginal sub-product. Fish meal was modelled as produced in conjugation with the by-product fish oil (see section 6.3), where 0.208 kg fish oil were produced for each kg fish meal. The fish used for fish meal were assumed 100% sand eel ex harbour (LCA-Food-DK, 2006) of which 4.66 kg was used to produce 1 kg fish meal. To increase representativeness, the heat usage for producing fish meal, has been calculated to an average of the usage in the fish industry (LCA-Food-DK, 2006). There was used 171 l natural gas in the processing of 1 kg fish meal, and the energy content of natural gas was assumed to be 36,3 kJ/l natural gas (LCA-Food-DK, 2006).

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[3] *Using soy meal as only protein source from the Ecoinvent 2 database decreases the GWP of fish feed with 5% and the total GWP of the functional unit with 4% and is within the confidence interval (thus statistically not different).*

[4] *Using palm oil as only oil source from the Ecoinvent 2 database decreases the GWP of fish feed with 24% and the total GWP of the functional unit with 15%.*

[5] *The percentages are the fraction of the total mass.*

[6] *In the calculations blood meal is substituted by fish meal for simplicity, because we do not have LCA data for blood meal, and blood meal can be substituted by fish meal in the feed-recipe. Furthermore, blood meal is a constrained resource, and can hence not respond to a change in the marked.*

Fish meal might be a restricted resource, due to quotas, but since it is mandatory in the fish feed (New and Wijkström, 2002), it is not substituted by other products (like soya).

6.3 Oils

The marginal oil when using the consequential approach in most food production system LCAs is palm oil (Schmidt, 2007). For many products, however, modelling the GWP with palm oil as only oil would mean a strong simplification and not reflect the reality (see 6.1). In fish feed the oil composition is important as certain oils cannot be substituted. In the current analysis the oils are therefore not treated as palm oil but modelled as described below.

6.3.1 Fish Oil

The production of fish oil is determined by the availability of fish and is restricted by quotes (Rosenlund, 2002), and the production can therefore not increase with an increasing demand. Fish meal and fish oil are, however, necessary products which are difficult to substitute, due to their composition (New and Wijkström, 2002). Fish oil was therefore partly modelled as a by-product of fish meal production (as described above) and partly as rape oil[7] which can substitute some of the fish oil in the fish feed production (i.e. no fish oil is produced as major product). The by-product of 0,208 kg fish oil per kg fish meal only covers 68% of the necessary amount, the remaining 32% of the fish oil share is modelled as rape oil (i.e. 0.039 kg per kg fish feed).

6.3.2 Rape Oil

In fish feed rape oil is modelled as the marginal oil source. Rape oil was modelled from the Ecoinvent 2 database (Althaus et al., 2007), i.e. rape oil at local storage that includes internal transports and average transport from mill to storage (Althaus et al., 2007). The module is using rape seed production, oil milling and transports (Althaus et al., 2007). Rape oil cannot easily be substituted in fish feed since it is a necessary ingredient; i.e. palm oil would result in a lower quality fish feed (according to the producer).[8]

6.4 Soybeans

Soybeans were modelled from Ecoinvent 2 database (Althaus et al., 2007) based on cultivation of in Brazil, including use of diesel, machines, fertilisers, and pesticides. In brief the assumptions underlying the soybean data (1 kg soybeans; fresh mass with a water content of 11 %) is as follow (Althaus et al., 2007). Cultivation of soybeans in Brazil is modelled with data from literature. Some data are extrapolated from Europe (production of fertilisers and pesticides) or Switzerland (machine use). The transports are modelled with standard distances. Carbon content: 0.388 kg/kg fresh mass. Biomass energy content: 20.45 MJ/kg fresh mass. Yield: 2544 kg/ha. The emission of N_2O to air is calculated from standard factors for mineral fertilisers from Nemecek et al. 2008 and for the emission from the crop residue as stated in Ecoinvent 2 database (Althaus et al., 2007). The emission of nitrate to water is calculated with a nitrogen loss factor of 30%.

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[7] *Note that palm oil is not used as the marginal oil, since it cannot be used in the fish feed, and the producer therefore need to buy rape oil instead (see section 6.3 for details).*

[8] *There are different data sources for GWP of rape oil (e.g. Schmidt, 2007, LCA-Food-DK, 2006). The data of Althaus et al., (2007) are, however, accessed of good quality, and thus used in the current analysis. The effect of a different data source is shown in the sensitivity section (7.2).*

6.5 Wheat

Conventional wheat was taken from LCA Food DK database (LCA-Food-DK, 2006) as produced by Dalgaard and Halberg from the Danish Institute of Agricultural Sciences in 2002 (see http://web.agrsci.dk/jbs/bepro/index_uk.shtml).

