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Greenhouse gas emissions from aquaculture

A life cycle assessment of three Asian systems

***Cover photographs*:**
Top to bottom: A large Nile tilapia pond, Mymensingh, Bangladesh (courtesy of FAO/Mohammad R. Hasan). Harvest of striped catfish, Mekong Delta, Viet Nam (courtesy of FAO/La Van Chung). A typical pond for major carp, with provision of aeration, Andhra Pradesh, India (courtesy of FAO/Rajendran Suresh).
***Cover design*:**
Mohammad R. Hasan and Jose Luis Castilla Civit.

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Preparation of this document

This technical paper was prepared under the coordination of Dr Mohammad R. Hasan of the Aquaculture Branch, FAO Fisheries and Aquaculture Department as a part of FAO's Strategic Objective (SO2): Increase and improve provision of goods and services from Agriculture, Forestry and Fisheries. This publication will contribute to the organizational outcome 20101: producers and natural resource managers adopt practices that increase and improve the provision of goods and services in agricultural sector production systems in a sustainable manner. The rationale of this study is to broaden the understanding of aquaculture's contribution to greenhouse gas emissions (GHG) and the potential mitigation through the management of aquaculture feeds and feeding.

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Field data in this study were collected by, and preliminary analysis conducted by, three national consultants: Mr Mohammad Mamun-Ur-Rashid (Nile tilapia, Bangladesh), Dr Rajendran Suresh (Indian major carps, India) and Mr La Van Chung (striped catfish, Viet Nam). The authors gratefully acknowledge the numerous fish farmers, feed dealers and feed producers in Bangladesh, India and Viet Nam for their voluntary and active support in providing valuable data and information during the field survey of this study.

This technical paper was edited by Dr Sarah L. Poynton for linguistic quality and technical content. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/search.php).

Ms Marianne Guyonnet and Ms Danielle Rizcallah are acknowledged for their assistance in quality control and FAO house style. Mr Jose Luis Castilla Civit prepared the layout design for printing. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Dr Malcolm Beveridge, Head of the Aquaculture Branch of the FAO Fisheries and Aquaculture Department is acknowledged for providing the necessary support, advice and insight to complete this publication.

Abstract

The rapid growth and development of global aquaculture has raised questions regarding the potential associated greenhouse gas (GHG) emissions. To gauge the scale of GHG emission in Asia, where growth has been greatest, a preliminary study was carried out on three aquaculture systems: Nile tilapia (*Oreochromis niloticus)* in Bangladesh, Indian major carps (*Catla catla*, *Cirrhinus cirrhosus*, *Labeo calbasu*, *Labeo rohita*) in India, and striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam. The analysis was intended to improve understanding of where and how GHG emissions arise in Asian aquaculture, and highlight weaknesses in the currently available data. This approach will guide future studies on how to develop cost-effective ways of improving aquaculture performance and reducing emissions, and how to improve data collection.

Primary data were collected from April to June 2014, using questionnaires to guide interviews at 5 or 6 feed mills and 10 – 12 farms per country. The units covered a range of approaches to feed manufacture and farming, to demonstrate the different methods used in each of the three aquaculture systems. Secondary data was used to determine the related GHG emissions from cradle to farm-gate. For each of the three systems, life cycle assessment models were prepared, from pre-farm, through the farming system, to harvest. The models were not continued to market, as so many different markets were found that it was not feasible to make a representation.

Output from the models showed distinct differences in the emissions associated with the three systems. The striped catfish system in Viet Nam had the lowest emissions (1.37 kg CO_2e/kg live weight fish), followed by the Nile tilapia in Bangladesh (1.58 kg CO_2e/kg live weight fish), and Indian major carps in India having the highest emissions (1.84 kg CO_2e/kg live weight fish), when excluding emissions from land use change. Although the ranking remained the same, the magnitude of emissions increased in all three systems, when including land use change in the model. The production of feed was the largest source of GHG emissions for all three systems, being mainly associated with the production of the raw materials. Transport of the raw materials to the mills, and of feed from the mills to the fish farms, were also significant sources of GHG emissions. There were differences in feed mill energy requirements between countries, possibly reflecting variation in technology applications and efficiencies.

High economic feed conversion ratios (eFCRs) exacerbated the impact of feed on GHG emissions, as more feed was required to produce one kilogram of fish. In particular, the Indian major carps showed high FCRs (1.0 – 5.0); the FCRs for striped catfish in Viet Nam and for Nile tilapia in Bangladesh were low (1.6 – 1.9 and 1.1 – 2.0 respectively). The study highlighted a recent increase in the use of commercial feed in Bangladesh and India, reducing the FCRs. Farming systems in the different countries required varying quantities of energy, reflecting the relative need for pumping to exchange water in the ponds, and other energy requirements on the farms, such as lighting and transport.

The report highlights the variation within every stage of production in each of the three aquaculture systems in Asia: raw materials used, energy use in the mills, transport methods for moving the feed to the farm, farming methods, survival of fish to harvest, and feed conversion ratios. The magnitude of this variation, in India and Bangladesh in particular, showed that significant work is needed to communicate and execute better feed formulation and farming practices. The report recommends methods which could reduce emission intensities related to the farming systems. Applying best practices uniformly on farms, and thus increasing efficiencies, appear to be major factors needing improvement.

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Abbreviations and acronyms

AFFRIS	Aquaculture Feed and Fertilizer Resources Information System
bFCR	biological feed conversion ratio
CE	cost-effectiveness
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent: the amount of CO_2 equivalent to the quantity of GHG gases associated with a process
eFCR	economic feed conversion ratio
DAP	diammonium phosphate
DDGS	distillers' dried grains with solubles
DE	digestible energy
DM	dry matter
DP	digestible protein
DP/DE	digestible protein to digestible energy ratio
EF	emission factor
EF per t.km	emission factor per tonne per kilometre
EI	emissions intensity, i.e. the emissions per unit of output, e.g. $kgCO_2e/kgLW$
EU	European Union
FAO	Food and Agriculture Organisation
FCR	feed conversion ratio
FU	functional unit
GHG	greenhouse gas
g	gram
GLEAM	global livestock environmental assessment model
GWP	global warming potential
h	hour
ha	hectare
HCFCs	hydrochlorofluorocarbons
HDPE	high density polyethylene
HUFAs	highly unsaturated fatty acids
kg	kilogram
$kgCO_2e$	kilograms carbon dioxide equivalent
km	kilometre
kWh	kilowatt hour
l	litre
LCA	life-cycle assessment
LUC	land use change
LW	live weight
m	metre
MJ	mega joules
mm	millimetre
N	nitrogen
N_2O	nitrous oxide
NA	not applicable

NaCl	sodium chloride
NRC	National Research Council, United States of America
NUE	nitrogen use efficiency
PAS 2050	publically available specification 2050
PE	polyethylene
PoE	point of entry to a country
PoP	place of production
PP	polypropylene
PPT	polypropylene terephthalate
TP	triple phosphate
TSP	triple super phosphate
USA	United States of America
VASEP	Vietnam Association of Seafood Exporters and Processors

Executive summary

The goal of this project was to undertake a preliminary life-cycle assessment (LCA) of the greenhouse gas (GHG) emissions arising from the production of three systems of farming fish in Asia: Nile tilapia *Oreochromis niloticus* in Bangladesh, Indian major carps *Catla catla*, *Cirrhinus cirrhosus*, *Labeo calbasu*, *Labeo rohita* in India, and striped catfish *Pangasianodon hypophthalmus* in Viet Nam. The analysis is intended to improve understanding of where and how GHG emissions arise in Asian aquaculture, so that future studies can focus on developing cost-effective ways of improving performance and reducing emissions.

To undertake the analysis, a life-cycle model for each of the three systems was developed. This model quantifies the emissions arising pre-farm, (known as "from cradle" i.e. during the production of inputs such as feed and fuel), on-farm, and post-farm (to the retail point). The model is based on primary data collected from surveys of feed mills and fish farms in the three countries, combined with secondary data, such as the feed material emissions from the FeedPrint database (http://webapplicaties.wur.nl/software/feedprint/). In each of the three countries, data were collected from 5 or 6 feed mills, and 10 to 12 farms, representing approximately 1.0 percent of the total number of mills and farm. To improve the validity of the data, the survey results were cross-checked against other GHG studies in aquaculture which had been conducted elsewhere, and outliers identified and removed.

The main results of the report are:

- The average emissions intensities (EI) from cradle to farm-gate, excluding emissions arising from land use change (LUC), were:
  - Bangladesh - Nile tilapia: 1.58 kg CO_2e/kg live weight fish
  - India - Indian major carps: 1.84 kg CO_2e/kg live weight fish
  - Viet Nam - striped catfish: 1.37 kg CO_2e/kg live weight fish
- The average EI from cradle to farm-gate, including emissions arising from LUC (based on the FeedPrint area–specific values) were:
  - Bangladesh - Nile tilapia: 1.81 kg CO_2e/kg live weight fish
  - India - Indian major carps: 2.12 kg CO_2e/kg live weight fish
  - Viet Nam - striped catfish: 1.61 kg CO_2e/kg live weight fish
- The production of feed was the largest source of GHG emissions across all three systems. This finding reinforces the influence of the economic feed conversion ratio (eFCR - the weight of feed required to produce one kilogramme of live fish at harvest, including mortalities) on EI. This result is not surprising, given that feed was the main input in each of the three systems studied.
- Most of the feed emissions arose during the production of the raw materials used for feed production. While the total magnitude of the feed emissions varied with feed formulations, the feed emissions were highest for the average formulations made in India, due to the presence of relatively high EI grains and oilseed meals.
- Transportation of raw materials from the place of production to the feed mills had a significant impact on the total EI, with large variations between countries. Viet Nam had the highest emissions arising from raw material transport, because a greater proportion of the raw materials were imported than was the case for Bangladesh or India (e.g. soy is shipped to Viet Nam from the United States of America and Argentina). Indian feed mills used a lot of domestic raw materials, so the total transport distance was the shortest.

- Emissions from the transport of feed from the feed mills to the fish farms were highest in Bangladesh, where the farms were often at a large distance (ranging from 50 km to 450 km) from the feed mill. In India, the average distance from the feed mill to the farms was only 40 km by truck, lowering the emissions. In Viet Nam, occasional use of boats to transport feed reduced the overall EI.
- Emissions from energy use in the feed mill were greater in India and Bangladesh than in Viet Nam. In Viet Nam there was a combination of moderate rates of energy consumption in the feed mills, and the use of renewable biomass fuels with lower EI than coal or fuel oil.
- On-farm nitrous oxide (N_2O) emissions were dependent on the amount of surplus N produced, and the rate at which it was converted to N_2O. The N_2O emissions, calculated using two emissions factors (EFs) of 0.71 percent and 1.80 percent, accounted for a significant proportion of the total emissions (i.e. >10 percent) in each of the three systems, even when the lower EF was used.
- Most on-farm energy use was related to pumping and lighting. Energy use was markedly greater in India and Bangladesh than in Viet Nam, most likely due to the lower rate of energy consumption and the lower EF for electricity in Viet Nam.

Comparison of the EI values in the present study with EI values previously reported shows that: (i) Nile tilapia results were similar to those reported in Pelletier and Tyedmers (2010); (ii) striped catfish results were lower than those in Bosma *et al.* (2009) because most of their rations had significantly higher feed EI than in the present study; and (iii) Nile tilapia and striped catfish results were markedly lower than reported in Henriksson *et al.* (2014a), however direct comparison is difficult because of different systems boundaries and functional units between studies. No previously published data could be found on the EI of Indian major carps.

The present study showed great variations in the three farming systems, both between feed mills and between farms within each country:

- Energy use by the feed mills was very variable; the within country range was smaller in Viet Nam than in Bangladesh or India.
- The type and application rates of organic and synthetic fertilizers in Bangladesh and India showed marked heterogeneity.
- Farm size, annual production, and stocking densities at harvest, ranged over almost an order of magnitude within Bangladesh and India, while the variation was much smaller in Viet Nam.
- The eFCR ranged from 1.1 to 2.0 in Bangladesh, and from 1.0 to 5.0 in India. In Viet Nam, there was much less variation, 1.6 to 1.9.

More work is required to understand the causes of these variations, and to identify ways to improve performance. However, the magnitude of the feed impact on fish EI, from raw material production to feed efficiencies on farm, is clear and makes the conclusions of the report robust.

The study covered only a small number of farms in each of the three countries, and does not claim to be representative of all practices. However, the report indicates great opportunities for further studies.

In the present study, fewer farms in Bangladesh and India were using farm-made feeds than previously reported in the literature. This difference may reflect actual changes in behaviour, or may be due to sampling bias. Little information could be found on the raw materials that these farmers used, and thus a more in depth study is recommended on the current use of farm-made feeds, and their raw material sources.

This descriptive study focused on quantifying the emissions and production from three aquaculture systems. The results raise the question of how these emissions can be reduced. Although a comprehensive review of potential mitigation measures is beyond the scope of this study, the present analysis indicates the following five potential approaches to reducing EI:

- Reducing emissions from feed material production by: (a) reducing the EI of individual feed materials, and/or, (b) substituting high EI materials with low EI materials.
- Reducing emissions from feed mill energy use through: (a) more efficient management of feed mills, and/or, (b) substituting high EI fuels with low EI alternatives.
- Improving the efficiency of feed conversion for fish by: (a) optimizing the nutritional content of feed and their availability, (b) improving feed management, and (c) increasing the dissolved oxygen in the water, so that the feed is used more efficiently.
- Improving fish health through: (a) better water quality management, (b) maintenance of appropriate fish stocking densities, (d) implementation of effective biosecurity measures, and (e) appropriate use of medicines.
- Reducing on-farm N_2O emissions by reducing: (a) the amount of N available for conversion to N_2O, and/or, (b) the rate at which surplus N is converted to N_2O.

To identify the most cost-effective mitigation measures, the emission reductions arising from the measures, and the costs of implementing them, must be quantified. Models such as the one developed for this project can support this endeavour by identifying and partially quantifying the systemic effects of mitigation measures.

A grow-out pond in a small catfish farm in Mekong Delta, Viet Nam (courtesy of FAO/Mohammad R. Hasan)

1. Introduction

1.1 AQUACULTURE AND GREENHOUSE GAS EMISSIONS

Total GHG emissions from terrestrial livestock supply chains have been estimated to be 7.1 Gt CO_2e (carbon dioxide equivalent) per annum (Gerber *et al.*, 2013), with most emissions arising from enteric fermentation, feed production and manure management. In contrast, the global emissions from aquaculture (the farming of aquatic plants and animals) have not been quantified, despite this being the most rapidly growing food sector.

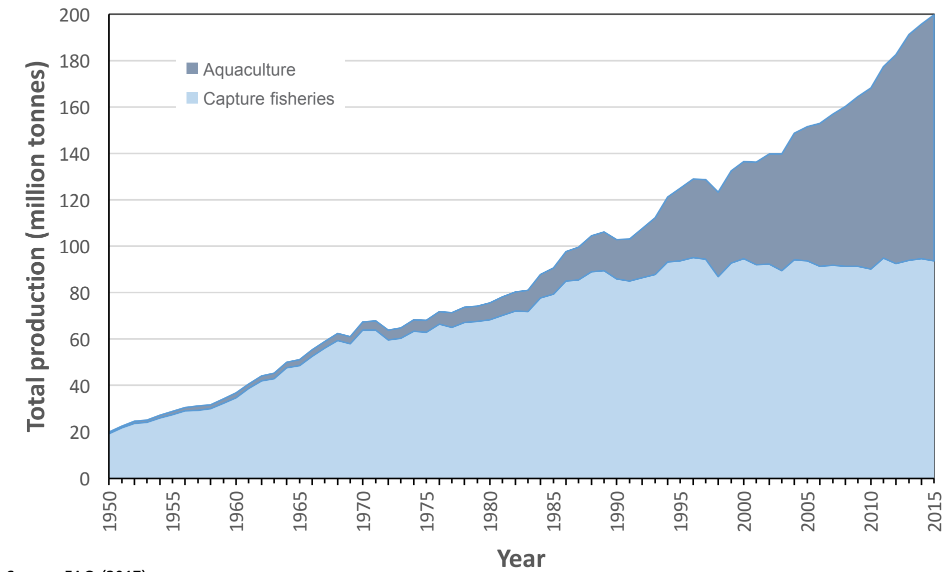
Aquaculture has developed very rapidly in the last 20 years (Figure 1), and current predictions are for continued rapid growth, to meet the global demand for seafood which cannot be supplied by fisheries alone.

Given the increasing importance of aquaculture for food security, it is important that its environmental performance is analysed to support decision-making along aquaculture supply chains.

For some aquaculture commodities, particularly marine species such as salmon and shrimp, research has been conducted and information has been developed regarding GHG emission and carbon footprint. However, for freshwater fish species significant for food security such as the Nile tilapia, Indian major carps, and striped catfish, much less is known. To address this gap in knowledge, the present study will therefore focus on these three groups farmed in freshwater in Asia, to highlight which data is available, and crucially, what extra research is required to understand more about the GHG emission and carbon footprint of these value chains.

A very wide variety of fish species are farmed under the auspices of aquaculture, with a corresponding variety of technologies and intensities. This variety causes some challenges when assessing the GHG emissions associated with this rapidly growing industry, and the associated value chain from raw materials to market.

FIGURE 1
World capture fisheries and aquaculture production from 1950 – 2015



Source: FAO (2017).

Feed for the fish is made from a range of raw materials, which can be sourced from the country in which the farm is located, or from international suppliers. These feed materials can be marine or terrestrial in origin, and based on plants, animals, minerals or even synthetic products.

Emissions of GHG arise during production of these raw materials (e.g. energy used by vessels that capture fish to produce fishmeal, and nitrous oxide (N_2O) emissions arising from crop cultivation), and during their subsequent processing and transportation. Aquaculture feed production requires energy, to grind and mix the raw materials, to make the pellets and to dry them. The total energy used depends on local energy supplies, as well as on production efficiencies. After production of the feed, transport is again involved to move the feed to the farms where it will be used.

Aquaculture farms are situated in a range of different sites, depending on the requirements of the species and the availability of land and water. Changes in profitability of aquaculture and other land uses have sometimes led to land being converted from agriculture to aquaculture. Furthermore, land may also be taken for aquaculture, by converting it from grassland, river banks or other natural habitats.

The farmed species are kept in different enclosures, depending on the species and the environment. The most commonly used fish enclosure is a pond, and tanks and net cages are also widely used. Good water quality inside in the enclosures is essential to the health of the animals farmed, and poor water quality may lead to increased GHG emissions, as excess nutrients are lost from the system and are broken down. Similarly, poor feed quality may reduce fish performance and increase GHG emissions. Some research suggests that well managed aquaculture ponds may act as carbon traps and contribute to mitigation (for example if sediments are later used for agriculture), thus making GHG emission accounting even more complicated (Verdegem and Bosma, 2009).

After harvesting, the fish are transported to market in one of three conditions: live, on ice or processed. Processing may result in losses of material from the system, which can increase the emission intensity [EI (kg of CO_2e per kg of product)] of the final product. Transport also adds to the GHG emissions.

1.2 AIM AND SCOPE OF THIS STUDY

This study quantifies the GHG emissions arising along the value chains of three aquaculture systems in three countries. Although the chains are distinct, they each represent large volumes of fish being grown and consumed.