6.6 Fish Waste used for Fodder

Fodder is introduced to the system in order to model the substitution of fish waste from the processing facility (see Figure 2 III). It is assumed that the marginal production of fodder is a combination of barley and soya meal, such that the protein and energy content in the barley/soya mix match the original fodder content (Weidema, 2003). In the fodder calculation differences in amino acid composition, vitamin content etc. between the barley/soya mix and the fish waste are not taken into account. In the production of soya meal there is a by-product of soya oil. It is assumed that the produced soya oil substitute palm oil at the world marked for plant oil (Dalgaard, 2008). One kg fish waste is modelled to substitute 0.25 Scandinavian Feed Units (SFU) 0.12 kg digestible protein (Vils, 2009). The amounts of barley and soya needed to substitute the fodder, and the replaced palm oil, are calculated by solving the below equation system, which describes the content of protein and SFU substituted by 1 kg fish waste.

$$\begin{bmatrix} p \\ f \\ o \end{bmatrix} = \begin{bmatrix} 0.436 \\ 1.207 \\ 0.244 \end{bmatrix} \cdot m_{soya\ meal} + \begin{bmatrix} 0.092 \\ 0.952 \\ 0 \end{bmatrix} \cdot m_{barley} + \begin{bmatrix} 0.019 \\ 0.191 \\ 1.000 \end{bmatrix} \cdot m_{palm\ oil}$$

Where *p* is the protein content in kg, *f is the energy* in SFU, *o* is the mass of plant oil in kg, and *m* is the mass, in kg, of soya meal, barley and palm oil, respectively (Schmidt, 2007). The global warming potential of barley, soya meal and palm oil is calculated as described below.

The terminal transport of fodder is not assumed to be affected by the change in fodder source, and hence no GWP for transport of fish waste for fodder, is included.

6.6.1 Barley

The marginal production of barley is assumed to be placed in Canada (Schmidt, 2007). The emissions of NO (0.55 g per kg barley), N_2O (0.76 g per kg barley), and the land use (3.44 m^2 arable land[9] per kg barley) are from (Schmidt, 2007). LCA data of machine usage, crop drying etc. are from the LCA of German produced barley from the Ecoinvent 2 database (Althaus et al., 2007). The production of barley is assumed to be global, and a change in the global transport of barley between the countries is therefore not taken into account.

6.6.2 Soya Meal and Palm Oil

The marginal productions of soya meal and palm oil are assumed to be placed in Argentina/Brazil and Malaysia/Indonesia, respectively (Schmidt, 2007). LCA data for soya beans, which are processed to soya meal and soya oil, are from the Ecoinvent 2 database (Ecoinvent 2007), and data for processing soya beans, and transporting the soya meal to Denmark, are taken from the LCA Food database (LCA-Food-DK, 2006). Palm oil is modelled by a LCA for palm oil produced by an oil mill in Malaysia/Indonesia; the data are from the Ecoinvent 2 database (Althaus et al., 2007). which includes the extraction of palm oil, palm kernel oil and palm kernel meal, from palm fruit bunches. Energy supply from extracted solids (fibres, shells, digester solids

[9] The increase in production is assumed to be achieved by increases in yields only Schmidt J.H. (2007) Life assessment of rapeseed oil and palm oil, Ålborg.

and empty fruit bunches) and treatment of specific wastewater effluents are taken into account.

6.7 Waste Water Treatment

Waste water treatment is modelled according to LCA Food DK Database (LCA-Food-DK, 2006) but adjusted to use the Danish electricity mix (see *Electricity*). For waste water treatment 1.1 kWh electricity is used for 1 kg chemical oxygen demand (COD) or 1 kg biological oxygen demand (BOD). At *Nielsby Dambrug* (i.e. fish farming) the energy usage for waste water treatment is included in the total energy usage.

6.8 Slurry

Slurry from fish farming is modelled to substitute inorganic fertilisers. Due to a chemical analysis of the slurry, 1 kg slurry contains 5.7g N and 5.0 g P (the analysis is performed by eurofins, july 2009). The inorganic fertiliser is modelled by ammonium nitrate phosphate, taken from Ecoinvent 2007 (Althaus et al., 2007). There is assumed 30 km transport for the slurry (see Transport).

6.9 Tap Water

Tap water is modelled by standard data for European tap water to end users. The data are from LCA food database (LCA-Food-DK, 2006), where 1 m^3 water uses 0.244 kg CO_2 equivalents from electricity (96%) and organic chemicals (4%).

6.10 Biogas

The fish waste product at farming was used for biogas. One kg fish waste was equivalent to 2.88 l biogas (Lanari and Franci, 1998). Biogas from waste product was modelled as in Ecoinvent 2007 (Althaus et al., 2007).

In brief, data represents the environmental exchanges due to biowaste pre treatment (inclusive the disposal of contaminants) biowaste digestion and post-composting of digested matter. In addition emissions to soil due to the use of presswater and digested matter as a fertiliser in agriculture are recorded. Spreading of the fertiliser, and transport from biowaste plant to farms, are taken into account. Gas purification and the use of the gas for co-generation are not included. Using system expansion (Weidema, 2003) we assumed that 1 m^3 produced biogas substituted 1 m^3 natural gas (see Figure 2, II).

6.11 Heat from Natural Gas

Heat from gas burning was modelled with natural gas burned in a condensing modulating boiler, with an energy loss of 2% in the burning process ('natural gas, burned in boiler condensing modulating <100kW' (Althaus et al., 2007)). An energy value of 39.6 MJ per Nm^3 natural gas was used.

In brief, the modelled heat production includes fuel input from low pressure network (based on Swiss network data), infrastructure (boiler), emissions, and electricity needed for operation. The module uses the average net efficiency for the type of boiler (estimated from literature) (Althaus et al., 2007).

6.12 Electricity

The usage of marginal electricity is modelled by the existing Danish grid, so standard data for the medium voltage (10 kV) net, incl. electricity import, is used. Marginal electricity is modelled as a mix of existing electricity sources in Denmark based on the year 2003 (medium voltage) as used in Ecoinvent 2 database and reported in Frischknecht et al. (2007), since it has not been possible to identify one marginal source of electricity. Most consequential analyses use either coal or gas. However, the described mix was used, because the marginal energy source is not known. The effects of choosing other marginal electricity suppliers are is shown in the sensitivity analysis in section 7.2.

In brief, the mix of existing electricity (proportion of kWh) originates from 48% coal, 24% natural gas, 12% wind power, 11% oil and 5% others.

6.13 Wood Chips

Wood chips for smoke production is modelled from a mix of unspecified hardwood (28%) and softwood (72%) as used in the Ecoinvent 2 database (Althaus et al., 2007).

In brief, the process includes the chopping of the average mix as used in Switzerland with a mobile chopper in the forest. Process data for Austria were used and includes the driving of the mobile chopper to and within the forest (Althaus et al., 2007).

6.14 Smolt

Production of smolt was modelled using 7 g trout feed as used for out-growing of the fishes (i.e. no separate feed for the smolt was assumed). In addition there was one mother fish for each 20.000 eggs produced (the mother fish was used for biogas production after usage). For production of smolt 0,001 kWh low voltage electricity at the Danish grid (Althaus et al., 2007) was used. For production of 1 kg fresh trout a need of 3 smolt was used in the calculations.

6.15 Salt

Salt was modelled as production of sodium chloride for production process standards in Switzerland (Althaus et al., 2007). There is used 10.22 g salt per FU.

6.16 Packaging

The smoked trout filet is packed in protected atmosphere (filled with N_2 and CO_2) in a plastic film container of 12 g. The plastic film was modelled as packaging film LDPE (Althaus et al., 2007).

In brief, this process contains the plastic amount and the transport of the plastic from the production site to the converting site as well as the dataset "extrusion, plastic film" (Althaus et al., 2007).

Each container included 0.45 l of mixed gas with 30% CO_2 and 70% N_2 which is 0.113 g pure CO_2 and 0.265 g pure N_2 that was modelled by liquid carbon dioxide and liquid nitrogen production (Althaus et al., 2007). After opening of the package the gases are released as CO_2 or N_2, which is taken into account in the calculations (N_2 has no consequence on GWP). Each 10 containers of trout filets are packed in one cardboard box of 83 g. The cardboard is modelled as corrugated cardboard mixed fibre from the

Ecoinvent database (Althaus et al., 2007). Biogenic CO_2 stored in the card boxes is not taken into account; i.e. it has a value of 0 CO2 equivalents as adjusted in the chosen LCIA method for GWP (IPCC, 2007).

In brief, this module includes the production of corrugated board out of the corrugated base papers. The following steps are included: energy production, corrugated board production itself, and waste water treatment (Althaus et al., 2007).

6.17 Transport

The four different transports (raw feed transport to feed factory, processed feed to trout farm, fresh trout from farming to the processing unit at *DanForel*, finished product from *DanForel* to the final market in Germany) were modelled with their specific transport modules. In all cases we assumed one-way transport; i.e. no empty back transport.

6.17.1 Raw Feed Material to Feed Factory

An average transport distance of 70 km was assumed for the ingredients (according to the producer, *Biomar*). The transport was modelled using standard values for a EURO4 transport lorry of >32t (including fuel consumption, construction, maintenance, road occupation etc.) (Althaus et al., 2007).

6.17.2 Processed Feed to Trout Farm

Transport from *BioMar* to the aquaculture farm was modelled with a distance of 100 km using the standard values for a EURO4 transport lorry of >32t (Althaus et al., 2007).

6.17.3 Slurry to Agricultural Fields

Transport of slurry from *Nielsby Dambrug* to agricultural fields the aquaculture farm was modelled with a distance of 30 km (according to the farmer) using the standard values for a EURO3 transport lorry of >32t (Althaus et al., 2007).

6.17.4 Fresh Trout from Farming to the Processing Unit at DanForel

Transport from fish farm to the processing plant (*DanForel*) was 45 km, and modelled using the standard values for a EURO4 transport lorry of >32t (Althaus et al., 2007). The transport of fresh fishes included additional transport of 4 l water per kg fish (with the fish).

6.17.5 Transport of the Final Product from DanForel to the Lidl Distribution-Center

The *Lidl* distribution Center is located between Kassel and Frankfurt in Germany at a distance of 600 km from Vejle. Transport is done with a cooling truck. This is modelled by standard values for a EURO4 transport lorry of >32t (Althaus et al., 2007), plus a truck cooling unit.