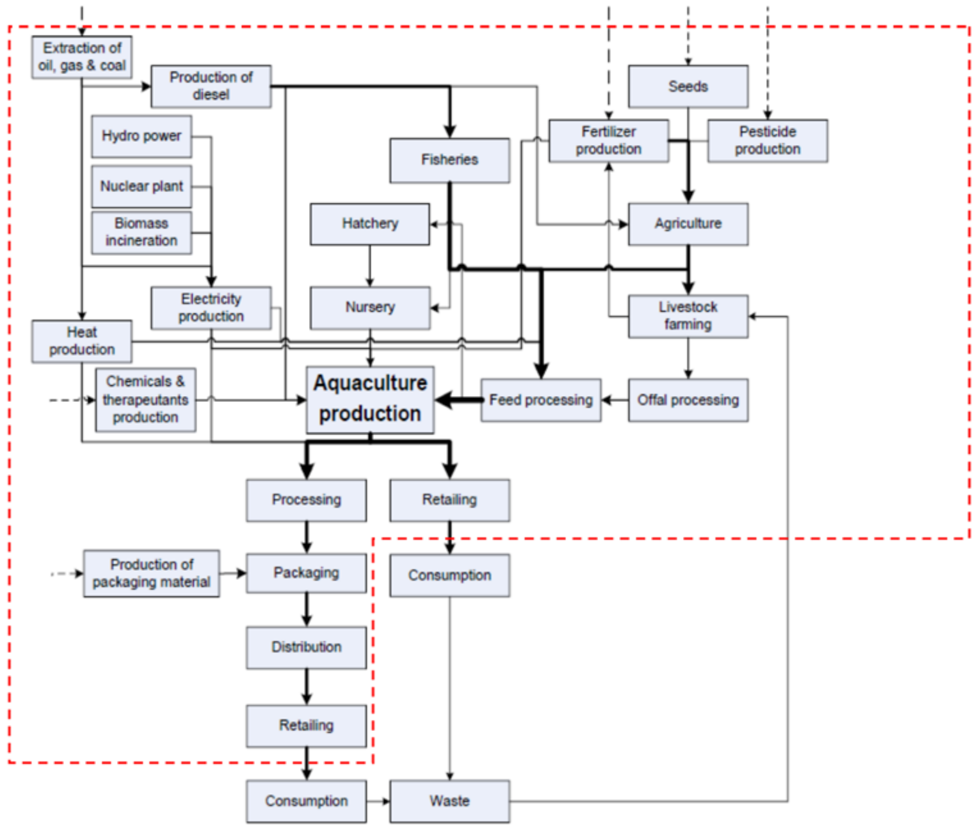
The aim of the study is to identify the locations and modes of GHG emissions along the value chains, and highlight areas where improvements might be made. Although the study is limited in its size, the scope of the field surveys captures a range of different fish farming systems (small- and large-scale), and documents the variety of approaches to feed production (farm-made and commercial, different methods and scales) within each country. The study will also show where more data is required to understand the issues in greater depth.

The system boundary of the study, shown in Figure 2, was defined based on a review of previous studies, which indicated that the EI was likely to be primarily a function of processes occurring during the following five stages:

- Production of feed raw materials, includins the origin and previous land use;
- Processing and transport of feed materials;
- Production of compound feed in feed mills and transport to the fish farm;
- Rearing of fish in the pond; and
- Transport of fish to processing and/or market.

Other inputs and losses were considered to be relatively small compared to the five factors listed above.

FIGURE 2
Inputs to the aquaculture chains which may impact GHG emissions. The system boundary of the study is indicated by the dashed red line



Source: Henriksson *et al*. (2014a).

1.3 THE THREE SYSTEMS STUDIED

1.3.1 Bangladesh: Nile tilapia

Nile tilapia, *Oreochromis niloticus*, were first introduced to Bangladesh in 1974 (Barman *et al*., 2003) and production has grown rapidly since then. In 2012 the national production was recorded as 130 000 tonnes, mainly for the domestic market (Globefish 2014a). The country has just started exporting fillets to the EU (Globefish 2014a).

Raised in ponds, Nile tilapia are hardy and require little technology to farm. This robustness has helped the industry grow to its current state, which is mostly sustained by small holders. However, it is expected that efficiency of the farming systems can be improved significantly with better management.

1.3.2 India: Indian major carps

The Indian major carps include catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus cirrhosus*) and orangefin labeo/calbasu (*Labeo calbasu*) (DAHDF, 2014). Landings of Indian major carps in India have increased steadily from 2.4 million tonnes in 2007 to 3.4 million tonnes in 2012, all for domestic consumption. The two most important states for the production of the major carps, comprising aquaculture and inland fisheries, are Andhra Pradesh and West Bengal (DAHDF, 2014). Major carps produced in India are primarily for domestic market.

Carp aquaculture is a very traditional industry, requiring little technology and making use of the local resources for feed. The farming is at low densities, using

polyculture of a variety of carp specie) to make the best use of the natural food production in the water, such as algae, phytoplankton and zooplankton. Feeds are also be provided for these fish species in the polyculture system.

1.3.3 Viet Nam: striped catfish

The production of striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam grew rapidly from the late 1990's to 2012, flattening off and even declining slightly thereafter. In 2013, 1.35 million tonnes of striped catfish were grown (Globefish, 2014b). The market for the fish is almost entirely for export, mainly as fillets. The market is global, with direct exports to more than 70 countries (Globefish, 2014b).

The fish can be farmed at high densities in ponds which are supplied with relatively warm freshwater. Regular changes of water allow the water quality to be maintained, and the fish are fed commercial feeds giving efficient growth

Distributing feed pellets in a net enclosure, Andhra Pradesh, India (courtesy of FAO/R. Ramakrishna)

2. Methodology

The work was split into two parts:

- Field surveys to collect raw data from feed mills, farms, markets and processing units.
- Modelling of the production, emissions and EI for each of the three systems using the data from the surveys and secondary sources.

2.1 FIELD SURVEYS

An expert in each of the three countries was identified, who could contact local feed mills and fish farms, and interview their personnel for the survey. The three experts had long experience of the industries in their countries, and some understanding of investigating GHG emissions related to farming practices.

2.1.1 Development of the questionnaires

To guide the interviews conducted at the feed mills and farms, five questionnaires were developed pertaining to: (i) raw material, (ii) feed mill, (iii) feed distribution, (iv) fish farm, and (v) fish market. Farmers making their own feeds were asked extra questions about the raw materials they used to make these feeds.

After a brief discussion with the experts who would collect the data, questions were developed for the feed mills and farms to understand the value chain in each country. These questions were generic for the three countries, which helped with cross-comparisons.

The basic questionnaires were then developed and shared with the experts in each country who would conduct the survey. They made suggestions for improvements, and then tested the questionnaires on two feed mills and two fish farms, returning the data. This input allowed a last round of development of the questionnaires, before the main data collection phase.

2.1.2 Data collection

During the main data collection phase conducted from April to June 2014, data was collected from 5 to 6 feed mills and 10 to 12 farms from each country. The aim was to survey a range of facilities representing the diversity of methods used in each country, to capture an impression of the variety of approaches to feed production (farm-made and commercial), and fish farming (small- and large-scale). A larger study of farms was not possible due to limited resources; the present study was designed to stimulate later larger scale surveys.

All questionnaires had sections which allowed notes to be added, explain the data or adding information not captured by the questionnaire.

To collect data, the experts made field visits to feed mills, fish farms, fish markets and processing factories as appropriate. Interviews were conducted with managers at these sites and the information required filled in. The experts were able to add notes to expand on the information.

2.1.3 Raw material questionnaire

The first questionnaire related to the raw materials used and their source (Appendix 1a). Each material used was reported, together with the country of origin, the normal volume transported to the mill in one order, the method of transportation and the transport distance. This information allowed estimation of GHG emissions related to

raw material production (according to the country of origin), and transport to the feed mill.

The same questions were asked of farmers who purchased prepared feed, and of farmers who made their own feed. Among the latter, whilst the farmers could report which raw materials they used and the ratios, they were often unable to provide information on the origin of the materials. Most materials were bought through dealers and the sources were obscured.

2.1.4 Feed mill questionnaire

In the second questionnaire, the energy sources and amounts used were reported (Appendix 1b). The method of production and the amount of feed made annually were reported, as well as the major packaging types and usage. Finally, the formulations for the feeds were reported, as well as the declared basic nutritional contents of the feeds.

In designing the survey, it was acknowledged that many feed mills would be unwilling to be fully disclose their feed formulation data. Some feed mills gave overall raw material usage for the year for all feeds (effectively a weighted average formulation). Most feed mills did not report the materials which were included at less than 2 percent of the feed, (these tended to be the special additives which feed mills included to attract their customers). These limitations were considered acceptable, since the aim of the project was make an initial determination of the GHG emissions of the feeds, rather than to undertake a comprehensive analysis.

2.1.5 Feed distribution questionnaire

The third questionnaire gathered data on the GHG emissions related to the transport of the feeds to the farms. Relatively small quantities of feed were moved short distances by a variety of methods, depending on the country. The methods and distances of feed distribution from the feed company to the farm were surveyed (Appendix 1c); this data was used for determining GHG emissions related to transport of feed to farms.

2.1.6 Fish farm questionnaire

The fourth questionnaire related to the activities on the fish farms (Appendix 1d). The farm's position, size and the number of units, farming method, details of pond depth, and any manuring, were recorded. The previous land use was also recorded, as this can impact GHG emissions relating to construction of the ponds and clearing of previous vegetation.

Data on the efficacy of transforming feed into fish were derived from production details, such as the normal input size of fingerlings and the normal harvest size, together with the range of economic feed conversion ratio (eFCR) values and average survival. The eFCR data were confirmed by the total feed used per year and the total weight of fish harvested. Data on inputs (e.g., feed, fertilisers, fuel) to the farm were obtained in a section on the type of feed used at the farm, and the use of fertilisers.

Energy use on the fish farm, such as that for pumping water, lighting, powering vehicles and housing for workers, was another potential source of GHG emissions. The questionnaire separately recorded the energy use for pumping, and for other uses, if such separate data was known.

2.1.7 Fish market questionnaire

The fifth and final questionnaire dealt with the final stage in the supply chain, the movement of the fish to the target market after harvesting (Appendix 1e). Transport information showed how the fish were moved from the farm to the markets, and whether they were moved live or dead. Any processing before sale was reported, together with processing losses and energy use if known.

2.1.8 Establishing the database

After the initial round of data collection, the data were transferred to a single database so that they could be interpreted. This transfer allowed further questions to be developed, to generate a clearer picture of the industries. The questions were dealt with *ad hoc* by the experts in each country, either generically or specifically depending on their nature. This information was then added to the database used to develop the GHG emissions model.

2.2 METHODOLOGY FOR QUANTIFYING GHG EMISSIONS

2.2.1 Model overview

To perform the analysis, an Excel-based model ("aquaculture LCA model v1.1") was developed (Appendix 2). The main sheet summarised key input: output ratios for the fish farms (e.g., the amounts of fingerlings, feed, fertiliser, packaging and energy use per kg of live weight output). These values were then used to calculate the total inputs, outputs, emissions and emissions intensities (EI) (kgCO_2e/kg output) for the defined level of production.

To perform the calculations, the main sheet drew on a series of 11 sub-sheets, which contained information on feed emissions, transport distances and emissions factors, feed mill energy use, packaging, pond N_2O and fingerling emissions. The data in the sub-sheets were primarily based on the surveys undertaken in this project (see Section 4.1), combined with data from other studies and databases (particularly Vellinga *et al.*, 2013, Henriksson *et al.*, 2014a,b and Feedipedia: www.feedipedia.org/node).

The version of the model used for the present report is essentially descriptive and static. However, to provide some flexibility, controls have been added which allow the following four key parameters to be varied:

1. Annual fish farm production (tLW)
2. Feed conversion ratio (FCR)
3. Pond N_2O emission factor, and
4. Approach used to calculate emissions from land use change (LUC)

The feed and fish farm surveys reported a range of values for some parameters (such as rates of on-farm energy use or FCR). The calculations in the main sheets were therefore undertaken for three cases, mean EI, low EI and high EI, for each of the three aquaculture systems.

2.2.2 System boundaries and scope

The pre-fish farm, on-farm and post-farm GHG emission categories included in the assessments are outlined in Tables 1, 2 and 3 respectively. The determination tasks, and the methods and sources used in the calculation of feed emissions are shown in Table 4.

A summary of the priorities for expanding the emission categories included, and for refining the emissions calculation methods, are provided in Section 7.5.

TABLE 1
GHG emissions categories: pre fish farm

Emissions category	Included?
N_2O	
Direct and indirect N_2O from	
application of synthetic N	y
application of manure	y
direct deposition of manure by scavenging animals	NA
crop residue management	y
N_2O losses related to changes in C stocks	y
Biomass burning	n
Biological fixation	n
CO_2	
Energy use in	
field operations	y
feed material processing (e.g. oil extraction)	y
feed mill for blending etc.	y
Fertilizer manufacture for use in feed and in ponds	y
Production of non-crop feeds (fishmeal, lime and synthetic amino acids)	y
Land use change (LUC) related to soybean cultivation	y
Land use (LU), i.e. changes in carbon stocks from land use under constant management practices	n
Emissions from lime application	y
Manufacture of feed packaging	y
Transport	
feed material to processing	y
shipping of imported feeds	y
road/rail/ship from port or place of production to feed mill	y
compound feed from mill to fish farm	y
Embedded energy related to manufacture of on-farm buildings and equipment	n
Production of cleaning agents, antibiotics and pharmaceuticals	n
CH_4	
Flooded rice cultivation	y
N_2O, CO_2, Rice CH_4	
Hatcheries/nurseries – emissions from energy use and feed	y

TABLE 2
GHG emissions categories: on fish farm

Emissions category	Included?
CH_4	
Enteric fermentation	NA
Anaerobic decomposition of organic matter (excreted volatile solids and uneaten feed)	n
NO_2	
Direct and indirect N_2O from excreted N and uneaten feed	y
Emissions from direct fertilization of pond	y
N_2O from the animal (invertebrates only?)	n
CO_2	
Direct on-farm energy use for pumping and lighting	y
LUC from pond construction	n
Pond cleaning maintenance	n
Sequestered in	
carbonates	n
pond sediments	n

TABLE 3
GHG emissions categories: post fish farm

Emissions category	Included?
CO_2	
Transport of	
live striped catfish to processing	y
whole dead tilapia/carps from farm to wholesale	y
Whole dead tilapia/carps from wholesale to retail	y
Manufacture of packaging	y
Retail	
Energy use	n
Losses and waste disposal	n
Post-retail energy loss	n
CO_2, HCFCs	
Transport of striped catfish fillets from	
processing to place of export	y
Viet Nam to point of entry into importing country	y
Primary processing (including chilling) of striped catfish	y
CO_2, CH_4	
On-site waste water treatment	n
Emissions from animal waste, or avoided emissions from on-site energy generation from waste	n
Emissions related to co-products e.g. rendering material, offal, hides and skin	n
Post-retail losses and waste disposal	n

2.2.3 Methods

Quantifying the emissions from feed production

Feed is the main input in most aquaculture systems and constitutes one of the main costs; feed is also a major source of emissions. For example for tilapia raised in Indonesia, feed production accounts for 92 percent of the total GHGs in lake systems, and 66 percent of the total GHG in pond systems (Pelletier and Tyedmers, 2010).

The feed element of the model determines the emissions intensity (EI) of the feed (as kg of CO_2e per kg of feed dry matter (DM)) at the point of entry to the fish farm. The information required, and the sources used for this, are summarised in Table 4. Data on emissions intensity were not available for all the feeds reported in the survey. In cases where data were missing, similar feeds were aggregated, or the values for related feeds were used as proxies.

On-farm energy

The emissions from on-farm energy use, primarily for pumping water, lighting and powering vehicles, were calculated by multiplying the rates of energy consumption reported in the fish farm surveys by emissions factors for diesel, electricity and petrol.

TABLE 4

Summary of the determination tasks, and methods and sources used in the calculations of feed emissions, following data inputs from the raw materials and feed mills questionnaires

Determination task	Methods and sources used in calculations
Percentage of each feed material in each ration	Survey of feed mills, which defined rations for each of the three aquaculture species/species group (see Appendix 3 and Section 5.3).
Nutritional values of rations	The DE% and CP content of each feed material were taken from AFFRIS (2014) (Nile tilapia values). Where necessary these values were augmented with data from other sources (e.g. gross energy was taken from Feedipedia (2014).
Non-LUC emissions from production of feed materials	To obtain as consistent a data set as possible, the emission intensities were based on those calculated in FeedPrint v2013.3 (see Vellinga *et al*., 2013): (http://webapplicaties.wur.nl/software/feedprint). Other sources were used to fill data gaps, e.g. fish oil (Pelletier and Tyedmers, 2010) and cassava (GLEAM in in MacLeod *et al*., 2013).
LUC emissions from production of feed materials	Several different approaches were used – see Section 6.10.
Origin of each feed material, and international transport distance	Origins were based on the feed survey. Shipping distances were based on the survey responses, with some additional distances taken from: www.portworld.com/map/
Average distance (in km) by road from place of production (PoP) for domestic feeds, or port of entry (PoE) for imported feeds, to feed mill	Average calculated for each country based on survey responses.
Average distance (in km) by road/rail/ship from feed mill to fish farm	Average calculated for each country based on survey responses.
Average distance (in km) that feed is transported from feed mill to farm via: (a) truck/small pickup/van, (b) Tempo/auto rickshaw, (c) boat	Average calculated for each country based on survey responses.
Amount of packaging used for feed	Average calculated for each country based on survey responses.
Emission factors for transport and packaging	Derived from Ramachandra and Shwetmala (2009), AEA (2010), and WRAP (2010).
Emission factors for energy used in the feed mill	Country-specific EF for electricity from IEA (2013). Default EF for gas from GLEAM (MacLeod *et al*., 2013). Default EF for fuel oil, diesel, coal, and furnace oil from Ramachandra and Shwetmala (2009). Biomass (rice husk and wood) assumed to have 0 emissions.
Feed mill energy use (i.e. the rate of energy use per unit of feed produced)	Average calculated for each country based on survey responses.

Quantifying pond N_2O emissions

According to Hu *et al.* (2012) N_2O emissions from the water body on the fish farm arise "from the microbial nitrification and denitrification, [the] same as in terrestrial or other aquatic ecosystems". However, quantifying the emissions from the pond surface to the air is challenging, because they depend on the pH and dissolved oxygen content of the pond, and both fluctuate greatly (Bosma *et al*., 2011).

Despite these difficulties, pond N_2O emissions were included in the present study, to illustrate their likely contribution to the total emissions, and to allow comparison of the GHG associated with aquaculture products to be compared with the GHG associated with terrestrial livestock products (for which N_2O from excreted N is routinely quantified).

Determining the amount of N available for conversion to N_2O

Surplus N amount was calculated as:

Fertiliser N (organic + inorganic) not taken up by aquatic biomass + uneaten feed N + excreted N

Determining the rate at which the surplus N is converted to N_2O

The N_2O emission from different aquaculture systems could vary greatly, depending on the environmental conditions, and Hu *et al.* (2012) noted that "nitrification and denitrification processes are influenced by many parameters (dissolved oxygen concentration, pH, temperature etc.)". To reflect to this variation, the present study used two rates of conversion of N to N_2O:

- 0.71 percent (Henriksson *et al.*, 2014a)
- 1.80 percent (Hu *et al.*, 2012)

Emissions arising from the production of fingerlings and fertiliser

The emissions from fingerling production were estimated by multiplying the amount of inputs (feed, electricity and diesel) required to produce 1 kg of tilapia fingerlings (reported in Pelletier and Tyedmers, 2010), by the emission factors derived in this study (see Appendix 6). This calculation gave the EI per kg of fingerling, a value which was then multiplied by the kg of fingerling input per kg of live weight (LW) output (derived from the fish farm surveys), to give the fingerling emissions per kg of LW output.

Emissions from fertiliser production were estimated by multiplying the amounts of fertiliser used per kg of output (derived from the fish farm surveys) by the mean emission factors for each fertiliser according to Vellinga *et al.* (2013).

Carbon sequestration in pond sediments

It has been suggested that ponds could act as a net carbon sink if primary productivity is stimulated (Boyd *et al.* 2010). However other studies (such as the SEAT project, see Henriksson *et al.* 2014a, b) exclude these potential sinks from their GHG calculations, due to uncertainties over the sequestration rates and permanence of the C storage, (most ponds get excavated, and much of the sequestered C could be oxidised, depending on how the sludge is managed).

Furthermore, stimulating primary productivity requires relatively large inputs of nitrogen and phosphorus to the water, which could lead to problems such as eutrophication. There is also a concern about fish welfare, as the nutrient additions significantly change the water quality, which may not suit some species of fish.

Given the uncertainties outlined above, pond C sequestration was excluded from the present study. However, it is recommended that further studies are carried out to determine the rates at which C could be sequestered in pond sediments.

Emissions post-farm

Emissions arising in post-farm transport were estimated by multiplying the average distances reported in the surveys by an emission factor for each of the main modes of transport: large trucks (GLEAM EF used); small trucks/vans (light goods vehicle EF in Ramachandra and Shwetmala, 2009); domestic boat transport (based on fuel consumption data collected in Viet Nam); and international shipping (GLEAM EF used).

Emissions arising during the manufacture of packaging were calculated by multiplying the rates of packaging use reported in the surveys by packaging emissions factors from WRAP (2010). The emissions factor for ice was based on Henriksson *et al.* (2014b).

Post-farm processing only applied to striped catfish in Viet Nam, as the carps and tilapia were sold whole at the retail point. The emissions were calculated by multiplying the average rate of electricity use reported in the survey (124 kWh/t LW) by the EF for electricity in Viet Nam.

3. Survey results

The sections below provide a summary of the results from the survey questionnaires. The raw data are collated in Appendix 3, and presented in full in Appendix 4.

3.1 AQUACULTURE VALUE CHAINS

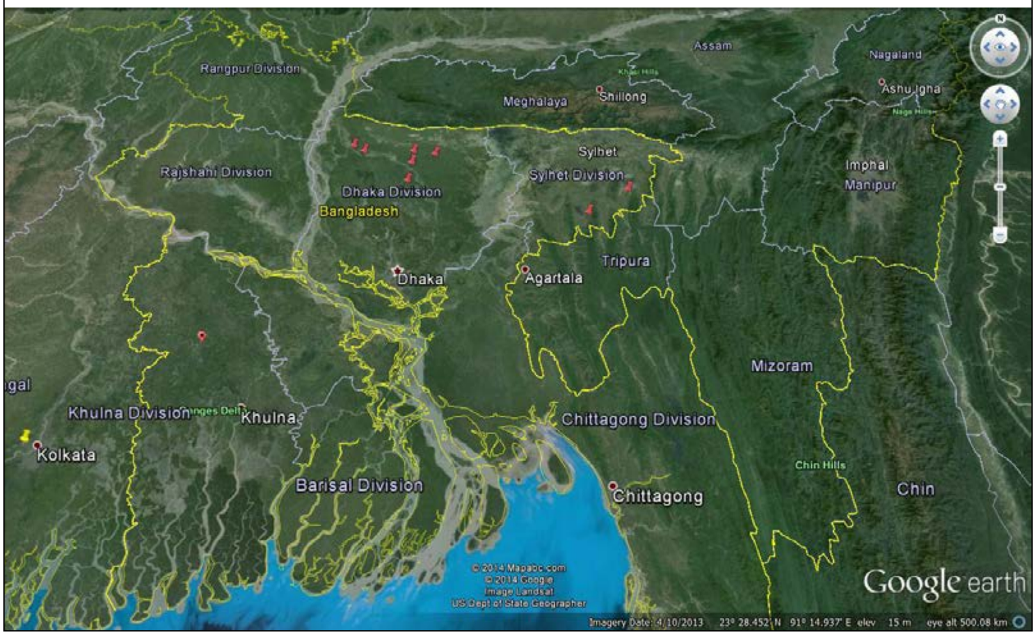
The surveys were conducted from May to September 2014. An overview of the three value chains, (Nile tilapia in Bangladesh, Indian major carps in India, and striped catfish in Viet Nam), shows them to be very distinct from each other, and presumably their development has been shaped by a mixture of the demands of the species, the local environment, and access to international logistics.

3.1.1 Nile tilapia in Bangladesh

The fish are grown in farms distributed around the Dhaka, Khulna and Sylhet Divisions (Figure 3). Farmed in ponds, the production cycle is typically around 6 months, to raise the fish from fingerlings to 300 to 400 g live weight. The tilapia are often farmed in a polyculture with other species of fish, such as Indian major and Chinese carps (bighead carp [*Hypophthalmichthys nobilis*], silver carp [*H. molitrix*], and grass carp [*Ctenopharyngodon idella*]), common carp (*Cyprinus carpio*), Indian major carps (rohu and catla), striped catfish, stinging catfish (*Heteropneustes fossilis*) and silver barb (*Barbonymus gonionotus*), with Nile tilapia representing more than 80 percent of the stocked crop. Stocking densities are low due to the oxygen demand of the fish in the ponds, making this a semi-intensive farming system. The 10 farms in the survey were typically small-scale, with one to six ponds, and a total water area of 0.6 to 13.0 ha.

Commercial feeds are typically used, although some farms also make their own feeds to reduce the cost. Some farms also add manures and fertilisers to the water at

FIGURE 3
Google Earth map of Bangladesh showing the position of the feed mills (house icons), fish farms (circles) and markets (pins) recorded in the survey



various stages of the tilapia production cycle, to supplement natural food production in the pond through algal and zooplankton growth.

The commercial feeds are made by mills within Bangladesh. The feeds are normally sold to the farmers through intermediates, the exceptions being a few mills supplying directly to very large farmers. Raw materials to make the feeds are sourced locally where possible, the remainder are imported. The main imports are materials high in protein, such as fishmeal, meat and bone meal, poultry meal, soybean meal and single cell protein meals, which are not produced in sufficiently large quantities locally.

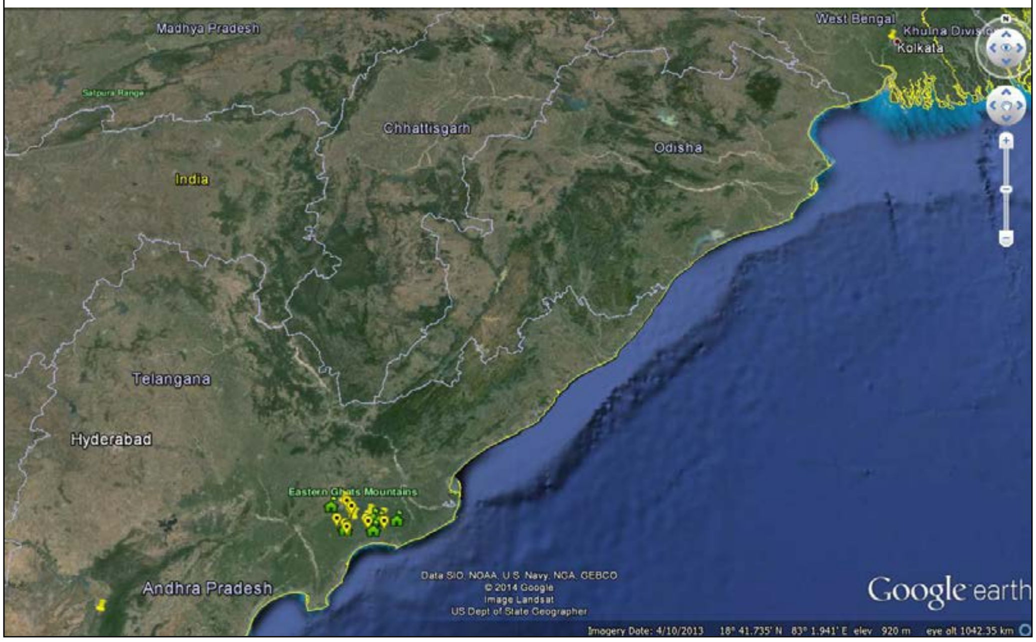
The main market for Nile tilapia in Bangladesh is domestic, with fish being sold in markets close to the farms and in cities such as Dhaka, Sylhet, Chittagong, Khulna, Mymensingh and Gazipur. The fish are sold whole, following transport by van or truck on ice in plastic/wooden boxes from the farms. Normally, the fish are taken to the local markets, and from there they are then sold on to the larger markets. However, if the farmers have a particularly large harvest, the whole harvest is often taken directly to the larger city markets.

3.1.2 Indian major carps in India

All of the 12 farms surveyed were in the state of Andhra Pradesh (Figure 4), a major focus of Indian major carp production, and thus an important example for this survey. Typically stocked as a mixture of rohu (majority) and catla (minority), grow out time ranged from 6 to 10 months, depending on stocking and harvest sizes. Stocking densities were low, making this a semi-extensive production system. The 12 farms typically consisted of one large pond, ranging from 3 to 18 ha (one farm had five ponds covering a total of 60 ha). Manures and fertilisers were used by all farms to enhance natural food production in the water.

All farms used commercial feeds, with some also making their own feeds. Most farms used extruded feeds (floating pellets), although two farms used steam pressed pellets (sinking). Three farms used mashes rather than pellets as the main source of nutrients. Although most farms had initially used mashes, they had switched to pellets

FIGURE 4
Google Earth map of Andhra Pradesh, India, showing the position of the feed mills (green house icons), fish farms (circles) and markets (pins) recorded in the survey



(floating or sinking, or a combination of both) as this form was more convenient to handle, and had proved to be more efficient in reducing feed conversion ratio.

The raw materials for the feeds were almost all sourced from within India, (the exception being one feed mill that used a source of ready mixed raw materials from Indonesia for 50 percent of its inputs). However, within India, the range of origins was diverse, spanning much of the country, depending on the requirements. This range of raw materials reflects the diversity of production of fishmeal, and agriculture and animal by-products in India.

3.1.3 Striped catfish in Viet Nam

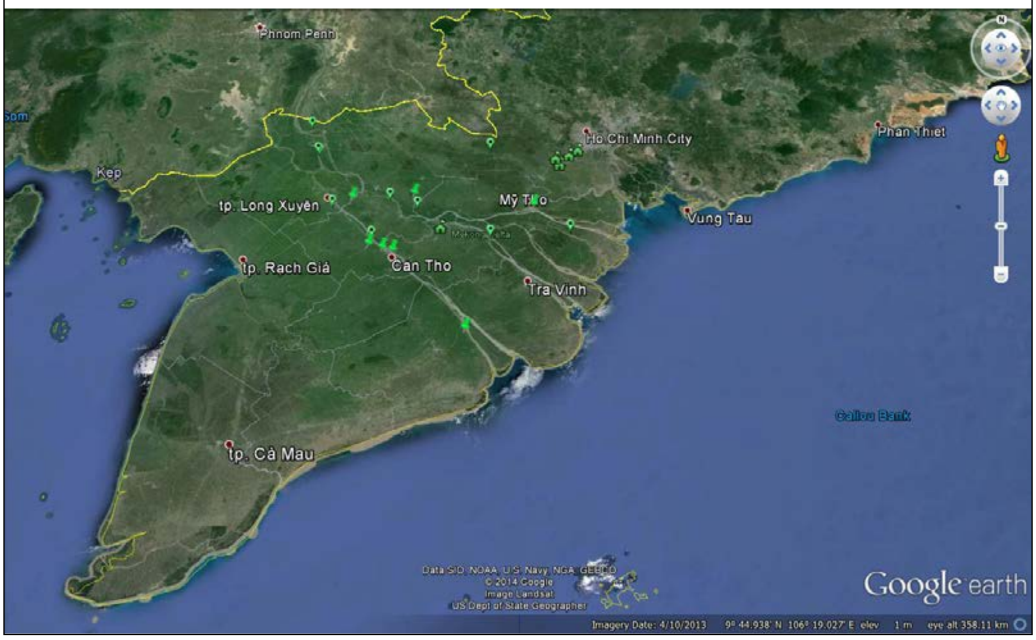
The striped catfish production in Viet Nam is based in the Mekong Delta (Figure 5), fitting the requirements of the fish with a steady supply of freshwater at temperatures over 22 °C year round. The survey therefore focussed on this area. The 10 farms were all pond based, with three to eight ponds per farm. Farm sizes ranged from 2.5 to 7.0 ha in total water area. The fish were stocked as fingerlings at 20 – 30 g, and were harvested at 800 – 1 000 g after 6 to 8 months at high stocking densities in very intensive farming systems.

The carbohydrate raw materials for feed could be sourced locally. In contrast, most protein containing raw materials were imported, because Viet Nam does not have an abundance of agricultural crops producing protein. The notable exception was fishmeal, which is produced locally, although its use for striped catfish feeds is limited, mainly due to its relatively high cost. Raw materials were imported from South America, North America, Europe, Australia and Asia. Transported by ship, the feed raw materials entered Viet Nam through one of the ports in the south, and were mainly transferred to trucks for transport to the feed mills. One feed mill made extensive use of boats to bring raw materials to the factory.

All of the feeds produced were extruded, so that they would float. After being bagged, the feed was transferred to farmers directly, or through traders by truck or boat (some farms have no effective road access). No farms reported using farm-made feeds, manures or fertilisers.

FIGURE 5

Google Earth map of the Mekong Delta in Viet Nam, showing the position of the feed mills (house icons), fish farms (circles) and markets (pins) recorded in the survey



At harvest, the fish were caught in the pond and transferred to boats which carried them live to the processing factory. Here the fish were slaughtered and processed. Most fish were filleted, but some were just gutted, or even sold whole; very few were sold live in the local markets. The bulk of striped catfish production is destined for export markets. The processed fish are frozen, boxed and stored in containers for export around the world. Most of the processing by-products are used, some are sold directly as food, the remainder are processed into fishmeal and oil and are used for animal feeds.

The Vietnamese value chain differs greatly from the other two chains: most raw materials are imported, and the bulk of fish production is exported. The product is very distinct also, with fillets being the main target for striped catfish, compared to whole fish for tilapia and major carps. Such major differences are expected to have important consequences for the GHG emissions associated with the three industries

3.2 FEED RAW MATERIALS[1]

Feed raw materials for aquaculture can be sourced locally or internationally, with the choice being dependent on local availability (with regard to both products and quality) compared to the price and relative ease of importation. The four major categories of the raw materials which are commonly used in formulations are: protein sources, lipid sources, carbohydrate sources, and micro-ingredients and additives. The ingredients used by the feed mills in the survey are shown in Table 5.

No lipid sources were used for the target species, except for a very small amount of lipid reported in two Indian feeds from three factories. This situation reflects the fact that the fish species considered in the survey are herbivorous or omnivorous, and can use carbohydrates for energy, a source which is generally much cheaper than lipid raw materials. Micro-ingredients were not studied in this survey as their volumes are relatively low, and the numerous varieties did not make it feasible to comprehensively evaluate them.

3.2.1 Protein sources[2]

In this study, the protein raw materials are split between animal sources and plant sources for convenience; there are also different commercial practices involved in the two groups of raw materials.

Animal protein sources

Fish and fishmeal

Fish proteins are generally very digestible, and closely match the amino acid requirements of the species to be fed. Fish derived products are therefore common ingredients of aquaculture feeds. These ingredients provide a distinctive smell, which is popular with farmers, and fish and fishmeal are often considered to add "taste" or "palatability" to the feeds, and thus these ingredients are also termed "attractants" (NRC, 2012).

Meat and bone meal

Meat and bone meal, waste products of livestock production, provide good sources of animal proteins, together with some ash. Meat and bone meal are available as high or low fat products, depending on the processing.

Poultry meal

Poultry meal, similar to meat and bone meal, but sourced solely from poultry processing, is another good source of highly digestible animal protein. Often, it is more expensive than meat and bone meal, and generally provides a higher protein

[1] Please see Appendix 4.2 for more details.

[2] Please see Appendix 4.2.1 for more details.

TABLE 5
Categories of raw materials used by the feed mills in the three countries in the survey

Protein sources		Carbohydrate sources	
Animal products	**Country**	**Material**	**Country**
Fish trimmings meal[1]	Viet Nam	Cassava	Viet Nam
Fishmeal	Bangladesh, India	Molasses	Bangladesh
Dry fish	Bangladesh	Maize	Bangladesh, India
Meat and bone meal[2]	Bangladesh, India, Viet Nam	Rice bran - full fat and de-oiled	Bangladesh, India, Viet Nam
Poultry meal	Bangladesh, India		
Blood meal	Viet Nam	Wheat - whole, bran and flour	Bangladesh, Viet Nam
Single cell protein	Bangladesh	Broken rice	India
		Rice polish	Bangladesh
Plant products	**Country**	**Lipid sources**	
Soybean - full-fat and de-oiled	Bangladesh, India, Viet Nam	**Material**	**Country**
Canola meal	Viet Nam	Fish oil	India
Rapeseed meal	Bangladesh, India	Poultry fat	India
Copra meal	Viet Nam		
Cottonseed meal	India		
Groundnut oil cake	India		
Guar meal	Bangladesh		
Mustard oil cake – full fat and de-oiled	Bangladesh		
Maize gluten	India		
DDGS[3]	India, Viet Nam		

Notes: [1]Fish trimmings from striped catfish, sardines or tuna; [2]meat and bone meal of high or low fat; [3]distiller's dried grains with solubles.

content and improved digestibility. Interestingly, although poultry meal was used in Bangladesh and India, it was not used in feed for striped catfish in Viet Nam. The reason for its exclusion may have been that the high cost of this raw material would have added significantly to the overall feed cost.

Blood meal

Another important source of animal protein is blood meal. Well processed blood meal is highly digestible, and is an excellent source of some important amino acids, particularly histidine (NRC, 2012). However, it is expensive, and so is used at relatively low concentrations in the feed. Blood meal is usually of porcine origin, due to restrictions on use of bovine protein products.

Plant protein sources

Plant protein sources are very abundant, there are several globally traded commodities, and they are generally cheaper to buy than are animal protein sources. Nutritionally, plant protein sources are often less digestible than animal sources, and individually their amino acid profiles do not match the fish requirements as closely. However, blending plant protein sources appropriately results in a good amino acid profile for the target fish species.

Oilseed meals

Many plants are farmed to produce oils from their seeds, their primary products. After the oils are extracted from the seeds, the remaining material can be high in protein, resulting in important feed raw materials.

Cereal by-product meals

The other plant protein sources used by feed mills in this study derived from cereals after processing: maize gluten meal and dried distillers grains with solubles (DDGS).

3.2.2 Carbohydrate sources[3]

Carbohydrate is an important dietary source of energy for Nile tilapia, Indian major carps, and striped catfish. Raw materials supplying carbohydrates are more common than raw materials supplying oil. Furthermore, the latter is a more expensive way of providing energy in the diet.

Cereal products

The global trade in cereals supports the use of cereals in feeds as a relatively cheap source of carbohydrates. The quality grades used in fish feed are generally lower than the food grade raw materials used for human consumption, and consequently the feed grades are significantly cheaper.

3.2.3 Lipid sources[4]

The three fish species/species groups in this study require relatively little lipid in their diets, as they are able to use carbohydrates for energy. Most of the required lipid is supplied by the low concentrations of lipids in the bulk raw materials, such as fish meal and full fat rice bran. However, in India three of the mills used fish oil and poultry fat as additional sources of lipids.

3.2.4 Other ingredients[5]

In Bangladesh, India and Viet Nam, a wide range of other ingredients and additives are promoted for use in fish feeds. In most cases, the feed mills view the mix of additives that they use as their proprietary knowledge, carefully guarding this information to gain an edge in the markets. Even when other ingredients were listed by the mills in this survey, details were scarce, and the percent inclusions was very low; thus this element of the feed is considered to have a low impact on the GHG emissions associated with the feeds.

3.2.5 Raw material transport[6]

In each of the three countries studied, a wide variety of local raw materials are available because of extensive agricultural production. The local raw materials require different transport methods to the international freight, typically small trucks in contrast to bulk haulage by ship. For imported raw materials, local transport is generally required between the point of import and the feed mill.

3.3 FEED FORMULATION[7]

Feed formulation is the preparation of a recipe from the available raw materials, and attempts to balance the nutritional requirements of the fish with the least cost. When deriving the formulations, the nutritional content of the raw materials is determined from book values, rather than from the actual raw material batches, as the capacity to analyse the latter is generally not feasible. The actual nutritional content of the batches may differ from the book values. The nutritional requirements of the fish may be found in the literature, or can be copied from competitor mills. Some mills may focus solely on protein and energy content, rather than such details as amino acid requirements.

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[3] Please see Appendix 4.2.2 for more details.
[4] Please see Appendix 4.2.3 for more details.
[5] Please see Appendix 4.2.4 for more details.
[6] Please see Appendix 4.2.5 for more details.
[7] Please see Appendix 4.3 for more details.

Lack of knowledge and detailed information about feed formulation results in sub-optimal feeds, which increases the biological feed conversion ratio (bFCR) of the feeds, as the fish will need to eat more to obtain their nutritional requirements.

Details of feed formulations are often commercially guarded, and there were limitations in the availability of data for this survey. Although most information was available from Bangladesh and India, the full formulation was often not given, in order to maintain a market edge, which was a key marketing strategy. Undisclosed minor ingredients were normally used at less than 2 percent of the total, but in some cases up to 10 percent of the total ingredients were not reported in this survey. For feed companies in Viet Nam, it was not possible to get details for all feeds. Instead, these companies provided the average total raw material consumption over the year, which equates to an average feed formulation for all sizes of feed made.

To compare the feed formulations used with the requirements of the fish, book values for the raw materials' protein and energy contents and relative digestibility were used to calculate the values for each feed (Appendix 5). These values could then be compared to the recommended requirements for each of the fish species, with the caution that not all of the raw materials were reported in the survey, so some nutrients may be under-estimated.