The GWP of the cooling unit was modelled with a keeping temperature at above 0°C according to the cooling unit TS600e produced by *Thermoking* (Thermoking, 2009). We assumed an average speed of 70 km h^{-1} and thus a use of 14.2h of the cooling unit, where 7,5 kW capacity is necessary for *Thermoking TS600e* (Thermoking, 2009). The whole truck is assumed to have a capacity of 18 t additional carriage. This results in a usage of 1.67 l natural gas per km transport of 1 t cooled fish filets. The usage of natural gas was modelled as the usage of natural gas for heat production (see section 6.14).

7 RESULTS

7.1 Contributors to Global Warming Potential

The global warming potential of a FU (one package of 125 g smoked trout fillet) is estimated to 496 g CO_2 equivalents and thus to 3968 g CO_2 equivalents per kg of the final product (see Table 2). This estimate does not include the contribution from transforming non-arable land to arable land, estimated to 2 g CO_2 equivalents per 125 g package smoked trout.

Figure 3 gives an overview of the total GWP of the final product as well as a detailed view to the three major production units. It shows that in total, fish feed is responsible for more than half of the GWP. This is a logical consequence of the fish feed being the major contributor to the GWP of fresh trout (86% to the GWP). Energy usage, transport and packaging are the other major contributors (Table2; Figure 3).

The main sources to the total GWP are shown in more detail in Table 2. It is seen that the high percentage of fish waste at the processing plant (i.e. through processing the whole fishes to filets) is a strong reason for relatively high GWP of the final fish filet product, compared to the fresh fish. I.e. in order to produce one 125 g filet in total 301 g fresh trout was necessary, thus a usage efficiency of only 41.5% (Table 3). The remaining 67.5% were lost during production through waste from head, bones, skin and intestines, fish dead, quality sorting, water loss during smoking, and others. It means that the usage of the produced fish feed (although its feed-efficiency is >1 for fresh fish) appears less efficient when focusing on the smoked filet as final product. In total 360 g fish feed were used per 125 g package smoked trout. The feed stuffs therefore accounts for about 62% of the total GWP (Table2; Figure 3).

Fish meal and rape oil are the strongest contributors to fish feed (35% and 34% of the GWP from feedstuffs; Tables 2 and 4). Table 4 illustrates the amounts and GWP for the separate analysis of the fish feed used. While per kg sand eels have a relatively low GWP, its low product efficiency (i.e. kg eel per kg fish meal) and the high energy amounts (heat) used for processing results in a relatively high GWP for fish meal. Hypothetical scenarios with other sources for the major feedstuffs are discussed in the sensitivity analysis (see section 7.2.3).

The gases responsible for the total GWP are illustrated in Figure 4. The majority of the GWP is due to CO_2 that originates from several energy sources used in the complete production cycle where fossil energy sources as gas, diesel or oil are used. The emissions of nitrous oxides originates mainly from agricultural products used for fish feed while methane mainly produced as by-exhausting from production of fossil fuels such as oil, diesel and natural gas (Althaus et al., 2007).

Table 2. Main Sources of Global Warming Potential. Shown are the major contributors to the GWP of one package or 125 g smoked trout Filet. The gas and electricity stated are only the usage at the feed factory (*BioMar*), the trout farm (*Nielsby Dambrug*) and the processing factory (*DanForel*), respectively; energy used at other sites are included in the relevant products/processes. Positive numbers in the table refer to products delivered to the factories, and negative numbers refer to by-products delivered from the factories. See Figure 2 for a diagram of the production process. Note that emissions from land transformation are not included. See Figure 3 for a graphical overview.

Source	Amount of product	CO_2-equivalents (g)	Proportion [a]
Feedstuff			
Fish meal	0.110 kg	111	22%
Vegetable oils	0.060 kg	113	23%
Soya products	0.031 kg	31	6%
Wheat	0.036 kg	25	5%
Other feed ingredients	-	16	3%
Waste used for feed	-0.15 kg	-20	-4%
Electricity			
Feed production	0.024 kWh	13	3%
Trout farming	0.045 kWh	24	5%
Processing	0.094 kWh	54	11%
Gas			
Feed production	0.21 MJ	16	3%
Processing	0.39 MJ	28	6%
Transport			
To Feed production factory	19 kg km	2	0%
To trout farm	35 kg km	3	1%
To processing factory	68 kg km	8	2%
To gate in Germany	88 kg km	10	2%
Packaging			
Plastics	12 g	52	10%
Cardbord	8 g	10	2%
Other			
Chemicals at trout farm	21 g	11	2%
Slurry from trout farm	125 g	-14	-3%
Salt for processing	10 g	2	0%
Remaining substances	-	2	0%
Total for one package	125 g	496	100%

[a] *The proportion is the GWP of the source, relative to the total potential of one FU.*

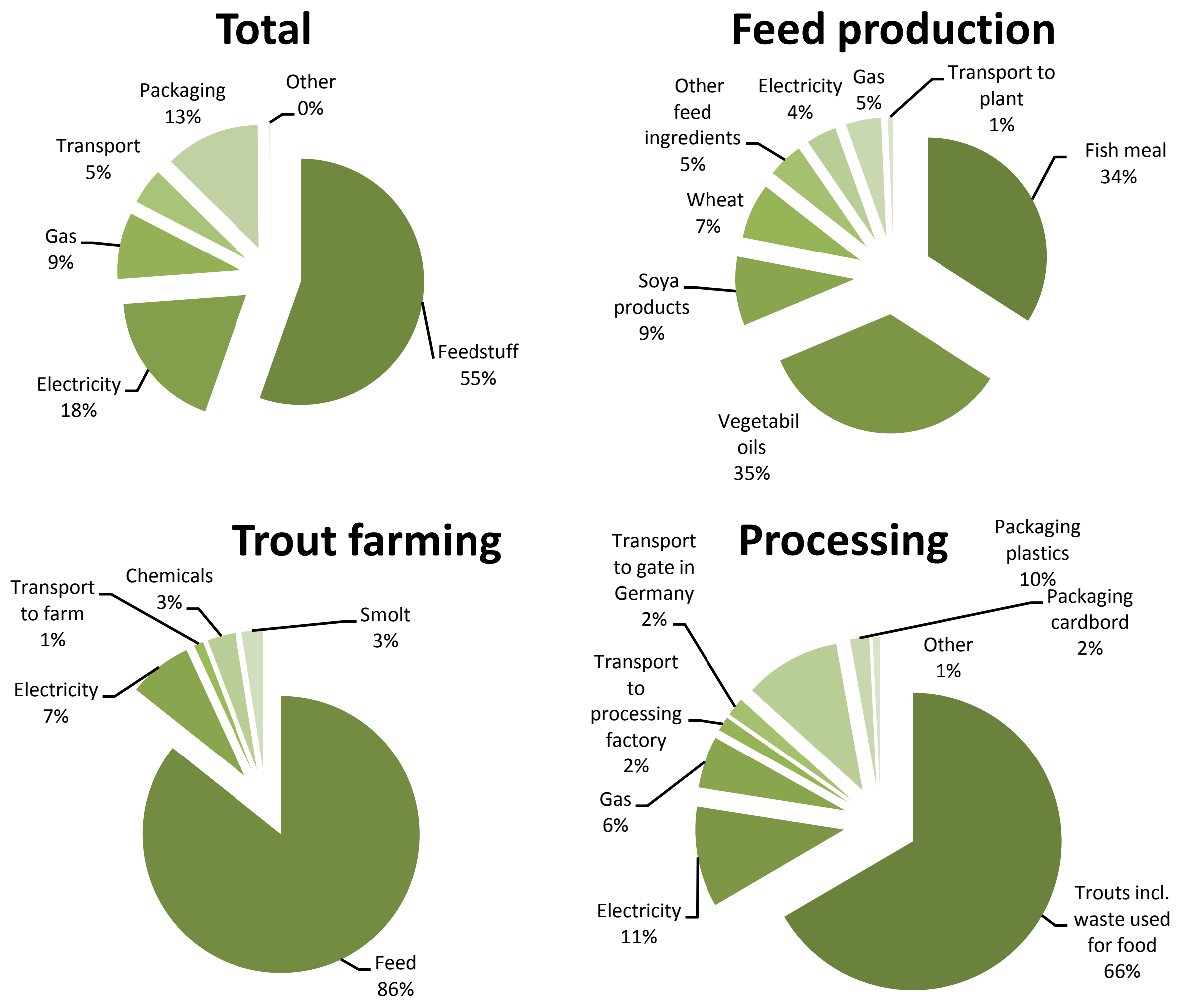

Figure 3. Main Sources of Global Warming Potential. *Shown are the major contributors to the GWP of one package or 125 g smoked trout Filet, in total, and separated on the three investigated contributors. The gas and electricity stated are only the usage at the feed factory (BioMar), the trout farm (Nielsby) and the processing factory (Danforel), respectively; energy used at other sites are included in the relevant products. See Figure 1 for a diagram of the production process, and Table 2 for details. Note that emissions from land transformation are not included.*

Table 3: Product flow for each process for the production of the 125 g packed fish filet. *Shown are the three major production units as illustrated in Figure 2 where. Fish feed for smolt production is included in the numbers.*

Process	Raw material to next process (g)	Fish disposal (fodder, biogas, or waste) (g)	Raw material usage efficiency (g product per g raw product)
Fish Feed	277	-	-
Fresh Fish	301	5	1.086
Fish Filet	125	176	0.415

Table 4: Major contributors to GWP of 1 kg fish feed.