3.3.1 Bangladesh[8]

There were wide variations in the nutrients estimated to be provided by the feeds for the tilapia in Bangladesh (Table 6). The quantity of protein and energy are below the optimal amount for growth, when compared with the recommended values of digestible protein (DP) of 29 percent, and digestible energy (DE) of 14.2 MJ/kg for tilapia over the whole life cycle, (a DP/DE of 20.4 g/MJ) (NRC, 2012). However, feeds of lower nutrient value are often made commercially, to reduce the cost of feed per kg, even though the efficacy of the feed is decreased. Nonetheless, the relative quantities of available protein and energy are well balanced in the feeds covered in this survey.

TABLE 6
Calculated protein and energy content of the feeds for four weight classes of Nile tilapia in Bangladesh

Fish weight (g)	CP (%)	DP (%)	GE (MJ/kg)	DE (MJ/kg)	DP/DE (g/MJ)
1 – 24	30.7 – 34.6	25.0 – 29.7	16.1 – 17.5	10.6 – 11.7	22.5 – 25.5
25 – 49	28.7 – 30.4	22.9 – 26.0	16.2 – 16.9	10.3 – 10.7	22.1 – 24.3
50 – 99	25.1 – 30.4	19.5 – 24.7	16.1 – 16.7	9.3 – 10.5	21.1 – 23.6
100 – harvest	25.1 – 29.0	19.0 – 23.4	16.1 – 16.6	9.0 – 10.5	21.1 – 22.2

Notes: CP = crude protein; DP = digestible protein; GE = gross energy; DE = digestible energy
Source: Appendix 5.

3.3.2 India[9]

The estimated properties of the feeds for major carps in India are given in Table 7. The digestible protein and energy provisions are well below the optimum (for rohu) of a digestible protein content of 32 percent and energy of 13.4 MJ/kg (DP/DE of 23.9 g/MJ) (NRC 2012). Furthermore, some feeds have low DP relative to DE (for example around 18 g/MJ), indicating a low supply of digestible protein. For other feeds, the ratio between DP and DE is similar to that of the recommendations, thus maintaining an appropriate balance between DP and DE.

[8] Please see Appendix 4.3.1 for more details.
[9] Please see Appendix 4.3.2 for more details.

TABLE 7
Calculated protein and energy content of the feeds for three weight classes of major carps in India

Fish weight (g)	CP (%)	DP (%)	GE (MJ/kg)	DE (MJ/kg)	DP/DE (g/MJ)
<50	26.8 – 31.3	21.6 – 26.1	16.2 – 18.9	10.2 – 12.9	17.9 – 25.9
50 – 99	25.0 – 31.3	18.1 – 26.1	16.1 – 18.9	8.8 – 12.9	17.9 – 26.9
100 – harvest	23.0 – 28.6	16.0 – 23.1	16.1 – 18.2	7.8 – 11.9	18.9 – 25.3

Notes: Excluded from this table is the feed mill using the 50 percent inclusion of premix, as it was not possible to determine the nutritional content of that premix.

CP = crude protein; DP = digestible protein; GE = gross energy; DE = digestible energy

Source: Appendix 5

3.3.3 Viet Nam[10]

Only the average use of raw materials was given by Vietnamese feed mills, thus only the average composition of the feeds could be estimated (Table 8). However, as this value is the weighted average over the life of the fish fed these feeds, it is still very relevant.

Despite the high production of striped catfish, there is little scientific literature on its nutritional requirements. Instead, information on the American channel catfish (*Ictalurus punctatus*) is often used as a guide. The digestible protein and energy contents of the feeds used for striped catfish in Viet Nam are much lower than those required to optimise growth of channel catfish, which requires 29 percent digestible protein and 12.6 MJ/kg digestible energy (equating to a DP/DE of 23.0 g/MJ) (NRC, 2012). In particular, the low protein content in the Vietnamese feeds (19.7 – 23.1 percent) creates an unbalanced diet, with a much lower amount of digestible protein compared to energy than is recommended. However, most feed mills focus on cost control, rather than optimising protein and energy supply for growth.

TABLE 8
Protein and energy contents of the feeds made in Viet Nam for striped catfish

CP (%)	DP (%)	GE (MJ/kg)	DE (MJ/kg)	DP/DE (g/MJ)
24.3 – 27.7	19.7 – 23.1	16.2 – 16.9	10.0 – 11.2	19.8 – 21.7

Notes: These values represent the average values of all the raw materials used by the feed mills over the year, rather than for individual feeds as reported for the other countries.

CP = crude protein; DP = digestible protein; GE = gross energy; DE = digestible energy

Source: Appendix 5.

3.4 FEED PRODUCTION[11]

A range of aquaculture feeds are used in Asia, from simply adding single raw materials directly to the pond, to complex formulated feeds. Intensive aquaculture relies heavily on complete formulated feeds, supplying all of the nutrition required by the fish.

Commercial companies supply feeds made either by extrusion or steam pelleting. Extrusion, by applying more energy to the raw materials, expands the starch greatly, and cooks the starch in the pellets more effectively than does steam pelleting; the raw materials are more digestible than in steam pelleting, due to the extra cooking in the extrusion process. Furthermore, extrusion creates a less dense pellet which floats. However, extrusion technology is more expensive, and tends to require more energy than steam pelleting.

Extrusion was reported from all three countries in the study. Steam pelleting was reported from Bangladesh and India, but not from Viet Nam.

[10] Please see Appendix 4.3.3 for more details.
[11] Please see Appendix 4.4 for more details.

3.4.1 Losses during production

During production, most raw materials are normally converted into feed. However, this may not happen the first time for all of the raw material. Some material is recycled, and is processed twice, thus more energy is used (Table 9). The amount of reworking required depends in part on the quality of the final pellet demanded by the farmer: the higher the quality required, the more rework is likely to be generated.

TABLE 9
Estimated amount of rework from the feed mills in the three countries surveyed. Data are percentage of total feed production

	Bangladesh	India	Viet Nam
Minimum	0.005	1.0	0.50
Average	0.009	1.5	1.55
Maximum	0.010	2.0	2.00

3.4.2 Packaging

Plastic packaging was used by all feed mills (Table 10). This high use reflects the environment in which the bags of feed will be stored before use, typically they will be exposed to rain and rough handling. These conditions necessitate the use of robust plastic, as paper bags would be damaged or destroyed.

TABLE 10
Feed packaging materials used in the three countries surveyed, and bag capacity and packing material weight

	Bangladesh PP and PPT	India HDPE	Viet Nam PE and PP
Bag capacity (kg)	25	40 / 50	15 / 25 / 40
Average packing material weight per tonne feed (kg/tonne)	2.93	0.69	4.73

HDPE = high density polyethylene; PE = polyethylene; PP = polypropylene; PPT = polypropylene terephthalate

3.5 FEED TRANSPORT[12]

Farms are often some distance from the feed mills, and therefore the feed has to be transported to them using local transport appropriate to the conditions and the quantity of feed. In the three countries, there was a wide range of boat and road transport methods used for feed transport. Boats were used mainly in Viet Nam, where many farms are not accessible by roads suitable for bringing the required amounts of feed. Road vehicles ranged from motorbikes, through vans to larger lorries depending on the volumes of feed being transported.

3.5.1 Losses in transport and on-farm

Damage to the bags of feed can occur due to bad handling, adverse weather, and a long distance journey. Bad handling can lead to torn bags and wasted feed. Rain is a major risk, wetting the feed which can destroy the pellets or allow mould to grow later. In this survey feed losses in transport were generally very low, and were controlled by the feed companies. For example, in Bangladesh, annual losses of this type were reported as being only between 100 kg and 300 kg per mill per year, which equals 0.0022 percent to 0.0033 percent of production, with an average of 0.0026 percent.

Further losses of feed will occur at the farm due to poor storage conditions. The main issue is likely to be the feed getting damp or wet, resulting in growth of mould. There may also be some contamination or consumption of the feed by pests and other

[12] Please see Appendix 4.5 for more details.

animals, and even some theft. None of these losses were reported in this survey. It is most likely that these losses would be included in the farms' calculations of FCR, as this would be considered feed purchased for the farm, compared to growth of fish biomass.

Additional sources of on-farm losses are broken pellets and dust: the feed dust is not eaten by the fish, often blowing away. In Viet Nam, the farmers have a very rigorous attitude towards dust, expecting a very low proportion in each bag (less than 0.25 percent, and preferably less than 0.18 percent). Indian farmers had a slightly greater tolerance of 0.2 percent to 0.325 percent dust in the bags at packing, so there is less than 1 percent at the farm. These expectations for low dust necessitate a lot of work by the feed mill to remove the dust before feed is sent to the farm, and may explain some of the high levels of rework reported (section 3.4).

3.6 FARMING[13]

3.6.1 Farming areas

All the farms in the survey raised their fish in ponds. The ponds were situated in lowland areas, near to rivers, to access to fresh water. Most the land used for ponds had previously been farmed.

There was marked variation between the three countries in the age of the farms. In India, some farms had been established for over 20 years, and there was only one new farm[14]. In contrast, Vietnamese farms were much more recently established, since the farming of striped catfish began in the early 2000's. Bangladesh was intermediate between India and Viet Nam in terms of farm age.

3.6.2 Farming techniques

The basis of the farming varied markedly between the three countries. In Bangladesh, most tilapia farms (9 out of 10) raised a minimum of 80 percent Nile tilapia, with the remainder (7.5 to 20.0 percent) comprising a mixture of other fish species (see section 3.1.1). Only one out of the 10 farms in Bangladesh reported a monoculture production of Nile tilapia. Although the present report focusses on tilapia in Bangladesh, the polyculture nature of production means that some caution has to be applied when interpreting the results.

In India, major carp production showed only rohu and catla in all of the farms surveyed; rohu was always the majority (90 percent by number), and catla the minority (10 percent) in all farms. In Viet Nam production of striped catfish was a monoculture.

Manure (organic fertilizers) was used in Bangladesh and India to promote growth of natural food such as algae and zooplankton in the ponds. Some farms also used inorganic fertilizers (mainly N and P) to stimulate production of natural food. The application of manure or fertilizer was not practiced in Viet Nam because the striped catfish stocked were too big to benefit from natural food that can be produced in the pond.

Most farms in the surveys used commercially produced feeds, mainly extruded (floating) pellets, but also some steam pressed (sinking) pellets. The recent adoption of these feeds by some farms indicated a progression towards a more developed aquaculture industry. Some farms still used farm-made feeds, particularly in Bangladesh but also in India, where mashes were also applied (Table 11). None of the farms surveyed reported using moist pellets.

[13] Please see Appendix 4.6 for more details.

[14] In this survey, new farms are those which are established for about two years.

TABLE 11
Percent of farms reporting use of each of three types of feed[a]

Type of feed	Bangladesh n = 10	India n = 12	Viet Nam n = 10
Mash	0	25	0
Pellet			
Steam pressed (sinking)	70	17	0
Extruded (floating)	60	83	100

[a] Some farms in Bangladesh and India use a mix of feeds, hence the totals may add up to greater than 100 percent.

3.6.3 Energy use

The farms reported their energy use as being mainly for pumping water, and for lighting. Mains electricity, diesel and petrol were the major sources, depending on the situation of the farm and the power requirement. A great variation in energy use was seen between farms in the same country, reflecting local conditions and the frequency of changing water in the ponds.

3.6.4 Fish production

In Bangladesh and India, the polyculture nature of the ponds makes it difficult to calculate the production efficiencies of individual species. In some farms, fish were regularly stocked and harvested throughout the year, with small crops of harvest sized fish being removed as they were caught, and small fish were returned to grow on. This practice makes it hard to define the productivity, and is a major cause of the variation seen in Table 12. Production of tilapia and major carps was usually efficient, although some of the maximum values for eFCR were very high for major carps. The practice of regular small stocking and harvest events in each pond, makes it difficult to determine the actual production results, but over time and by assessing many farms, a reasonable picture can be built up.

The monoculture nature of the Vietnamese striped catfish industry makes it relatively straightforward to follow the production system.

The monoculture of the striped catfish enabled a much greater production of fish per unit area than for tilapia and major carps (Table 12), and the use of the commercial feeds apparently resulted in a good eFCR.

TABLE 12
Production details and efficiencies of the three systems. Data are presented as averages, except where otherwise stated

	Bangladesh	India		Viet Nam
	Nile tilapia	Rohu	Catla	Striped catfish
Stocking size (g)[a]	15 (1 – 50)	160 (50 – 300)	210 (50 – 600)	27 (20 – 30)
Harvest size (g)[a]	310 (180 – 750)	1240 (1000 – 2000)	2340 (1350 – 3000)	880 (750 – 1020)
Total harvest/year (tonnes/year)	52	135		1480
Total harvest per square metre of water (kg/m^2/crop)	1.930	0.995		34.9
Grow out time (days)	184	230		220
eFCR (economic feed conversion ratio)	1.59	1.8		1.69
Survival (%)[b]	88	98[c]		80

Notes: Data are presented as averages, except where otherwise stated.

[a] Sizes are reported as average above, and (minimum – maximum) beneath.

[b] Survival was calculated from the number of fish stocked and the number harvested.

[c] Farmers in India did not count the number of fish stocked, so this is unlikely to be an accurate number.

3.7 FISH HARVESTING AND MARKETS[15]

At the end of the growth phase, the fish are harvested from the ponds and sent to market. In Bangladesh and India, most of the farms net through the ponds, catching the large fish and returning the small ones to grow on. In contrast, as previously noted, in Viet Nam harvesting is on an "all in, all out" basis, where the pond is emptied.

In Bangladesh and India, the main markets are for whole fish, mainly dead on ice; in Bangladesh there is also a limited market for live fish. In contrast, in Viet Nam, fish are taken live by boat to a processing plant where they are killed and processed.

Due to the differences between the markets, and in the processes to get there, each country have been summarised separately in appendices. The data obtained are recorded in Appendices 3 and 4.7, together with a brief explanation of the markets for the different countries. The range of markets and the variety of end uses made it difficult to obtain sufficient data in this limited survey, thus investigation of emissions intensity stopped at the farm-gate.

Feeding striped catfish with commercial pelleted feed from a floating raft in an integrated enterprise farm in Mekong Delta, Viet Nam (courtesy of FAO/Mohammad R. Hasan)

[15] Please see Appendix 4.7 for more details.

4. Model results

The LCA (life-cycle assessment) model ("aquaculture LCA model v1.1") was used to calculate the GHG emissions from the three aquaculture systems. The results of this analysis are presented below, along with brief explanations.

4.1 EMISSIONS FROM CRADLE TO FARM GATE

The emissions intensities for each country, expressed per kg of live weight at the farm gate are given in Figure 6. These values are based on the average values for key parameters reported in the surveys (see section 3).

Under the assumptions used in Figure 6 (no LUC and an EF for pond N_2O of 0.71 percent) Indian major carps in India had the highest EI, followed by Nile tilapia in Bangladesh, and striped catfish in Viet Nam. When LUC is included, the results are quite different (see Figure 7). For all three systems, feed production was the biggest source of emissions. Note that the emissions arising from fingerling production are higher for Indian carps due to the larger size of the fingerlings in this system.

4.2 EMISSIONS FROM THE PRODUCTION OF FEED MATERIALS

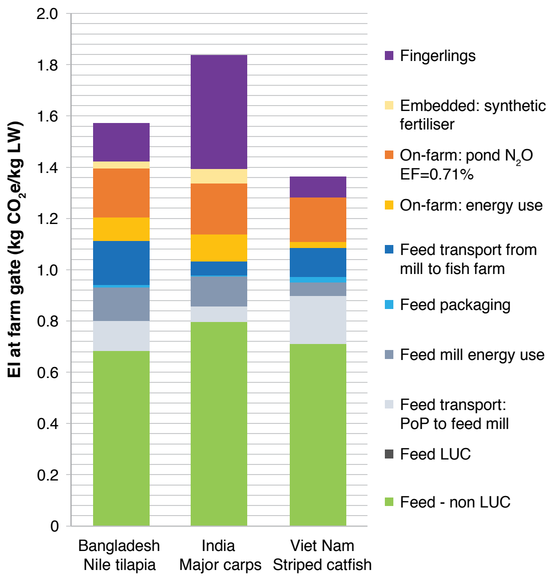
Production of feed materials is the biggest single source of emissions for all three systems, accounting for 43 percent of the EI for Indian carps and tilapia, and 52 percent for the striped catfish (Figure 6).

The contribution of the feed materials to the total EI is a function of two elements: (i) the EI of the feed material (i.e. kg CO_2e per kg of feed), and (ii) the number of kg of feed required to produce 1 kg of live weight (LW) fish, i.e. the feed conversion ratio (FCR). The higher FCR of the Indian major carps (relative to the Nile tilapia and striped catfish) is offset by the higher feed EI for Indian carps (Table 13). The feed EI depends on the composition of the ration, as there is a wide variation in the EI of individual feed materials (see Appendix 6 for the EI of each feed material at its point of production).

The differences in the feed EI between the three systems (not including LUC or transport/blending) arise primarily as a result of the following:

- carp rations have high amounts (18–20 percent) of high EI grains (maize and broken rice), and smaller but significant amounts of cottonseed meal, which has a higher EI than other oilseed meals
- striped catfish rations have lower amounts of high EI fish products (1.5 percent) compared to the rations for carp (2.7 percent) or Nile tilapia (6.2 percent)
- compared to carp and Nile tilapia, striped catfish rations have more animal by-products (which tend to be high protein and low EI), and significant amounts of low EI cassava

FIGURE 6
Emissions intensity from cradle to farm gate



Notes: EF = emission factor; LUC = land use change; PoP = place of feed material production.

FIGURE 7

Emissions intensity of fish from cradle to farm gate, under different LUC methods (N_2O EF: 0.71%)

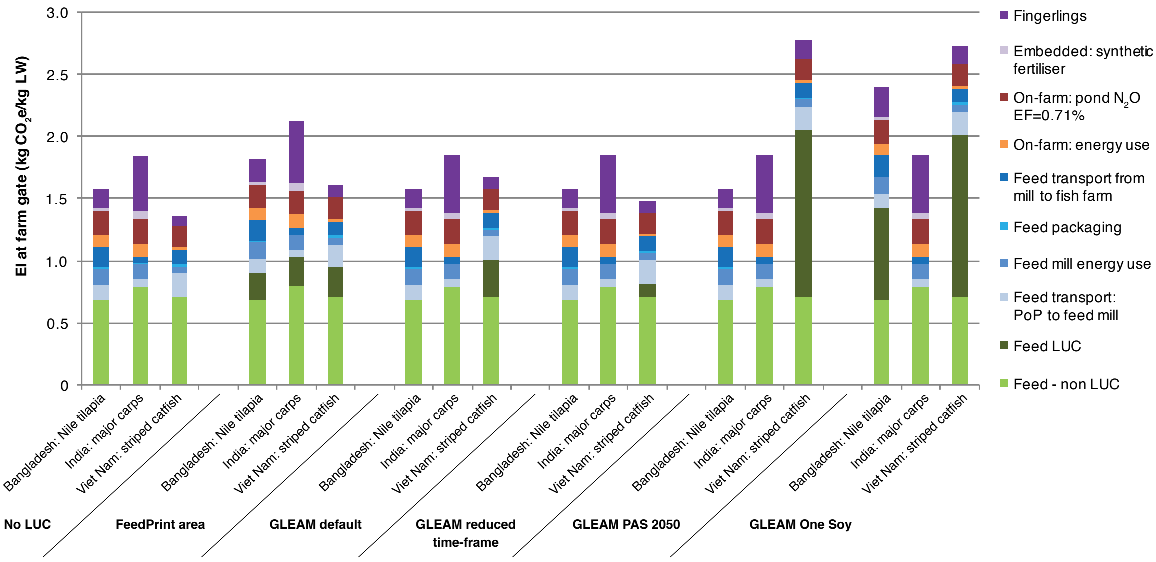


TABLE 13

Emission intensities (EI) and feed conversion ratio (FCR) for post-fingerling stage (no LUC and an EF for pond N_2O of 0.71%)

	Nile tilapia	Indian carps (pellet fed)	Striped catfish
Feed material production EI (kg CO_2e/kg DM)	0.51	0.69	0.49
Feed conversion ratio (kg dry feed fed/kg live weight gain)	1.43	1.32	1.52
Feed material production EI (kg CO_2e/kg LW gain)	0.72	0.91	0.74

4.3 EMISSIONS FROM THE TRANSPORT OF FEED MATERIALS

Emissions from the transport of feed material from their place of production to the feed mill vary between the systems, reflecting the greater reliance on imports in Bangladesh (soy from United States of America, meat and bone meal from the European Union) and Viet Nam (soy from United States of America and Argentina), than in India. Transport emissions are lowest for the Indian carp rations, reflecting the predominance of domestically produced feeds in this system.