Process	CO_2-equivalents (kg)	CO_2-equivalents (in %)
Fish Meal	0.40	34%
Sand eel	0.31	
Heat	0.19	
Rape Oil	-0.15	
Processing	0.05	
Rape oil	0.41	35%
Total Fish Feed	1.17	100%

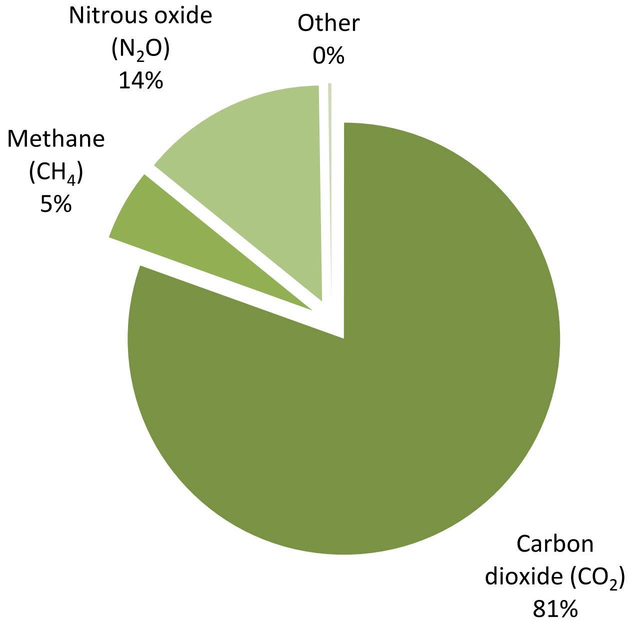

Figure 4. Contribution from different Greenhouse Gases. *Shown are the major contributors to the GWP. The contribution of each gas is in CO_2 equivalents. Note that emissions from land transformation are not included.*

7.2 Sensitivity Analysis

7.2.1 Variance of Estimate

A lower boundary on the range of variation for the GWP is estimated, under the used model, by the Bootstrap method implemented in SimaPro, using 1000 Monte Carlo simulations (PRé Consultants, 2008). An estimated 95% confidence interval[10] of the GWP of 1 package of 125 g smoked trout spans from 460 g to 547 g CO_2-equivalents.

The estimated confidence interval represents a lower boundary on the expected range of variation (variance) for the GWP estimate because not all sources of variance are included. Further variation may be expected because:

- Only 66% of the background data used in the LCA model contain information on variance, and the remaining 34% are hence modelled with zero variance.
- There may be uncertainties due to the choice between different model-scenarios (see below).

7.2.2 Impact of the chosen Method

In the current analysis system expansion was used as part of the consequential LCA (Weidema, 2003) that is the preferred method following ISO 14044 (ISO, 2006). In order to discuss the results in comparison to other investigations and/or to benchmark the results to other investigations the impact of the method needs to be discussed. In our analysis system expansion was used in several cases (for overview see Table 1). For comparison, the GWP of the FU is shown in cases where system expansion is not used (see Table 5).

Table 5. Cases without system expansion. *Shown are the GWP of the FU, if system expansion is not used. . The cases do not use the attributional method, instead the products are simply assumed to be worthless waste products without further systematic effect.*

Product	Substitution in case of system expansion	Total GWP (g CO_2 equivalents)	Increase in GWP (%)
Waste used for biogas	Natural gas	496	0
Waste used for animal fodder	Barley, soya meal, palm oil	516	4%
Slurry	Fertiliser	510	3%

[10] *The confidence interval is the estimated range the true value is estimated to be within, with 95% probability.*

7.2.3 Alternative Model Scenarios

Model assumptions concerning major contributors to the global warming potential are investigated, and the results are shown in Table 6. Alternative scenarios are not considered for the gas and transport parts, since they are modelled from specific information of the conditions related to the specific production, and they are responsible for a minor part of the total GWP.

Table 6: Alternative model scenarios*. Shown is the global warming potential of the FU (1 package of 125 g smoked trout fillet), under different alternative model scenarios. Negative numbers refer to an increase in GWP.*

Alternative Scenario		Total GWP ($g\ CO_2$ equivalents)	Reduction (%)
0	Used scenario (reference)	496	-
1	Coal power only	620	-25%
2	Wind power only	407	18%
3	Co-generation of heat and power using biogas at processing plant	471	5%
4	Co-generation of heat and power using natural gas at processing plant	491	1%
5	Fish meal in feed substituted by soybean meal[11]	536	-8%
6	Soybean meal in feed substituted by fish meal	491	1%
7	Fish waste used for biogas	496	0%
8	Feed coefficient of 0.80	461	7%
9	Feed coefficient of 1.00	531	-7%

One source of uncertainty can be the GWP from transformation of land for growing crops. The main source of GWP from land transformation, in this case, is growing of soya. The estimated effect of including land transformation for soya production[12] yields a net increase of 47 g CO_2 equivalents for the trout feed, and a net reduction of 46 g CO_2 equivalents on the waste for feed, per package of 125 g smoked trout. The total effect on the complete product, however, is less than 2 g CO_2 equivalents, i.e. <0.5%.

The two processes with largest contribution to the total GWP are feedstuffs and electricity (see Figure 3), and alternative scenarios are therefore investigated for these processes.