4.4 EMISSIONS FROM ENERGY USE IN THE FEED MILLS

The average amount of energy consumed per kg of feed produced varies between the three countries (Table 14). The rates of energy consumption in the present study are consistent with the results presented in Bosma *et al.* (2011) (0.71 kWh/kg feed) and Henriksson *et al.* (2014b) (0.14 to 1.05 kWh/kg feed).

Variation in the rates of energy consumption reflects the type of feed materials being processed, and the variation in the quality of the fuels used. In India and Viet Nam, a significant proportion of the energy used is in the form of biomass, which includes relatively low quality fuels (i.e. low energy density and low conversion efficiencies). However, biomass is assumed to have zero net GHG emissions, which therefore lowers the overall EI of the feed. In India this emission reduction is offset by the higher electricity emission factor (see Appendix 7).

TABLE 14
Energy consumption in kilowatt-hour (kWh) and emissions, per kg of feed produced

	Bangladesh	India	Viet Nam
Energy consumption			
kWh/kg feed	0.27	0.63	0.47
kWh/kg feed (excluding biomass energy)	0.27	0.12	0.10
Emissions			
kg CO_2e/kg feed	0.10	0.10	0.04

4.5 EMISSIONS FROM TRANSPORT OF FEED FROM MILL TO FARM

These emissions are a function of the transport distance, and mode of transport (see Appendix 7). The low transport emissions in India reflect the short average transport distance (44 km). The longest transport distance is in Viet Nam (196 km compared to 123 km in Bangladesh), however much of this transport is by boat, which has a lower EF per tonne km than transport by road.

4.6 COMPARISON OF TOTAL FEED EMISSION INTENSITY (EI) FROM PRESENT STUDY WITH OTHER STUDIES

The total feed EI results from the model are broadly consistent with those reported in other studies (see Table 15), though the results in Bosma *et al.* (2011) also highlight the effect of ration composition on feed EI.

TABLE 15
Comparison of total feed EI from model used in present study with values from other studies*

Study and species	Feed EI kg CO_2e/kg feed (DM) at fish farm					
	LUC method					
Present study	a	b	c	d	e	f
Nile tilapia	0.82	0.99	0.82	0.82	0.82	1.37
Indian carps (pellet fed)	0.89	1.09	0.89	0.89	0.89	0.89
Striped catfish	0.74	0.90	0.94	0.82	1.66	1.63
Bosma *et al.* (2011)**						
Catfish	0.98 – 2.55**					
Pelletier and Tyedmers (2009)						
Tilapia	0.79**					

Notes: *LUC method: a - No LUC; b - FeedPrint area; c - GLEAM default; d - GLEAM reduced time-frame; e - GLEAM PAS 2050; and f - One Soy; **does not specify if kg are “as fed” or dry matter

4.7 EMISSIONS FROM ON-FARM ENERGY

The emissions arising from on-farm energy use depend on the rate of energy use and the energy EFs. Diesel and electricity dominate the on-farm energy, and these are used primarily for pumping (for water exchange and aeration), and to a lesser extent, lighting and powering boats and other vehicles.

The emissions are markedly lower in Viet Nam (24 g CO_2e/kg LW) than in India (105 g CO_2e/kg LW) or Bangladesh (92 g CO_2e/kg LW), due to the lower rate of energy consumption and the lower EF for electricity in the former (Table 16).

The rates of on-farm energy use determined in the present study are similar to those reported for catfish in Bosma *et al.* (2011) and Henriksson *et al.* (2014b), but somewhat lower than Pelletier and Tyedmers (2010) and Henriksson *et al.* (2014b) for tilapia (Table 17).

TABLE 16
Emission factors for three different energy sources used in calculation of on-farm energy emissions

Energy source	Emission factor kg CO_2e/MJ
Diesel	
all three countries	0.109
Petrol	
all three countries	0.071
Electricity	
Bangladesh	0.163
India	0.251
Viet Nam	0.115

TABLE 17
Rates of on-farm use of three different energy sources, and total energy use

	Energy use (MJ/tonne fish)				
Species, country and system	**Diesel**	**Petrol**	**Electricity**	**Total**	***Source***
Nile tilapia					
Bangladesh					
Pond	280	0	433	713	This study - survey
Pond	51	0	2 730	2 781	Pelletier and Tyedmers (2010)[1]
Pond	7 934	0	6 750	14 684	Henriksson *et al.* (2014b)
Major carps[2]					
India					
Pond	424	118	258	800	This study - survey
Striped catfish					
Viet Nam					
Pond	5	0	203	209	This study - survey
Small farms	293	0	367	660	Henriksson *et al.* (2014b)
Medium farms	229	0	637	867	Henriksson *et al.* (2014b)
Large farms	35	0	205	241	Henricksson *et al.* (2014b)
Cages in ponds	177	0	148	324	Bosma *et al.* (2011)

Note: [1]Data in this study are from a single farm and may not be representative; [2]Fed with pellet feeds.

For tilapia, there was marked variation in the rate of energy consumption reported in three different studies, which is likely to be due in part to the extent to which tidal water exchange is exploited, thereby reducing the energy required to pump water.

4.8 POND N_2O AND NUTRIENT USE EFFICIENCY

The pond N_2O emissions for each system are given in Table 18. There is little variation between the systems, in part due to the limitations of the survey method. The pond N_2O emissions in this study are consistent with those of Henriksson *et al.* (2014a) (Table 19).

TABLE 18
Ponds N_2O expressed in absolute terms, and as a percent of the total emissions (no LUC)

	Nile tilapia	Indian carps (pellet fed)	Striped catfish
Absolute terms (g CO_2e/kg LW)			
EF: 0.71%	190	198	173
EF: 1.8%	482	503	438
% of total GHG emissions			
EF: 0.71%	12	11	13
EF: 1.8%	26	23	27

The pond N_2O can represent a significant percent of the total emissions, depending on how they are calculated, where the systems boundary is drawn, and which emissions categories are included.

TABLE 19
Comparison of the pond N_2O in the present study and Henriksson *et al.* (2014a)

Species, country and system	Pond N_2O (kg CO_2e/kg LW)	Study
Nile tilapia, Bangladesh		
ponds	0.190	This study, EF=0.71%
ponds	0.482	This study, EF=1.8%
Nile tilapia, Thailand		
ponds	0.248	Henriksson *et al.* (2014a)*
intensive cages	0.400	Henriksson *et al.* (2014a)*
Major carps, India		
ponds	0.198	This study, EF=0.71%
ponds	0.503	This study, EF=1.8%
Striped catfish, Viet Nam		
ponds	0.173	This study, EF=0.71%
ponds	0.438	This study, EF=1.8%
small farms	0.347	Henriksson *et al.* (2014a)*
medium farms	0.353	Henriksson *et al.* (2014a)*
large farms	0.299	Henriksson *et al.* (2014a)*

Notes: *The results in Henriksson et al. (2014a) are expressed per kg of frozen edible yield, which should, when using mass allocation, be the same as when expressed per kg of LW.

The nutrient use efficiency determined in the present study (Table 20) was consistent with Hu *et al.* (2012), who found that “Results from a variety of aquaculture systems indicated that, on average 25 percent (range: 11–36 percent) of the nitrogen consumed can be converted to fish biomass”.

TABLE 20
Nutrient use efficiency (%) calculated using the results in the survey

	Nile tilapia	Major carps	Striped catfish
Average	22	33	34
Minimum	20	26	34
Maximum	24	40	35

NUE = kg N out (fish protein): kg N in (feed, manure and synthetic fertiliser)

4.9 EMISSIONS ARISING FROM LAND USE CHANGE (LUC)

The method used to quantify emissions arising from land use change (LUC) can lead to marked variations in the total emissions intensity that is determined (see Figure 7). The five methods used in the present study are summarised in Table 21 below; for further explanation, see MacLeod *et al.* (2013) and Vellinga *et al.* (2013). The effects of the methods on the feed material EI at PoP are shown in Table 22.

The FeedPrint area method (method 1) allocates LUC emissions to all crops, so there is little difference between the emissions per kg of DM between feed materials, (although the emissions will be inversely proportional to the yield per hectare, so rations based on higher yielding crops will have lower EI than lower yielding ones. Under the other four methods, LUC emissions are allocated to soy only. Methods 2-4 only allocate LUC emissions to soy imported from countries that have undergone

TABLE 21
Summary of the five methods used to quantify emissions from LUC

	Method	Summary
1	FeedPrint area	Total agricultural LUC emissions allocated to all crops (not just soy)
	GLEAM	
2	default	LUC emissions in Brazil and Argentina from 1990–2006 allocated to soy imported from these countries
3	reduced time frame	As per 2, but for 2002 – 2007
4	PAS 2050	As per 1–3, allocates LUC to soy grown within a country, but uses a different approach to determining rates and drivers of LUC
5	One Soy	Allocated all LUC from soy to all traded soy

significant recent LUC driven by soy area expansion, i.e. Brazil and Argentina. Using methods 2–4, only striped catfish in Viet Nam receives LUC emissions, due to the importation of soymeal from Argentina. These emissions are particularly high under the PAS 2050 method, which has a high EF for Argentina. Using the One-Soy approach, LUC emissions are allocated to all imported soy, which means that striped catfish in Viet Nam receives LUC emissions (arising from the importation of soy from Argentina and the United States of America), while Nile tilapia in Bangladesh receive the LUC emissions due to the importation of soy from the United States of America.

In summary, LUC emissions can make a marked difference to the total EI of fish produced, depending on the method used to quantify the emissions and the assumptions about where the soy is produced.

TABLE 22
Calculation of feed material EI (g/kg DM at PoP) using six different methods for quantifying from LUC induced by soy cultivation

Country	Feed	No LUC	FeedPrint area	GLEAM default	GLEAM reduced time-frame	GLEAM PAS 2050	GLEAM One Soy	Soybean/ soybean meal in the ration %
		EI (g/kg DM at PoP)						
Bangladesh								
	Ration 1: tilapia nursery	510	685	510	510	510	1 351	30
	Ration 2: tilapia starter	521	693	521	521	521	1 209	26
	Ration 3: tilapia grower	519	675	519	519	519	902	18
	Ration 4: tilapia finisher	476	616	476	476	476	742	17
India								
	Ration 9: carp nursery	713	926	713	713	713	713	34
	Ration 10: carp starter	675	873	675	675	675	675	28
	Ration 11: carp grower	662	852	662	662	662	662	26
Viet Nam								
	Ration 5: catfish	518	670	744	601	1 545	1 440	26
	Ration 6: catfish	454	620	633	519	1 266	1 312	24

Note: The percent of soybean/soybean meal in each ration is given in the right hand column. The proportions of each feed material are defined in Appendix 8.

5. Discussion

5.1 COMPARING SURVEY RESULTS WITH OTHER STUDIES

The number of feed mills and farms included in the survey was small compared to the total number in each of the three countries. To place the survey findings in context, a brief comparison is now presented of the current field survey data with that from the published literature.

5.1.1 Bangladesh: Nile tilapia

Pond-based aquaculture is the most common method of farming tilapia in Bangladesh, although some cage culture has been tested (Hussain, 2009; Baqui and Bhujel, 2011), with the market size being 150 g to 300 g. The current survey showed that the average weight at harvest is 300 g, however some larger fish up to 750 g are also being harvested.

Feed production and management

No published data could be found on raw materials and formulations for tilapia feed in Bangladesh. However, the data from the current survey are similar to those for tilapia feeds used in Viet Nam (Robb pers. obs.). According to Baqui and Bhujel (2011), floating feed was first introduced to Bangladesh in 2006. The present survey showed that 60 – 80 percent of farms use only commercial feed (mixture of floating and sinking pellets), with another 20 – 40 percent using a mix of commercial and farm-made feeds – a rapid adoption of the floating feeds by the farmers.

Feed conversion

In the current survey, the average eFCR was 1.59 (Table 12). If the eFCR is calculated for only the farms using commercial feeds, the value drops to 1.47. Recent data on tilapia farming in Bangladesh proved difficult to find. Several comparisons can be made with similar tilapia production elsewhere in Asia: (i) an average eFCR of 1.36 was reported by farmers, and recalculated as 1.27, for pond culture in Thailand (Henriksson *et al.*, 2014b); (ii) an average eFCR of 1.70 was determined for tilapia in pond culture in China (polyculture of tilapia with carp), with large variations between provinces (Henriksson *et al.*, 2014b), (iii) an eFCR of 1.40 to 1.80 for tilapia raised in monoculture in cages in Thailand (Bhujel, 2013); and (iv) a markedly lower eFCR (0.60) for tilapia raised in pond culture (Bhujel, 2013), the lower value being due to the heavy use of fertilisers to promote natural growth of feed.

On-farm energy use

According to the present study, most of the on-farm energy is used for pumping water. The ponds in Bangladesh are often situated on land above the height of the river that supplies their water. With seasonal fluctuations in river height, the energy required to pump water up to the fish ponds is high. The rates of energy use in tilapia and carp ponds reported in this study are similar, but markedly lower than the rates reported for pond tilapia in Henriksson *et al.* (2014b) and Pelletier and Tyedmers (2010) (Table 17). Further investigation is required to determine the cause of this discrepancy.

Conclusion

The data collected in the current survey are comparable with data from other countries' tilapia production in ponds. However, there is scope to make a broader survey of

tilapia farming in Bangladesh to check the on-farm energy consumption, expand the available data, and bring them up to date with current practices.

5.1.2 India: major carps

Andhra Pradesh, a major state for aquaculture of major carps in India, was previously reviewed with respect to feeding and feed management by Ramakrishna *et al.* (2013), using data collected in 2009 and 2010. They reported that the main districts in Andhra Pradesh for farming of major carps were Nellore, Krishna, West Godavari and East Godavari, overlapping the areas considered in the current survey.

Feed production and management

An important difference between the results of the current survey and those of the previous study is the recent increased use of commercial feeds by farmers, and the decreased use of mashes. The 2009 – 2010 survey (Ramakrishna *et al.*, 2013) found that only 1.3 percent of farms used only commercial feeds, and 23 percent of farms used some commercial feeds to supplement farm-made feeds. In contrast, the present survey conducted in 2014 found that 8 of 12 farms (66 percent) were using only commercial pellets (with no use of farm-made feeds).

The present study reported that none of the 12 farms were using only mashes or farm-made feeds. This is in marked contrast to the 65 percent of farms using only mashes or farm-made feeds reported by Ramakrishna *et al.* (2013); such use was a mix of farm-made feeds or mashes, supplemented with commercial pellets at between 16 and 52 percent of the total. The increase in the use of commercial feeds in Andhra Pradesh in recent years is marked, and it will be important to see how representative this is of changes across the whole country.

In the 2009 – 2010 survey by Ramakrishna *et al.* (2013), concerns about quality issues with feed raw materials were reported by the farmers. Thus, a move to higher quality pellets was expected. A secondary reason for the change to pellets may be to minimise losses of feed; in 2009 – 2010, most farmers reported losing between 1 percent and 10 percent of their feed on farm, through a variety of causes.

Mashes and farm-made feeds in the current survey depended on de-oiled rice bran and groundnut oil cake, consistent with Ramakrishna *et al.* (2013), although they also reported that cottonseed cake and raw rice bran were used as secondary ingredients. By contrast, the commercial feed mills use a much broader spread of raw materials, which may still include de-oiled rice bran, and to a lesser extent the groundnut oil cake. In culture of major carps in Bangladesh, Sarder (2013) reported a wider range of ingredients for farm-made feeds, including wheat, mustard oil cake, rice bran, fishmeal and corn flour, depending on the location of the farm and the locally available resources.

Feed conversion

It is likely that the switch from farm-made feeds to commercially manufactured pelleted feeds led to the marked decrease in eFCR from 2.3 – 4.1 in 2009 – 2010 (Ramakrishna *et al.* 2013), to the average of 1.80 in 2014 that is now reported.

The maximum eFCR reported in the present study was 5.00, on a farm using 84 percent farm-made feeds (only de-oiled rice bran as a mash). If the farms using farm-made feeds were excluded from calculations of eFCR, the average eFCR for major carps was 1.47, clearly showing the improvement in nutrition provided by commercial feeds compared to farm-made feed (i.e., mashes).

Manure and fertiliser types in the present survey were similar to those previously documented by Ramakrishna *et al.* (2013) for major carps in India, and for major carps in Bangladesh by Sarder (2013). The wide range in doses observed in 2009 – 2010 was still found in 2014, highlighting the need for clear recommendations on appropriate use of these materials to promote natural food growth in the ponds.

On-farm energy use

On-farm energy use was not reported by Ramakrishna *et al.* (2013), nor could data be found in other publications.

A high rate of fuel consumption, particularly of diesel, was observed in the current survey. Energy audits may be an appropriate way of clarifying why, and how, energy is used, and to identify opportunities to improve energy efficiency.

Conclusion

It appears that the limited sample of feed mills and farms in the present survey can be considered representative of the industry in Andhra Pradesh. It is important to note the apparent progression towards the sole use of commercially made pellets; this should be confirmed by a broader survey.

5.1.3 Viet Nam: striped catfish

The production of striped catfish in Viet Nam is concentrated in the Mekong Delta (De Silva and Phuong, 2011), where the current survey was focussed, and is based entirely on pond culture. The farm size and area, and pond depth (3.5 to 4.5 m for most farms), currently reported are similar to those reported by Phan *et al.* (2009). The current survey reported a stock weight for fingerlings of approximately 20 g, and a harvest weight of 750 g to 1 000 g, consistent with Phan *et al*. (2009).

Pond preparation treatments, such as liming or chlorination, were reported by Bosma *et al*. (2009) and Phan *et al*. (2009), however they were not covered in the current survey, as it was considered that the GHG emissions arising from these activities would be relatively small. Pond preparation could be included in subsequent work.

Feed production and management

Floating extruded feeds were introduced in Viet Nam the late 1990's, and as in India, these commercial feeds have largely replaced farm-made feeds. In the present survey, all striped catfish farms in Viet Nam used commercial feeds. Phan *et al.* (2009) reported that although 97 percent of farms used commercially made feeds, 37 percent of the farms used farm-made feeds as a top-up, and in times of economic pressure.

In the current survey, the feed used for the grow-out of striped catfish was slightly different to that reported by Bosma *et al.* (2009). Farmers now use 22 or 26 percent protein feed for the largest fish, in contrast to the 18 percent protein feed used previously. Small fish are now raised on higher protein diets for longer duration, using 28 percent protein to 200 g compare to 26 percent protein feed used for similar sized fish as reported by Bosma *et al.* (2009). Although the feed ingredients and sources reported in the present study are similar to those reported by Bosma *et al*. (2009, 2011), there are marked changes in formulations between these studies. Most notable is the decrease in fishmeal, which ranged from 8 – 26 percent in the past, to current rates of 4 – 6 percent (if it is used at all). This decrease has been balanced by the increased use of animal by-product meals.

Feed conversion

The FCR for striped catfish farmed in Viet Nam has remained relatively consistent over recent years. The current survey showed an average of 1.69, which was similar to that reported by Henriksson *et al*. (2014b) of 1.64 to 1.70 (depending on farm size), and Phan *et al*. (2009) of 1.69 for commercial pellets (farm-made feed had an average FCR of 2.25). These studies all reported FCR values markedly lower than the 1.86 reported by Bosma *et al.* (2011), even though Bosma *et al*. excluded the use of farm-made feed from their study.

On-farm energy use

The on-farm energy use reported in the present study is lower than that reported by Bosma *et al.* (2009) and Henriksson *et al.* (2014b) (Table 17). However, it should be noted that Henriksson *et al.* (2014b) reported that energy varied considerably between striped catfish systems in Viet Nam, probably due to variation in the extent to which energy was used for water exchange.

Conclusion

Comparing the current survey with previous reports shows that the current data is representative of the striped catfish industry in the Mekong Delta of Viet Nam. It is apparent that farm-made feeds have been almost completely phased out since the previous work.

5.2 RESULTS OF THE LIFE CYCLE ANALYSIS OF AQUACULTURE PRODUCTION

The average EI for Nile tilapia, Indian major carps and striped catfish at the farm gate was 1.58, 1.84 and 1.37 kg CO_2e/kg live weight respectively (Table 23). The tilapia results for this study are similar to those reported in Pelletier and Tyedmers (2010). No previously published data could be found on the EI of major carps, thus no comparisons are possible. The EI for striped catfish in Bosma *et al.* (2009) is higher than the value of 1.37 in the present study, because most of the rations they studied had markedly higher feed EI, (EIs in excess of 2.00 kg CO_2e/kg feed). Only one of their seven rations has an EI similar to the present study, and the EI of the fish with this similar ration (2.85 kg CO_2e/kg LW) was much closer to the result in the present study. Furthermore, Bosma *et al.* (2009) report an FCR 10 percent higher than the present study, which also contributes to the higher EI. The EI for striped catfish and Nile tilapia results reported in Henriksson *et al.* (2014b) are markedly higher than the current study, however a direct comparison must be approached with caution, as their study had different systems boundaries and functional units.

TABLE 23
Comparison of the EI calculated in the present study and in other studies

Species	System	Country	EI	Functional unit, kg CO_2e per kg of	Study
Nile tilapia					
	Pond	Bangladesh	1.58	LW at farm gate	Present study
	Lake	Indonesia	1.52	LW at farm gate	Pelletier and Tyedmers (2010)
	Pond	Indonesia	2.10	LW at farm gate	Pelletier and Tyedmers (2010)
	Pond	Thailand	10.35	Frozen fillet at import to EU	Henriksson *et al.* (2014a)
Indian major carps					
	Pond	India	1.84	LW at farm gate	Present study
Striped catfish					
	Pond	Viet Nam	1.37	LW at farm gate	Present study
	Pond – small	Viet Nam	8.02	Frozen fillet at import to EU	Henriksson *et al.* (2014a)
	Pond – medium	Viet Nam	7.88	Frozen fillet at import to EU	Henriksson *et al.* (2014a)
	Pond – large	Viet Nam	6.88	Frozen fillet at import to EU	Henriksson *et al.* (2014a)
	Pond[1]	Viet Nam	8.93	LW at farm gate	Bosma *et al.* (2009)
	Pond[2]	Viet Nam	2.85	LW at farm gate	Bosma *et al.* (2009)

Notes: Results for the present study are for an N2O EF of 0.71% and no LUC; [1]on average ration; [2]on low EI ration.

The present results are consistent with other LCA studies in identifying feed as the single biggest source of GHG emissions from cradle to farm-gate. Pond N_2O and CO_2 arising from on-farm energy use were also significant sources of emissions.

The importance of feed emissions means that the EI per tonne of fish is strongly influenced by: (a) the way in which feed materials are produced, (b) the composition of the ration, and (c) the efficiency with which each kg of feed is converted into live weight gain i.e. the eFCR.

Fingerling production was not investigated in detail in the present study. The emissions arising from fingerling production were calculated in a rudimentary way (see Section 4.9), and further data should be collected, to support the calculations for all three species.

5.3 IDENTIFYING MEASURES TO IMPROVE THE EI OF AQUACULTURE

The current small-scale, descriptive study has allowed quantification of emissions and production from three aquaculture systems under current conditions. The results raise the key question of how these emissions might be reduced.

This study adopted a partial life-cycle approach, i.e. it quantified the emissions arising from cradle to farm gate. Adopting such a life-cycle approach allows examination of the whole supply chain, or most of it, when trying to identify areas for improvement. In theory, there is a wide range of measures that could be used to reduce the EI of Asian aquaculture. The challenge is to identify those measures that provide mitigation in ways that are technically effective, economically efficient, and acceptable to producers and consumers.

Although providing a comprehensive review of possible mitigation measures is beyond the scope of this study, some examples are presented below, along with discussion of how the model could be developed to evaluate such mitigation measures.

5.3.1 Reducing emissions from feed material production

The emissions arising from the production of feed materials (not including their subsequent transport and blending) can be reduced by: (a) reducing the EI of individual feed materials, and / or (b) substituting high EI materials for lower EI materials.

There is a wide range of ways in which the emissions from feed material production can be reduced. MacLeod *et al.* (2010) identified 97 measures, such as changing aspects of agronomy and nutrition management, which could reduce on-farm crop and soil emissions. Further reductions may be achieved by reducing the losses of feed material that occur post-production, in storage (particularly in warm, humid climates), processing and transport. However, uptake of these measures is often beyond the control of those directly involved in the aquaculture industry.

Replacing a high EI feed material with a lower EI alternative can reduce the feed emissions. However, this approach raises questions such as: What are the effects of the change in ration on fish performance? Is there adequate supply of the substitute feed material? What does it cost? What would the effect be of changing the ration on the quality and nutritional value of the fish produced? Some classes of feed materials with similar nutritional and emission profiles include materials which are relatively interchangeable, for example carbohydrate-supplying raw materials such as wheat and maize. However there are exceptions, for example maize is not used for striped catfish feeds because of the pigments which are transferred to the flesh. However, in reality, price and availability currently have a much greater influence on feed formulation than does EI.

5.3.2 Reducing feed mill energy use emissions

The survey responses indicated a wide variation in the rates of energy use in feed mills per unit of feed produced. While some variation may be due to differences in the way

energy consumption is recorded, the wide range suggests there is scope for further investigation of the causes of the variation, and thereby identifying ways of improving energy efficiency. Such improvements could be achieved by training operators in more efficient management of the feed mills, by setting and meeting better operating targets, and through the selection of more efficient equipment when establishing or upgrading feed mills.

Substituting high EI fuels for lower EI alternatives could also be used to reduce feed mill energy use emissions. For example, replacing coal with biomass should reduce emissions, but care should be taken to ensure the biomass production is not displacing food/feed crop production, or inducing direct or indirect LUC.

5.3.3 Improving efficiency of feed management and feed conversion

Feed management and feed conversion were recognised as key areas requiring improvement in Asian and African aquaculture (Shipton and Hasan, 2013). There is a strong financial aspect to this, as more efficient use of resources should bring increased profitability. In addition, as feed is the biggest source of GHG, achievements in reducing overall eFCR should have a beneficial impact on reducing the total EI. In recent years, FCR has generally decreased in aquaculture, through improved nutritional knowledge and improved farming methods (Bureau and Hua, 2010). However, more can be done to improve the current commercial situation.

Optimising feeding

Feeding may be made more efficient by identifying and using more appropriate nutritional targets for the species, and using better quality raw materials. However, these changes will also increase the unit price of the feeds, which may make them unaffordable for some farmers.

More nutritional studies are required on the target fish species to support the goals presented by NRC (2012). Such studies would investigate the protein and energy requirements of the fish, and their amino acid needs. Feeding individual amino acids in excess of requirement results in increased NH_3 excretion, whilst under-supply increases the consumption of feed by the fish to achieve the amount required for growth (Bureau and Hua 2010). Field trials of feeds closer to the nutritional goals of the fish are required to quantify the economic and EI impacts of the changes.

Through altering the FCR and reducing waste in the ponds, fish health and performance may improve, so balancing the cost of production. If positive effects are found and are demonstrated to farmers, then practices will change. However, many of the feed mills in Bangladesh, India, and Viet Nam, do not undertake such investigations, and thus are unlikely to initiate these kind of changes.

Improvements in ration formulation can be made by providing training for formulators and other feed mill managers. Updating the companies on the latest knowledge of the nutritional requirements for the species will enable them to choose whether to alter the feed, in decisions driven by market forces.

The use of appropriate feed additives should also be considered. As discussed, many feed raw materials used for the three species in this survey are relatively poorly digested by the fish. In particular, phytate in the raw materials interferes with protein and phosphorus digestion, increasing the feed required to achieve a certain growth. The use of the enzyme phytase to break down the phytate improves nutrient digestibility, and so reduces FCR for tilapia (Cao *et al.*, 2008; Tudkaew *et al.*, 2008), rohu (Baruah *et al*., 2007a) and striped catfish (Debnath *et al.*, 2005).

Feed management

According to the present survey, there were no major losses associated with storage of feed on farms. This was in contrast to the report by Ramakrishna *et al*. (2013) which

discussed the significant impact of poor on-farm storage on the quality of feed in Andhra Pradesh, India.

How the feed is presented to the fish has a large impact on the total eFCR (Rana and Hasan, 2013; Robb *et al.*, 2013). If the feeds are not effectively spread across the ponds, many fish will not eat enough feed to grow efficiently. If insufficient feed is given, fish will eat but will use a greater proportion of the feed for maintenance of energy rather than growth. If too much feed is given, which is rare with floating feeds, but can easily happen with sinking feeds, feed is wasted.

Timing and number of meals per day are also important for each species (Rana and Hasan, 2013; Robb *et al.*, 2013). Fish are mainly fed during the day, when the oxygen content of the water is typically higher than at night. However, feeding late in the day increases the risk that the oxygen content in water will naturally decrease whilst the fish are still trying to digest the feed, making the process less efficient. Fish activity around feeding further decreases the oxygen content in water, again reducing the efficacy of feed digestion and absorption. More training on feed management is required for farm managers and workers, to ensure that the fish are presented with the correct amount of feed at the optimal times.

Water quality

Fish need oxygen to digest the feed efficiently. In ponds, there is often a risk of low oxygen concentrations, especially with striped catfish, where farm water quality is typically very poor (Lefevre *et al.*, 2011). Increasing water exchange or adding aerators to the ponds may help to increase the dissolved oxygen in the water, enabling the feed to be used more efficiently. Depending on the specific measures undertaken, this addition may lead to changes in energy costs and emissions. The costs and net GHG effects of different water quality measures should be investigated to identify the most cost-effective options.

5.3.4 Improving the EI by improving fish health

Fish disease leads to direct farm level losses from mortality, a lowering of the efficiency of the production, and a reduction in output quantity and/or quality. Reducing disease could, in principle, lead to significant reductions in emissions intensity, for example by improving the feed conversion ratio of individual animals, or reducing losses from mortality. Average mortalities on the grow-out farms rates reported in this study were 12 percent for tilapia in Bangladesh, 2 percent for major carps in India, and 20 percent for catfish in Viet Nam. The lower mortality for major carps is partly due to the larger size of the fingerling when they are brought onto the grow out farm.

Improved fish health could be realised through better water quality management, more nutritious feed, appropriate fish stocking densities, as well as through implementation of effective biosecurity measures and appropriate use of medicines. Although the inter-relationship between these factors is obvious, the optimal points are not yet defined or communicated to the farmers.

5.3.5 Reducing on-farm N_2O

The N_2O emissions from ponds can be reduced by either reducing the amount of N available for conversion to N_2O, and/or reducing the rate at which the surplus N is converted to N_2O.

Reducing surplus N

Improving the overall nutrient use efficiency (NUE) of the system will lead to reduced amounts of surplus N per kg of fish produced (i.e. N inputs not converted into tissue by the fish), which will in turn reduce the N_2O emissions - assuming the rate of conversion of N to N_2O is constant. The NUE could be improved in a number of ways, such as:

- Decreasing the percent of uneaten feed (by manipulating the amount, timing, distribution, particle type and size).
- More closely matching the feed N content to the fish requirements (particularly amino acid content).
- Making the N in the feed more available (for example through the use of phytase).
- Closer matching of synthetic and organic N application to pond requirement.

It has been argued that switching from conventional aquaculture to alternative aquaculture systems, such as those using aquaponics and bioflocs technology, could also reduce N_2O by increasing the amount of N retained in biomass (Hu *et al.*, 2012).

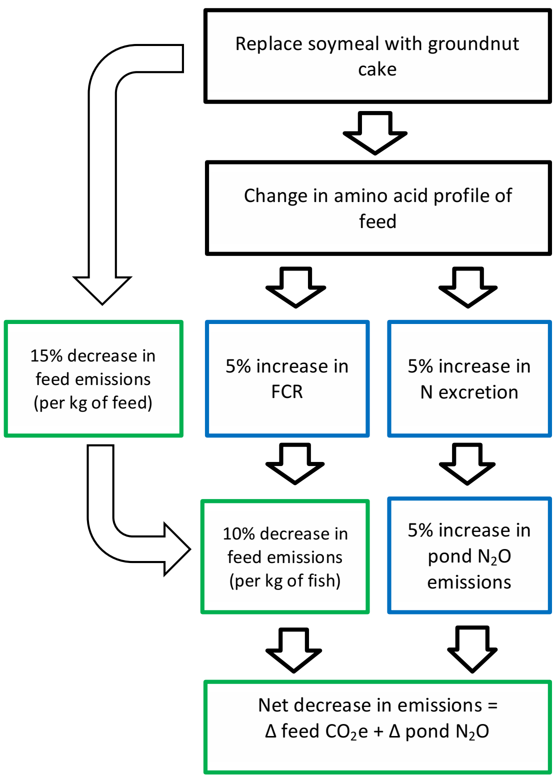
There is also evidence that traditional integrated crop-fish systems have better NUE (Xie *et al.*, 2011) and lower N_2O (and CH_4) emissions than do rice monoculture systems (Yuan *et al.*, 2009). For further discussion of the potential for integrated rice-fish systems, see Miao (2009) and FAO (2012).

Reducing the N_2O EF

The rate at which N is converted to N_2O in the ponds is a function of parameters including concentration of N compounds such as NH_3, dissolved oxygen concentration, pH, water temperature, salinity, concentration of toxic compounds such as H_2S, and the presence of other aquatic organisms. Hu *et al.* (2012) concluded that "the most common method to control N_2O emission from aquaculture is to keep the system under optimal operating conditions, such as appropriate pH and temperature, sufficient DO, good quality feed, etc.". However, Hu *et al.* (2012) also note that further work is required to develop the "comprehensive understanding of the production mechanisms of N_2O in aquaculture systems" required to develop recommendations for N_2O mitigation measures.

FIGURE 8

Systemic effects of replacing a high EI feed material with a low EI feed material (green boxes indicate emission decrease, blue boxes emission increase)

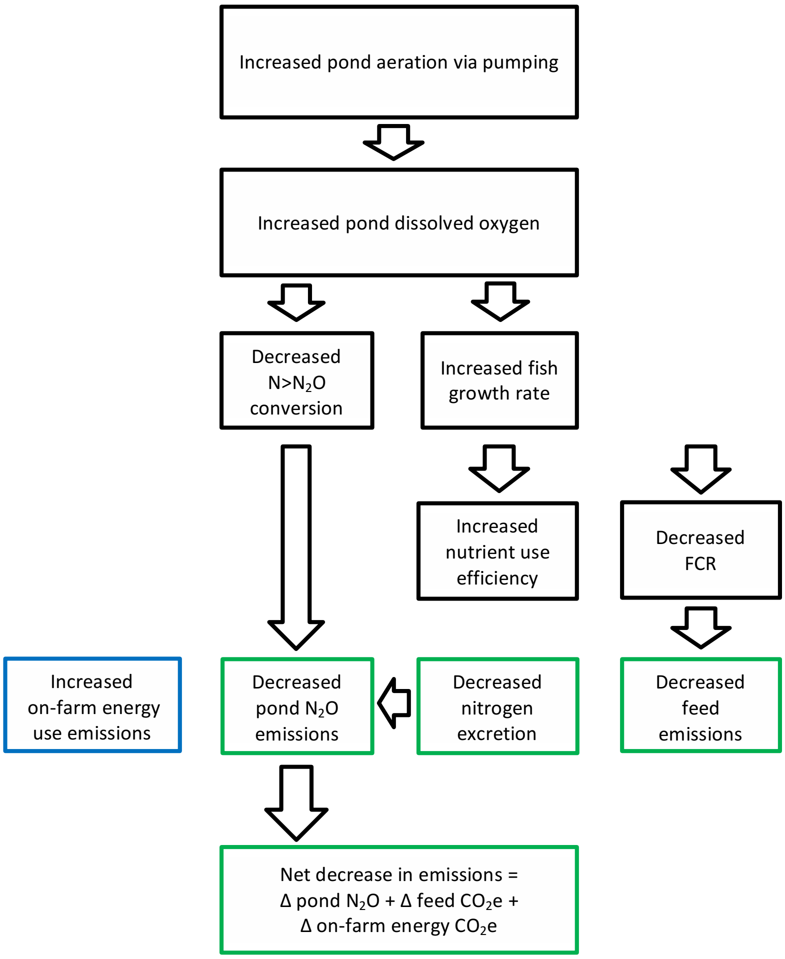


5.4 EVALUATING MEASURES TO IMPROVE THE EI OF AQUACULTURE

To identify the most cost-effective (CE) mitigation measures, it is necessary to quantify: (a) the emission reductions arising from the measures, and (b) the costs of implementing them. The ease with which the CE of a measure can be quantified is partly dependent on the nature of the measure.

Some measures are relatively discrete, which makes quantifying the CE straightforward. For example, the mitigation impact and cost of switching from using coal to gas can be readily quantified using published emission factors and fuel prices. In contrast, many measures can have systemic effects, and/or unintended consequences, and quantification of their CE is more challenging. For example, substituting higher EI feed materials with lower EI feed materials can reduce feed emissions. However, if the substitute feed material has different nutritional properties, these may affect the physical performance of the fish, leading to an increase in FCR and N excretion, and consequent increases in emissions (Figure 8). An additional example of a systemic measure

FIGURE 9
Systemic effects of increasing the pond dissolved oxygen content through increased aeration (green boxes indicate emission decrease, and blue boxes emission increase)



is increased pond aeration, which would decrease the feed emissions and pond N_2O, while increasing the emissions arising from on-farm energy use (Figure 9).

These systemic effects should be taken into account when evaluating the efficacy of alternative measures, although this is often difficult in practice. Models such as the one developed for the present study can help, by allowing comparison of the performance of an aquaculture system with and without a mitigation measure. For example, version 1.1 of the model allows for variation in the FCR, the pond N_2O EF, and the ration composition. While this functionality provides some scope for modelling the effect of mitigation measures, the limitations of the model should be borne in mind. Some of the key links required to determine the systemic effects are not yet included. For example, there is no link between the nutritional value of the ration and the FCR. Given the sensitivity of the overall EI to these parameters, it is important that these are linked in a way that captures the systemic effects of changes in ration composition. Some examples of the extent to which the model could capture the emissions effect of three different mitigation measures are given in Table 24.

For changes to be implemented in the field, there have to be some economic benefits, to the feed mill and/or to the farmer. Therefore, to identify the most cost-effective mitigation options, quantification of the effects on emissions and costs of implementation is required. Cost-effectiveness analysis is especially important for striped catfish, where the low market price has already made farmers struggle to continue in business.

TABLE 24
Examples of the extent to which three different GHG mitigation measures could be captured with v1.1 of the model

Mitigation measure	Modelled the measure with v1.1
Changing fuel in feed mill	Yes, by changing the energy EF. Model would need to account for potential (food) displacement effects of bioenergy or induced LUC.
Changing ration composition	Potentially can be modelled, provided a link can be made between ration composition and fish performance. For optimization, more information is needed on raw material prices and nutritional properties, especially digestibility.
Improved aeration	Potentially can be modelled, but challenging to do so. Knowledge is needed of the relationship between [DO] and: (a) fish health and performance, and (b) nitrification/denitrification processes.

5.5 IMPROVING THE QUANTIFICATION OF GHG EMISSIONS IN THE MODEL

In addition to improving the functionality of the model, as discussed above, there is scope for improving the validity of the model results by increasing the number of emission categories included, and refining the emissions calculation methods (Table 25).

TABLE 25
Summary of the priorities for increasing the emission categories included, and for refining the emissions calculation methods

Emission category	Priority for future inclusion or refinement
Pre fish farm	
Feed transport from PoE/PoP to mill	Refinement of domestic road and ship EFs
Feed transport from mill to fish farm	Refinement of domestic road and ship EFs
On fish farm	
Hatcheries/nurseries	Potentially significant – refine method
On-farm energy use	Investigate the marked difference between the energy use in this study and other studies.
Fish health and mortalities	These can have a significant influence on EI, so refine the model to reflect different health status.
Direct and indirect N_2O from surplus N	Pond N_2O EF is important and requires further investigation, specifically improved nutrient budgeting and refined N_2O EF.
LUC from pond construction*	Complex, but should be quantified if the pond was constructed within 20 years, see BSI (2012, p26)
C sequestration in pond sediments*	Potentially significant. Include once there is greater certainty on the net sequestration rates. Also investigate practicality of achieving this and growing the fish healthily.
Post fish farm	
Live animals and products to slaughter and processing plant*	Not a major source of emissions, but boat transport in Viet Nam requires clarification.
Fish and processed products to retail point (including chilling)*	Refine EFs, particularly where chilled transport is used.
Energy use and coolants*	Could make a significant impact on the emissions intensity of the consumed product due to refrigeration
Packaging*	Packaging unlikely to be a significant source of emissions, but can influence retail and post-retail loss rates.