Alternative scenarios 1 and 2 investigate the effect of using electricity solely produced by coal power or wind power. They show that the GWP estimate is sensitive to the choice of model. Coal power is modelled by *Nordel* hard coal power plants, and wind power is modelled as 2 MW offshore Danish wind mills; the data are from the Ecoinvent 2 database (Althaus et al., 2007).

Alternative scenarios 3 and 4 investigate the impact of replacing the gas burners at the processing plant (*DanForel*) with a gas driven co-generation unit for heating and electricity production. The scenarios the unit is modelled to supply the entire heat demand, whereas the cogenerated electricity can replace only a part of the usage at

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[11] *There is a need of 1.65 kg soja meal to substitute 1 kg fish meal (Jokumsen A. (2006) Økologisk fiskeopdræt. Rapport fra en vidensyntese om udviklingsmuligheder indenfor økologisk fiskeopdræt i Danmark, FØJO-rapport, Forskningscenter for Økologisk Jordbrug og Fødevaresystemer. pp. 111.)*

[12] *According to the used model for soya production; see the inventory section.*

the processing plant. In scenario 4, natural gas is used as heat source, and in scenario 3, biogas is used as heat source. Both scenarios are modelled by a 100 kW gas turbine, where the gas source is natural gas or biogas, respectively; the data are from the Ecoinvent 2 database (Althaus et al., 2007).

From scenario 3 in Table 6, it is seen that investing in a biogas powered co-generation unit at the processing plant can reduce the entire GWP of smoked trout by 5%, and the GWP share from the processing plant (excl. trout farming and transport) by 19%. Using electricity from wind power only, has a strong potential to reduce the GWP (scenario2, Table 6), but since wind power may be limited by the number of mills that the government allow to install in Denmark, there may be difficulties in implementing this option.

Since world production of fish meal and fish oil is controlled by quotes and is being reduced (Rosenlund, 2002) discussions on alternatives for the fish based fish feed content is discussed (Papatryphon et al., 2004; Pelletier and Tyedmers, 2007; Rosenlund, 2002) and this has consequences on GWP, too (Papatryphon et al., 2004). Substituting different shares of the feed stuff with others as e.g. fish meal with soybean meal (Kristofersson and Anderson, 2006) was tested in alternative scenario 5 and 6. Traditionally fish meal and soybean meal are closely related with price demand (Kristofersson and Anderson, 2006), however, fishmeal cannot easily be substituted for the diets of fish (New and Wijkström, 2002), while for fats and oils plant oils are a real alternative (Rosenlund, 2002).

In scenario 7, the consequence of using the fish waste from the processing plant for biogas, rather than animal fodder is investigated (see sections 6.7 and 6.13 for descriptions of the fodder and biogas processes). It is seen that the GWP potential is not significantly changing, i.e. with less than 0.05%.

In scenario 8 and 9, the effect of a changed feed coefficient is investigated. In the actual calculation is the feed coefficient is 0.9 (kg fish feed used to grow-out of 1 kg of fresh trout; i.e. excluding feed for smolt production). At a super efficient fish farm (feed coefficient=0.8; scenario 8 in Table 6) the GWP is 7% lower since there is a higher efficiency, see scenario 8, and likewise the GWP is corresponding higher in a less efficient farm (feed coefficient=1.0; scenario 9 in Table 6).

In agricultural field products there exists a large variation and uncertainty in the field emissions of N_2O and this can lead to a significant difference in the GWP of the final product. To illustrate that effect we compare two data sources on rape oil production as basis for fish feed as illustrated in Table 7. The difference of GWP of the raw product rape seed is with a difference of 21% in a reasonable range, while in the final product (fish feed) it only accounts for a difference of 5%. While there are only small differences of CO_2 and CH_4 emissions, Table 8 shows that the major difference is due to the effect of N_2O emitted from agricultural land.

Table 7: Comparing rape seed data sources*. Shown is the global warming potential of 1 kg rape seed, 1 kg oil, and 1 kg fish feed while using EcoInvent 2 database (Althaus et al., 2007) or data published by Schmidt, 2007.*

Data Source	GWP rape seed at farm ($g\ CO_2$ equivalents)	GWP rape oil at mill ($g\ CO_2$ equivalents)	GWP fish feed ($g\ CO_2$ equivalents)
EcoInvent 2	0.90	1.83	1.17
Schmidt, 2007	1.09	2.2	1.23

***Table 8: Contributions to GWP on different data sources of rape seed**. Shown is the global warming potential of 1 kg rape oil at local storage while using EcoInvent 2 database (Althaus et al., 2007) or data published by Schmidt, 2007.*

Data Source	CO_2 (g CO_2 equivalents)	N_2O (g CO_2 equivalents)	CH_4 (g CO_2 equivalents)
EcoInvent 2	0.94	0.88	0.04
Schmidt, 2007	0.79	1.42	0.03

7.3 Benchmarking the Results

It is of interest to compare the here calculated GWP of smoked trout filet (produced as described) with calculations of others. No clearly described report on trout filet could be found. However, in the last few years different investigations using LCA techniques have been performed on cultivated fish in aquaculture on e.g. the total Norwegian fish industry including cultivated trout (Ellingsen et al., 2009), salmonid cultures including trout in Canada or France (Aubin et al., 2009; Ayer and Tyedmers, 2009; Roque d'Orbcastel et al., 2009). These investigations already pinpointed clearly the importance and strong impact of fish feed on GWP in farmed fish. Others investigated therefore the GWP on fish feed only (Papatryphon et al., 2004; Pelletier and Tyedmers, 2007; Rosenlund, 2002) and different ingredients of fish feed were compared and possible substitutions were discussed.