Notes: Please see Appendix 9 for more discussion of this subject; Emission categories marked * are not included in the results reported in this study.

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Appendixes

Feed storage in an industrial feed mill, Bhaluka, Bangladesh
(courtesy of FAO/Mohammad R. Hasan)

Appendix 1.

APPENDIX 1A. RAW MATERIAL QUESTIONNAIRE

Raw material questionnaire: please fill in the white boxes

Feed Mill Name:		Date:	
Address:		Notes:	

	Raw material			Transport						
				Please provide as much information as possible - names of cities and ports are acceptable if distances are not known						
				Volume normally transported per order (tonne)	Truck journeys		Rail journeys		Ship journeys	
	Name	Origin			1	2	1	2	1	2
Example 1	Soybean meal	Argentina		300	500 km from farm to Buenos Aires port	80 km from HCMC port to factory	0 km	0 km	Buenos Airies port to HCMC port, Viet nam	0 km
Example 2	Soybean meal	USA		500	50 km from farm to Chicago	0 km	0 km	0 km	Chicago to HCMC port	80 km from HCMC port to factory
Example 3	Fishmeal	Viet Nam		50	140 km from port to factory	0 km	0 km	0 km	0 km	0 km
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										

APPENDIX 1B. FEED MILL QUESTIONNAIRE

Feed mill questionnaire: please fill in the white boxes

Feed mill name:		Date:	

Address:		Notes:

FMQ1: General information

1,1	Total feed produced per year (tonne)	
1,2	Number of feed products	

FMQ2: Feed mill energy use

Please indicate which is used and whether the data is per tonne or per year

		Energy source	Approximate energy / year
2,1	Electricity (kWh)		
2,2	Gas (m^3)		
2,3	Fuel oil (kg)		
2,4	Coal (kg)		
2,5	Rice husk (kg)		
2,6	Other (please state)		

FMQ3: Feed packaging use

	Packaging type	Bag size (kg)	Amount used per year (kg)
3,1			
3,2			
3,3			

FMQ4: Formulation - or approximate use of ingredients used

			Feed type 1	Feed type 2	Feed type 3	Feed type 4	Feed type 5
		Feed name					
		Fish species					
		Fish size (g)					
		Pellet size (mm)					
		Protein (%)					
		Oil (%)					
No.	Raw material		% of total	% of total	% of total	% of total	% of total
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Note: The feed mill may not be able or willing to give out the actual formulations, but may agree to show total tonnage of individual raw materials used annually. This will give an average feed formulation. Please then record this and the quantity of each feed type made during that time, including the product characteristics, such as protein, oil and pellet size.

APPENDIX 1C. FEED DISTRIBUTION QUESTIONNAIRE

Feed distribution questionnaire: please fill in the white boxes

Feed mill name:		Date:	

Address:		Notes:	

FDQ1: General information

1,1	Total feed produced per year (tonne)	
1,2	Number of feed products	

FDQ2: Direct sales to customers

	Customer	Journey Information						
		Truck		Boat		Other (specify)		
		Distance (km)	Feed weight (tonne)	Distance (km)	Feed weight (tonne)	Transport type	Distance (km)	Feed weight (tonne)
2,1	1							
2,2	2							
2,3	3							
2,4	4							
2,5	5							
2,6	6							

FDQ3: Sales to customers via traders

	Trader		Journey Information						
			Truck		Boat		Other (Specify)		
			Distance (km)	Feed weight (tonne)	Distance (km)	Feed weight (tonne)	Transport type	Distance (km)	Feed weight (tonne)
3,1	1	Trader:							
3.1.1		Customer 1							
3.1.2		Customer 2							
3.1.3		Customer 3							
3.1.4		Customer 4							
3,2	2	Trader:							
3.2.1		Customer 1							
3.2.2		Customer 2							
3.2.3		Customer 3							
3.2.4		Customer 4							
3,3	3	Trader:							
3.3.1		Customer 1							
3.3.2		Customer 2							
3.3.3		Customer 3							
3.3.4		Customer 4							
3,4	4	Trader:							
3.4.1		Customer 1							
3.4.2		Customer 2							
3.4.3		Customer 3							
3.4.4		Customer 4							

Notes:

APPENDIX 1D. FISH FARM QUESTIONNAIRE

Fish farm questionnaire: please fill in the white boxes

Source of information		Interview date	

FFQ1: Farm Details

1,1	Species (proportions if more than one)	
1,2	Farm location (e.g., address or GPS co-ordinates)	
1,3	Farm size (land and water area)	

FFQ2: Farming method

2,1	Pond	
2,2	Cage in pond	
2,3	Cage in river	
2,4	Cage in lake	

Notes

FFQ3: Pond Details

3,1	If ponds - area of ponds (m^2)	
3.1.1	Depth of ponds (m)	
3.1.2	Number of ponds	
3,2	When were ponds setup?	
3,3	What was previous land use?	
3,4	Are manures used? How much?	
3.5.1	Manure type 1	
3.5.2	Manure type 2	
3.5.3	Manure type 3	

Notes

Please note manure type and amount used/year

FFQ4: Production details

4,1	Fingerling size at input (g)	
4,2	Fish size at harvest (g)	
4,3	Minimum eFCR	
4,4	Average eFCR	
4,5	Maximum eFCR	
4,6	Average survival	

4,7	Average grow-out time (days)	
4,8	Total harvest per year (tonne)	
4,9	Total feed per year (tonne)	

Notes

FFQ5: Energy use

5,1	Are machines used?	
5,2	Diesel (litres/tonne of fish)	
5,3	Petrol (litres / tonne of fish)	
5,4	Electricity (kWh / tonne of fish)	

Notes

Please note uses of energy and splits
e.g., pumping, lighting, etc.

FFQ6: Feed Type

6,1	Farm-made (%)	
6,2	Commercial (%)	
6,3	Name of Commercial Feed Mills	

6,4	Pond fertiliser (kg/yr)	
6,5	Mash (%)	
6,6	Moist pellet (%)	
6,7	Sinking presseed pellet (%)	
6,8	Extruded pellet (%)	
6,9	Extruded floating pellet (%)	

Notes

What type of fertiliser if used and % N, P and K?
If commercial feeds, what are feed names?
If farm-made feed, fill in raw materials sheet

Notes

APPENDIX 1E. FISH MARKET QUESTIONNAIRE

Fish market questionnaire: please fill in the white boxes

Source of information		Date	
Name and location of market			

FMaQ1: Main markets

1,1	Species	
1,2	Domestic (%)	
1,3	Export (%)	
1,4	Live (%)	
1,5	Whole (%)	
1,6	Gutted (%)	
1,7	Filleted (%)	
	If gutted or filleted, what are the yields?	
1,8	Gutted yield (%)	
1,9	Fillet yield (%)	

FMaQ2: Processing details

	Processing energy requirements	
2,1	Processing electrical power (kWh/tonne of whole fish)	
2,2	Waste treatment power (kWh/tonne of whole fish)	
2,3	Refrigeration power (kWh/tonne of whole fish)	
2,4	Freezing power (kWh/tonne of whole fish)	

	Packaging Requirements	Material	Mass (kg/tonne of fish)
2,5	Material 1		
2,6	Material 2		

What happens to the waste? Reject fish, guts, bones, etc.

FMaQ3: Transport method

		Journey 1				Journey 2			
		Departure	Destination	Distance (km)	Mass per load (tonne)	Departure	Destination	Distance (km)	Mass per load (tonne)
3,1	Boat - live haul								
3,2	Truck								
3,3	Refridgerated truck								
3,4	Ship - frozen container								
3,5	Air freight								

Notes

Feeds being loaded on a truck in a feed mill, Andhra Pradesh, India
(courtesy of FAO/Rajendran Suresh)

Appendix 2. Aquaculture life cycle analysis (LCA) model

OVERVIEW

An Excel-based model ("aquaculture LCA model v1.1a") was developed to undertake the analysis. A brief description of each sheet in the model is given in Table A2.1. The main sheet summarises key input: output ratios for the fish farms e.g., the amounts of fingerling, feed, fertiliser, packaging and energy use per kg of LW output. These data are then used to calculate the total inputs, outputs, emissions and emissions intensities (EI) (kg CO_2e/kg output) for the defined level of production. The feed and fish farm surveys reported a range of values for some parameters (such as rates of on-farm energy use or FCR). Thus, the calculations in "Main" sheets were undertaken for three cases, mean EI, low EI, and high EI, for each of the three aquaculture systems.

To perform the calculations, main sheet draws on a series of sub-sheets, which contain information on feed emissions, transport distances and emissions factors, feed mill energy use, packaging, pond N_2O and fingerling emissions. The data in the sub-sheets are primarily based on the surveys undertaken in this project, combined with data taken from other studies and databases (particularly Vellinga *et al.*, 2013, Henriksson *et al.*, 2014a,b and Feedipedia).

TABLE A2.1
Brief descriptions of the sheets in "aquaculture LCA model v1.1a"

Sheet Name	Description
Read me	Changes to the model are recorded in this sheet.
Main sheet	Performs the final calculation of total emissions and emissions intensity.
Constants	List of values for constants, and the sources used to determine them.
Feed	Calculates the emissions, digestible energy and crude protein per kg of feed for each ration.
Feed nutritional values	Inventory of feed material nutritional values.
FeedPrint feed EI	Inventory of feed material emissions extracted (primarily) from the FeedPrint database.
Other EI	Inventory of feed material emissions from other sources.
Transport distances	Inventory of transport distances and modes for feed materials and fish.
Transport EFs	Inventory of emission factors for a range of transport modes.
Feed mill energy use	Inventory of feed mill rates of energy consumption and energy emission factors.
Packaging	Inventory of rates of packaging use for feed and fish, and packaging emission factors.
Fish pond N_2O	Inventory of data required in the calculation of pond N_2O.
Fingerling EF	Calculation of the fingerling emission factors.

CHANGING THE VALUES OF SELECTED PARAMETERS

The current version of the model is essentially descriptive and static. However, to provide some flexibility, controls have been added which allow four key parameters to be varied: (i) annual fish farm production (tonnes LW), (ii) FCR, (iii) pond N_2O emission factor, and (iv) approach used to calculate emissions from land use change (LUC).

Annual fish farm production (t LW)

Annual production can be varied using the controls in cells F7:N7 (Main). Changing production leads to proportionate changes in inputs and outputs.

FCR

The FCR can be varied using the controls in cells F8:N8 (Main). To use the controls, the FCR value in cell C6 (Main) should be set to "specific". When cell C6 is set to "default", the calculations use the default FCR values in cells C5:N5.

Pond N_2O emission factor

The value for this parameter can be set to either 0.71 or 1.80 using the control in cell C7 (main sheet).

Land use change emissions method

One of six different approaches for calculating emissions from land use change (LUC) to crop feed material production, can be selected in cell C8 (Main).

1. No LUC
2. FeedPrint area
3. GLEAM default
4. GLEAM PAS 2050
5. GLEAM One Soy
6. GLEAM reduced time-frame

The region where the soy was grown can affect the LUC emissions, under methods 3, 4 and 6. The proportion of soy sourced from Brazil and Argentina can be defined by entering the percent into cells A44 and A45 (Feed).

Mortality

A control has been included for fish mortality in F9:N9, (Main), though this is not linked to the calculations in v1.1a.

Appendix 3. Collated raw data from feed mills, farms, markets and processors

Raw data collected from feed mills, farms, markets and processors are presented in MS Excel and can be found in the following links:

Feed mill collated data:
www.fao.org/fileadmin/user_upload/affris/docs/Appendix_3.1.xlsx

Farm and market collated data:
www.fao.org/fileadmin/user_upload/affris/docs/Appendix_3.2.xlsx

Transporting feed by a manually driven rickshaw van, Mymensingh, Bangladesh (courtesy of FAO/Nesar Ahmed)

Transporting feed by a van with an engine, Mymensingh, Bangladesh (courtesy of FAO/Nesar Ahmed)

Appendix 4. Survey results

The following sections present the results of the survey, summarising the data collected from the feed mills and farms. This text expands on the information given in Chapter 3 of the main report.

APPENDIX 4.1 AQUACULTURE VALUE CHAINS

The full report of the value chains overview is given in Chapter 3 of the main report.

APPENDIX 4.2 FEED RAW MATERIALS

Feed raw materials for aquaculture can be sourced locally in many countries, and there is a global trade in many suitable alternatives. The choice of raw materials depends on what is available locally (regarding products and quality), compared to the price and relative ease of importation.

Raw materials can be split into four major categories, which are commonly used in formulation:

- Protein sources
- Lipid sources
- Carbohydrate sources
- Micro-ingredients and additives

The ingredients used by the feed mills are shown in Table 5 of the main report. Lipid sources were rarely used for the target species, reflecting the fact that the fish are herbivorous or omnivorous, and can use carbohydrates for energy, which are generally much cheaper than lipid raw materials.

Micro-ingredients were not studied in this survey as their volumes are relatively low, and there are so many types that it was not feasible to evaluate them comprehensively.

Appendix 4.2.1 Protein sources

Raw materials which mainly provide protein are, in this survey, split between animal sources and plant sources for convenience. However, there are also different commercial practicalities involved in the two groups.

Animal protein sources

Fish and fishmeal

Fish proteins are generally very digestible and closely match the amino acid requirements of the species. Therefore, fish-derived products are popular ingredients of aquaculture feeds (Table A4.1). Furthermore, these products provide a distinctive smell that is popular with farmers, and is often considered to add "taste" or "palatability" to the feeds, hence the fish proteins are often termed "attractants" (NRC, 2012).

Wet or dried fish can be minced and added to the feeds. Globally, wet fish are commonly used in farm-made feeds, using fish which are not suitable for direct human consumption. Use of such unprocessed material is considered a clear risk for transmission of disease to the farmed fish, although the processing of the feed through the pellet mill may kill some pathogens. In Bangladesh, three of the feed mills surveyed used dried fish as a source of animal protein, as it is more practical for commercial feed mills than handling wet fish.

Cooked, dried fishmeal are widely used in the manufacture of aquaculture feeds, and about half of the feed mills questioned in this survey used fishmeal in their feeds for the target species. Fishmeal can be prepared from whole fish caught specifically for

this purpose (commonly small fish, not often used for direct human consumption), or from trimmings and waste from commercial fish processing operations. Whilst the use of trimmings and waste provides an excellent use of resources, to reduce the risk of disease or chemical circulation within one system, care needs to be taken to ensure that waste from one farmed species is not fed back to the same species.

Fishmeal are produced in many countries, and are globally traded as commodities. Within Asia, there is significant production of cheap, relatively low quality, fishmeal from fish not considered suitable for human consumption. The meal is normally processed from the whole fish, without pressing out the oil, resulting in a fishmeal, which is lower in protein and higher in oil and ash, than higher quality meals.

Fishmeal processed from trimmings and waste streams tend to be higher in ash and lower in protein than is the case with high quality fishmeal. This difference is due to the relatively low proportion of muscle to bones and oily viscera in the trimming meal.

TABLE A4.1
Type and origin of fish protein products used by feed mills in the survey

Country of feed production	Product type	Country of supply	Source/fish species (if known)
Bangladesh			
	Steam dried fishmeal	Malaysia	Not known
	Fishmeal	Viet Nam	Not known
	Dry fish	Bangladesh	Not known
India			
	Fishmeal	India: Mangalore, Karnataka	Not known, but likely to be Indian sardine
Viet Nam			
	Fishmeal	Viet Nam	Not known, but likely to be a mix of anchoveta species (*Encrashicholina* spp.)
	Fish trimming meal	Viet Nam	Tuna, sardine or striped catfish[1] trimmings

[1]The striped catfish meal was sourced by the company, but not used for feed for striped catfish – it was used for other fish feeds

Meat and bone meal

A waste product of livestock production, meat and bone meal provides a good source of animal protein, together with some ash. This meal is available as high or low fat products, depending on the processing. The meal originates from meat processing units. Once the cuts of muscle and other desirable tissues have been removed, the carcass is ground up to use the remaining nutrients.

European meat and bone meals are generally of porcine origin, due to the regional restrictions on use of ruminant material in meat and bone meal. From other sources though, material from any animal could be used.

The major sources of meat and bone meals are Europe, North America and South America (Table A4.2). In Asia, there is little generation of the material that yields meat and bone meal, because there is relatively little trimming of meat from animal carcasses until they reach the consumer level. However, this survey revealed that some meat and bone meal was sourced from Delhi and Tamil Nadu in India.

Poultry meal

Similar to meat and bone meal, but sourced solely from poultry processing, poultry meal is another good source of highly digestible animal protein. Often, poultry meal is more expensive than meat and bone meal, and provided a higher protein content and improved digestibility. Interestingly, poultry meal was not used in Viet Nam for the

striped catfish feeds, probably because of the marked impact of the raw material costs on the overall feed cost.

Blood meal

Blood meal is another important source of animal protein. This is commonly of porcine origin rather than bovine origin, due to the restrictions on bovine protein products. Well processed blood meal is highly digestible, and is an excellent source of some important amino acids particularly histidine (NRC, 2012). However, blood meal is expensive, and therefore is used at relatively low concentrations in the feed.

TABLE A4.2
Origin of animal meals used by feed mills in this survey

Country of Feed Production	Product Type	Country of Supply
Bangladesh		
	Meat and bone meal	Europe
	Poultry meal	Saudi Arabia
	Single celled protein	United States of America
India		
	Meat and bone meal	India
	Poultry meal	India
Viet Nam		
	Meat and bone meal	Italy
	Blood meal	Italy

Single cell protein

There is a growing international industry in products from single celled organisms, the waste streams of which often include proteins. Whilst the nutritional specifications of such products are good, the price is often high, and therefore their use is frequently restricting to low inclusions. Only one company in the study reported using such a protein source, the company was based in Bangladesh and sourced the single cell protein from the United States of America. Other companies may well use the primary target products of single cell organisms, such as oligosaccharides, but did not report them.

Plant protein sources

Plant protein sources are very abundant and there are several globally traded commodities. Generally, plant proteins are cheaper than animal protein sources. However, plant protein sources are often less digestible than animal sources, and individually their amino acid profiles do not match the fish requirements as closely. However, appropriate blending of plant protein sources can result in a good amino acid profile for the target fish species.

Oilseed meals

Many plants are farmed to produce oils from their seeds, their primary products. After the oils are extracted from the seeds, the remaining materials can be high in protein, and are important feed raw materials (Table A4.3).

Soybean are farmed in very large quantities in United States of America, Argentina and Brazil, and on a smaller scale in Bangladesh, China, and India. Exported whole bean, or ready crushed meal, are sold in many countries, and soybean meal is one of the cheapest sources of protein. Soybean and soybean meal are commonly used in aquaculture feeds; they have a protein content of more than 40 percent after crushing, and an amino acid profile which reasonably approaches the requirements of the fish.

Rapeseed, and its variety canola, are highly valued for their oils and meals. Rapeseed inclusions are usually limited in feed, because of the bitter compounds, particularly erucic acid, that rapeseed contains. In contrast, canola is more flexible, and this variety was bred to reduce the presence of the bitter compounds.

Cottonseed meal is a good source of protein, however it contains the anti-nutritional compound gossypol, and thus only a low percentage of cottonseed meal is included in feeds. However, it is still a useful raw material, because it is relatively cheap due to its limitations. Mustard oil cake also contains increased concentrations of anti-nutritional compounds; erucic acid, tannins and glucosinolates associated with the oily fraction (NRC, 2012), hence the use of de-oiled mustard seed cake as a feed ingredient.

Copra meal, made from coconut husks after oil extraction, is a common form of cheap protein for livestock and fish feeds. The production process carries a risk of mycotoxin contamination, especially with aflatoxins, during sun-drying. This toxicity risk limits the inclusion of copra meal. However, the relatively high fibre content and low protein content make it useful as a protein-carrying filler in formulations. The low price of copra meal in comparison to other oilseed meals means copra meal is a useful ingredient, usually comprising less than 10 percent of the total mix.

Guar meal is the main by-product of guar gum extraction from *Cyamopsis tetragonoloba*. Although relatively rich in protein (approximately 40 percent of dry matter), guar meal also contains many anti-nutritional factors (such as phytate and saponins) limiting its inclusion in the diet.