Analysis on GWP of farmed fresh trout production were reported as 1.8 kg CO_2 equivalents (LCA-Food-DK, 2006), 2.0 kg CO_2 equivalents (Roque d'Orbcastel et al., 2009) and 2.8 kg CO_2 equivalents per kg fresh trout (Aubin et al., 2009) (the latter two are French productions). Ayer and Tyedmers (2009) benchmarked the production systems for *Atlantic sal*mon or *Arctic char* and also reported on usage of 2.8 kg CO_2 equivalents per kg fresh fish.

In this analysis the estimated GWP is only 1.2 kg CO_2 equivalents per kg fresh trout (fish from *Nielsby Dambrug*) that is even lower as calculated in LCA-Food-DK (2006). The large difference to the French production is that the produced trout is partly larger (between 270 and 3500 g) that resulted in a higher feed conversion ratio of 1.21 (Aubin et al., 2009), compared to 0.9 in our case. This ratio points out that one explanation for the relatively low GWP in this study is a high feed efficiency at the trout farm.

Other explanations are found in a comparison to the standard Danish trout production (LCA-Food-DK, 2006), where improvements are made in e.g. a better feed conversion ratio (that was 0.94 in LCA-Food-DK), re-usage of the slurry, and especially a very low energy consumption per kg fish (i.e. 0.14 kWh at *Nielsby Dambrug* compared to 0.8 kWh for an average fish farm as used by LCA-Food-DK (2006). Using the 0.8 kWh at *Nielsby Dambrug* under *ceteris paribus* conditions would increase GWP to 1.53 kg CO_2 equivalents. And the 35% difference can to 100% explained by five points, as it can be attributed to 1. Low energy consumption at fish farm (20%), 2. lower GWP at feed production (6%), 3. a better feed conversion ratio (3%), 4. use of slurry as fertiliser (3%), and 5. the choice of the electricity mix (3%).

In this study, fish feed accounts for the major part of the GWP (1.17 kg CO_2 equivalents per kg fish feed; see Table 4). Depending on the kind of study and feed composition numbers between 0.55 kg CO_2 equivalents (Seppala et al., 2001) and 1.34 kg CO_2 equivalents per kg fish feed (Papatryphon et al., 2004) were reported. These numbers are in the same scope as our study.

The current study, however, only focused on GWP as impact category while some other categories are of high importance especially in farmed fish, such as eutrophication, acidification and net primary production use (Papatryphon et al., 2004) and a reduction in one category can easily lead to an increase of another (Papatryphon et al., 2004; Pelletier and Tyedmers, 2007).

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APPENDIX

External Review

The report has been reviewed by Associate Professor Mikkel Thrane from the Department of Development and Planning at Aalborg University, Denmark, which stated the following comments (copy of the original email reply):

- Den marginale olie bør modelleres som palmeolie ifølge data fra Jannick
- Den marginale proteinkilde bør modelleres som soyamel ifølge data fra Randi/Jannick
- Når i efterspørger fiskemel bliver der også produceret fiskeolie. Det er fiskemel, som er det bestemmende produktet, og fiskeolien fortrænger i denne sammenhæng antageligt palmeolie. Lav derfor systemudvidelse med palmeolie.
Brug her data fra Jannick.
- Når i efterspørger fiskeolie bør det modelleres som palmeolie. Dels fordi fiskeolie er et 'afhængigt-samprodukt' og dels fordi der er begrænsninger på produktionen af fiskemel og olie (kvoter mv.)
- Når der efterspørges fiskemel antager i at produktionen af fiskemel påvirkes. Det er ok, men det er nok mere sandsynligt at der er soyamel, der påvirkes. Derfor er det fint at i modellerer soya i følsomhedsvurderingen.
Brug blot Randis/Jannicks tal for soyamel istedet.
- Lav en mere detaljeret beskrivelse af jeres elektricitetsmodel, med kilder og mere information. Jeg mener under alle omstændigheder ikke at der er rigtigt at have elektricitet baseret på halm og affaldsforbrænding med i modellen.
- Se i øvrigt mine kommentarer omkring landuse til sidst i rapporten:-)

PS: Det er og bliver (ikke mindst) en kanon rapport!! Undskyld jeg er så kritisk, men det er jo ens pligt som reviewer. Der er nogen reviewere som tager lettere på det, men det er faktisk problematisk syntes jeg. Og SIK som du nævnte bruger jo normalt ikke konsekvenstankegangen:-)

The report is largely adjusted to the reviewer's comments and in cases of differences the authors described the reason for the chosen method.