TABLE A4.3
Product type and country origin of oilseed meals used by feed mills in this survey

Country of Feed Production	Product Type	Country of Supply
Bangladesh		
	Soybean meal (full fat)	Bangladesh, India and United States of America
	Soybean meal (de-oiled)	Bangladesh
	Rapeseed meal	India
	Mustard oil cake	Bangladesh
	Guar meal	India
India		
	Soybean meal	India
	Rapeseed meal	India
	Cottonseed meal	India
	Mustard oil cake	India
	Groundnut oil cake	India
Viet Nam		
	Soybean meal	Argentina and United States of America
	Rapeseed meal	India
	Canola meal	Canada and United Arab Emirates[1]
	Copra meal	Philippines and Indonesia

[1]United Arab Emirates has a large crushing plant for canola seeds imported from Canada, where they are grown. The crushed products (oils and meals) are then exported or used domestically.

Cereal by-product meals

The other plant protein sources used by feed mills in this study were derived from cereals after processing.

After maize is wet milled to produce corn flour for human consumption, one of the by-products is maize gluten meal, which is relatively low in fibre and high in protein

(over 60 percent), making it a very good source of protein for animal and fish feeds. Provided processing is suitable, digestibility of maize gluten meal can be high, making the price high in many cases. It is generally the price of maize meal which limits its inclusions to only the higher protein (hence higher priced) feeds.

An additional cereal by-product meal is dried distillers grains with solubles (DDGS). This material is the main by-product of the distillation of alcohol from either maize or wheat, although the DDGS reported in this survey was only from maize. For both grains, the bran is milled from the grain before it is sent for fermentation, which removes the bulk of the starch. Centrifugation separates the alcohol from the wet grains and some soluble proteins and other compounds: these can be combined and dried to form the DDGS.

A concern with use of DDGS in fish feed has been the common problem of spoilage moulds and the resulting mycotoxins. This problem is attributable to the focus of production being on the quality of the alcohol, not on the protein fraction. Although, historically, there have been significant concerns about mycotoxin risk in DDGS, limiting the inclusions of DDGS in the fish diets, more focus on quality has improved the situation, and the risk of contaminants has been reduced.

Appendix 4.2.2 Carbohydrate sources

Carbohydrate is an important dietary source of energy for the three species of fish studied. Furthermore, raw materials supplying carbohydrates were much more common than raw materials supplying oil, since the latter is a more expensive way of providing energy in the diet.

Cereal products

The global trade in cereals supports the use of cereals in feeds as a relatively cheap source of carbohydrates (Table A4.4). The grade of cereal used in fish feed is generally of lower quality, and therefore cheaper price, than that for human consumption.

TABLE A4.4

Product type and country of origin of carbohydrate source raw materials used by feed mills in this survey

Country of Feed Production	Product Type	Country of Supply
Bangladesh		
	Maize	Bangladesh
	Rice products	Bangladesh
	Wheat products	Bangladesh
India		
	Maize	India
	Rice products	India
	Wheat products	India
Viet Nam		
	Cassava	Viet Nam
	Rice products	Viet Nam
	Wheat products	Australia, European Union

Rice

Rice products were commonly used by the feed mills in all three countries, each of which are significant producers of rice. Rice milling creates a large amount of by-products, with the following estimated proportions: hulls 20 percent, bran 10 percent, polish 3 percent, broken rice 1 – 17 percent, and polished rice 50 – 66 percent (Feedipedia, 2014).

Rice bran is a useful source of protein, oil and carbohydrate, although the oil can quickly become rancid after processing due to the presence of a lipolytic enzyme, activated when the bran is extracted. This limitation led to the development of defatted, or de-oiled rice bran, where the oil is extracted, leaving the low fat raw material. Rice bran has hulls added to it by the producer, diluting the product, and increasing the fibre content. This process can be detrimental to the digestibility of the raw material, and concerns over this have led to a limit of between 10 and 15 percent of rice bran in the diet. Rice bran also contains phytate, which has anti-nutritional effects in the feed, also limiting the desired inclusion rate.

Rice polish are extracted after the bulk of the bran has been removed, depending on the degree of polish required on the end product. This fraction contains the endosperm, with higher concentrations of starch than in the bran.

Broken rice was only reported as a raw material for feed in India in this survey. This by-product consists of the broken grains and dust left over at the end of the process. Larger particles of broken rice grains may go to human consumption, depending on the grade of rice to be sold, whereas the volume of small particles makes a useful feed raw material.

Wheat

Wheat products were widely used in Bangladesh and Viet Nam according to the survey, only one mill in Viet Nam did not use wheat products. Although whole wheat is commonly used elsewhere in aquaculture feeds, all of the surveyed five mills in Bangladesh used wheat flour, and four of the five surveyed mills in Viet Nam used wheat bran. Bangladeshi mills used domestically produced and milled wheat, whilst Viet Nam imported wheat from Europe, India and Australia, with some further processing in Viet Nam to make wheat bran. India did not report the use of any wheat or wheat products in feed in this survey.

Maize

Maize was used in Bangladesh and India for feeds for the tilapia and major carps respectively. Consumers in some countries like tilapia meat to have a yellowish colour, so maize is included in tilapia feeds as the yellow pigments in the grains are taken up by the fish, and deposited in the flesh. With carp, the colour of the fillet is less important, especially as the bulk of the fish are sold whole.

Maize was not used in Viet Nam striped catfish aquaculture, as the yellow pigments in the grains can be taken up by the fish and deposited in the flesh. As the quality criteria for striped catfish are based on a white fillet, such colouration would downgrade the meat. Instead, Vietnamese feed producers for the striped catfish industry use wheat, rice or cassava products as the main sources of carbohydrates.

Cassava

Commonly grown in Viet Nam, cassava is a cheap, rich source of carbohydrates, and is used in the feed for the striped catfish. There is much discussion about the requirement to skin the material, which can contain toxins in the skin, but materials are used skin-on and skin-off depending on the buyers' demands. Cassava is very seasonal, with only one crop per year. Drying the crop effectively before storage is essential to prevent mould growth, which can ruin the remainder of the crop. Whilst no evidence of mycotoxins has yet been found on cassava, the moulds obviously reduce the calorific value of the material and are undesirable.

It is not clear why cassava is not used for feeds in India and Bangladesh, as it is grown in these countries (FAO, 2004).

Molasses

Used by only one feed mill in Bangladesh, molasses is added to feeds to attract fish (the smell and colour are clear indicators to the farmers). The molasses used by this feed mill was made from sugar cane produced in Bangladesh.

Appendix 4.2.3 Lipid sources

The three fish species investigated in this project require relatively little lipid in their diets, because they can use carbohydrates for energy. Most of the limited lipid they require is supplied by the low concentrations of lipids in the bulk raw materials. However, in India three of the mills used some extra sources of lipid, namely fish oil and poultry fat.

Fish oil

Fish oil is extracted from fish at the same time as making fishmeal. The fish oil is a good source of n-3 HUFAs, which are important for nutrition for many juvenile fish, and it provides a smell to the feed. Although the smell is favoured by the farmers, there are questions about whether it acts as an attractant to fish which tend to eat rapidly.

Fish oil was only used in India, by two feed mills. The range of use was from one to 10 percent of the diet, with higher content in the fingerling diets. The higher percentage use was surprising, as fish oil is an expensive commodity.

Poultry fat

A by-product of the poultry industry, poultry fat is globally traded. However, the single feed mill using poultry fat in the study was in India, and sourced the poultry fat locally within Andhra Pradesh. Poultry fat is a good source of cheap lipids, tends to contain less saturated fat than does fat from bovine or porcine sources, and has a fatty acid profile that follows that of the poultry feed the birds received. In the present survey, poultry fat was used at only one percent of the diet, providing an inexpensive energy supplement.

Appendix 4.2.4 Other ingredients

A wide range of other ingredients and additives are promoted in the three countries for use in feeds. In most cases, the feed mills view the mix of additives they use as their proprietary knowledge, carefully guarding this to gain an edge in the markets. Although some of the other ingredients and additives were listed by the mills in this survey, the details were scarce. Nonetheless, theses inclusions would be at very low percentages in the feed, and thus they are considered to have a low impact on the GHG emissions associated with the feeds.

Salt

Natural salt (NaCl) is often added to aquaculture feeds, especially for freshwater fish which tend to loose salts due to osmosis. Normally salt is added at 1 to 2 percent of the diet. There is evidence that it can improve growth rates in freshwater fish (NRC, 2012). However, only one feed mill in the present survey reported using it.

Vitamin and mineral premixes

Vitamins and minerals are essential additions to most feed mixes, promoting the healthy growth of fish, especially the juveniles and broodstock. Details of the mix of vitamins and minerals are normally proprietary knowledge for the feed mills, although several suppliers of these products also make generic mixes to buy off the shelf. Many products are normally blended together in such mixes, sourced by the supplier from many different sources, thus making it hard to determine the impact of these products on the GHG emissions.

The efficacy of the vitamin and mineral mixes depends very much on the supplier. For example, many of the products degrade with time and poor storage. Furthermore, adulteration of feed ingredients, such as using citric acid instead of vitamin C to achieve a similar taste, may occur when selling such products to small feed mills and farmers, who do not buy directly from the supplier. Such poor quality products will not give as good a fish performance as could be expected with a good formulation.

Use of vitamin and mineral premixes were only reported by Vietnamese feed mills. However, such products were probably also used in Bangladesh and India, since the sum of declared ingredients reported from their feed other mills was less than 100 percent, (indicating that there were other ingredients). However, the inclusion of vitamin and minerals was normally less than four percent of the total feed, thus their likely contribution to the GHG emissions associated with the feed would be correspondingly small.

Appendix 4.2.5 Raw material transport

In countries with extensive agricultural production, for example Bangladesh, India and Viet Nam, local raw materials offer good value and availability to feed mills. Each of the three target countries in this survey have access to a wide variety of local raw materials. These local sourced raw materials require different transport methods to that for international freight.

As has already been discussed, raw materials are also globally traded. Local transport is typically also required for internationally sourced raw materials, to convey them between the point of import and the feed mill.

Lorry freight

The bulk of goods covered in this survey were transported by lorry at some point, from the point of production or import to the factory. The size of the lorries varied from 15 to 30 tonnes between the countries, depending on the supplier and the local regulations and availability.

Boat freight

Bulk freighters and container vessels are used to move large quantities of goods around the world. Commodity crops, such as wheat, maize and soybeans are often carried in bulk vessels. In this survey, the goods are typically unloaded at the point of importation, and loaded onto local trucks for distribution to the feed mills.

Viet Nam made the greatest use of sea freight, especially to import feed materials used as protein sources, as the only significant local source of protein is fishmeal.

One feed mill in Viet Nam made use of small boat freight to bring materials from the main point of import to the factory, for goods such as soybean meal, copra meal, and meat and bone meal. Rice bran, produced in the Mekong Delta, was also transported by small boats to this company from the rice processing companies, which normally have their own small quays for loading boats in this region of Viet Nam.

Rail freight

Rail freight was only reported from India in this survey. In India, rail freight was used for movement of goods from Rajasthan (de-oiled mustard cake and rapeseed meal) and West Bengal (de-oiled rice bran), these distances were the greatest for goods moved within India.

In Bangladesh, the mills were not in a region covered by the rail network. In Viet Nam, the survey dealt with mills in the Mekong Delta, where the rail network does not extend.

APPENDIX 4.3 FEED FORMULATION

Feed formulation is carried out to balance the nutritional requirements of the fish, with the nutritional content of the available raw materials, at the best price. Due to analytical constraints, the book values for the nutritional content of the raw materials are often used in feed formulation calculations, even though some of these values may differ significantly from the actual value of the materials used. While some feed mills have their own analytical facilities, (at least for checking the protein, oil and moisture content of the raw materials), other feed mills will rely solely on the information provided by the seller.

The nutritional requirements of the fish can be determined by commercial formulators from available literature or from further research, and from copying the other feed mills' products. However, some of the simple methods of determining the nutritional requirements may focus solely on the protein and energy content of the feed, without considering the amino acid requirements of the fish. This limited approach may increase the FCR of the feeds, as the fish will need to eat more feed to obtain their essential amino acid requirements.

Details of feed formulations are often commercially guarded. For Bangladesh and India, the full formulation were often not given, thus maintaining confidentiality about some of the ingredients used in small quantity, which would be part of the mills' marketing strategy to their customers. Such ingredients are normally used at less than 2 percent of the total. However, in some cases up to 10 percent of the total ingredients were not reported in this survey. For Viet Nam, it was not possible to get details for all feeds from Vietnamese companies. Instead, these companies provided the average total raw material consumption over the year, which equates to an average feed formulation for all sizes of feed made.

The details of the formulation will be discussed country by country below, as they apply to the different fish species. The formulation information provided by the companies was used to estimate the quantity of protein and energy in the diets – including digestible protein and digestible energy. Book values for the raw materials' protein and energy contents and relative digestibilities were used to calculate the digestibility values for each feed (Appendix 4). These values could then be compared to the recommended requirements for each species, with the caveat that not all of the raw materials were reported in the survey, so some nutrients may be under-estimated.

Appendix 4.3.1 Bangladesh

Across the five mills surveyed, 18 different raw materials were reported (Table A4.5). There was a wide range of the percentage of each raw material that was included in the feed. Proteins from animal sources were generally included at lower rates, although in some feeds the inclusion of meat and bone meal and poultry meals were notably high. Meat and bone meal used in Bangladesh and India are of low fat quality while this feed ingredient used in Viet Nam contains high fat. Proteins from plant raw materials were used as much as expected, although some high inclusions of rapeseed meal (29.5 percent) and rice bran (35 percent) were noted, which were higher than expected. The use of wheat flour was more common than that of whole wheat, perhaps reflected the greater availability of the former product and the ease of handling, as the whole wheat would require more grinding.

Abundant information is available on the nutritional requirements of tilapia, including a review by NRC (2012), and many research papers. However, feed manufacturers and farmers often consider as prohibitive, the cost of producing diets matching these nutritional requirements. Therefore, cheaper, lower specification feeds are often produced and used, even though they are less efficient than the optimal feeds.

Among the five feed mills in Bangladesh that were studied in detail, there is considerable variation in the declared protein and oil contents of the feed they

produce (Table A4.6.1). The calculated nutrient contents of the feeds (Table A4.6.2) show even wider variations. The NRC (2012) recommends digestible protein of 29 percent and digestible energy of 14.2 MJ/kg for tilapia over the whole life cycle (a DP/DE of 20.4 g/MJ). Comparing this with the calculated values, whilst protein and energy are supplied below the optimal quantity for growth, the ratio of protein to energy is close to the recommendation, giving a balanced diet.

TABLE A4.5

Inclusion of 18 raw materials, as minimum and maximum percentage, in tilapia feeds from five mills in Bangladesh[1]

Raw Material	Minimum (%)	Maximum (%)	Number of mills using the raw material
Protein (animal sources)			
Dry fish	4.0	10.0	2.0
Fishmeal	6.0	12.0	2.0
Meat and bone meal (low fat)	10.0	22.5	2.0
Poultry meal	4.5	17.5	3.0
Fish protein concentrate (60% protein)	10.0	10.0	1.0
Single cell protein	2.0	2.0	1.0
Protein (plant sources)			
Soybean meal	10.0	35.0	5.0
Soybean meal (full fat)	1.0	5.0	3.0
Rapeseed meal	7.0	29.5	5.0
Guar meal	10.0	12.0	1.0
Mustard oil cake	10.0	12.0	1.0
Carbohydrates			
Rice bran	7.0	35.0	4.0
De-oiled rice bran	6.0	15.0	1.0
Rice polishing	25.0	30.0	1.0
Wheat	6.0	10.0	1.0
Wheat flour	5.0	25.0	5.0
Maize	4.0	15.0	3.0
Molasses	1.5	2.0	1.0

[1]No vitamin and mineral premixes were reported in this survey, although they were used by the feed mills.

TABLE A4.6.1

Declared protein and oil content, and pellet sizes, in tilapia feeds from five mills in Bangladesh

Fish size (g)	Declared protein (%)	Declared oil (%)	Pellet diameter (mm)
1 – 24	32 – 36	6 – 8.25	0.5 – 2.0
25 – 49	30	6 – 8	2.0 – 3.0
50 – 99	28 – 30	6 – 10	2.5 – 4.0
100 to harvest	27 – 29	6 – 10	2.5 – 4.0

TABLE A4.6.2

Calculated protein and energy contents of tilapia feeds from five mills in Bangladesh

Fish size (g)	Crude protein (%)	Digestible protein (%)	GE (MJ/kg)	DE (MJ/kg)	DP/DE (g/MJ)
1 – 24	30.7 – 34.6	25.0 – 29.7	16.1 – 17.5	10.6 – 11.7	22.5 – 25.5
25 – 49	28.7 – 30.4	22.9 – 26.0	16.2 – 16.9	10.3 – 10.7	22.1 – 24.3
50 – 99	25.1 – 30.4	19.5 – 24.7	16.1 – 16.7	9.3 – 10.5	21.1 – 23.6
100 to harvest	25.1 – 29.0	19.0 – 23.4	16.1 – 16.6	9.0 – 10.5	21.1 – 22.2

Notes: GE = gross energy; DE = digestible energy; DP/DE = digestible protein to digestible energy ratio

Appendix 4.3.2 India

A total of 18 raw materials were used by the six feed mills surveyed (Table A4.7). All raw materials were sourced within India, except for one feed mill, which used a 50 percent inclusion of a premix of raw materials from Indonesia. The mix of raw materials in that pre-mix was not shared with the survey, so had to be excluded from the data analysis

Animal protein sources were used at very low levels by four of the mills, the low levels mainly reflecting the higher prices of animal protein compared with plant protein. Soybean meal was the major protein provider, with other plant protein sources typically ranging from 5 to 10 percent of the feed, even up to 15 percent for rapeseed meal. Rice bran and de-oiled rice bran were important ingredients, as by-products of the domestic rice harvests. Maize and broken rice were the main providers of carbohydrates, along with the carbohydrates included in the raw materials of plant origin used primarily as protein source. The use of oils (fish and poultry) by three of the mills was notably different to other mills, especially the high inclusion of up to 10 percent for the smaller fish, which would have resulted in much higher oil content in the feed than declared.

TABLE A4.7
Inclusion of 18 raw materials, as minimum and maximum percentage, in major carp feeds from six mills in India[1]

Raw material	Minimum (%)	Maximum (%)	Number of mills using the raw material
Protein (animal sources)			
Fishmeal	0.5	5.0	3.0
Meat and bone meal (low fat)	5.0	5.0	1.0
Poultry meal	4.0	4.0	1.0
Protein (plant sources)			
Soybean meal	15.0	40.0	6.0
Rapeseed	8.0	15.0	3.0
Cottonseed meal	5.0	10.0	4.0
Mustard oil cake	5.0	8.0	1.0
Mustard cake (de-oiled)	7.0	7.0	1.0
Maize gluten	5.0	7.0	1.0
Groundnut oil cake	3.0	7.0	3.0
DDGS	5.0	10.0	2.0
Carbohydrates			
Rice bran	5.0	15.0	3.0
Rice bran (de-oiled)	8.0	35.0	6.0
Broken rice	4.5	10.0	5.0
Maize	-	15.0	6.0
Lipids			
Fish oil	1.0	10.0	2.0
Poultry fat	1.0	1.0	1.0
Premix			
Premix[2]	50.0	50.0	1.0

[1]Inclusion of vitamin and mineral premixes was not given in this survey and so they are excluded from this table;
[2]Premix of major raw materials, ready mixed in Indonesia and shipped to India.

Among the major carps, the dietary requirements of rohu are probably the best known, and are summarised in NRC (2012) and AFFRIS (www.fao.org/fileadmin/user_upload/affris/docs/Rohu_Labeo/English/table_2.htm). A digestible protein content of 32 percent, and energy of 13.4 MJ/kg are recommended (DP/DE of 23.9 g/MJ).

The declared protein and oil contents of the feeds are shown in Table A4.8.1, whilst the calculated nutritional value of the feeds, based on the formulation data, is given in Table A4.8.2. The digestible protein and energy provisions (Table A4.8.2) are well below the optimal levels recommended by NRC (2012). For some feeds the ratio between DP and DE is similar to the recommendations, thus the balance is maintained. In contrast, other feeds have low DP relative to DE (for example around 18 g/MJ), indicating a low supply of digestible protein.

TABLE A4.8.1

Declared protein and oil content, and pellet sizes, in major carp feeds from six mills in India

Fish size (g)	Crude protein (%)	Crude lipid (%)	Pellet size (diameter in mm)
1- 49	32.0	5.0	2.0 – 4.0
50 – 99	28.0 – 32.0	3.5 – 6.0	3.0 – 4.0
100 - harvest	24.0 – 30.0	3.5 – 5.0	4.0 – 5.0

TABLE A4.8.2

Calculated protein and energy contents of major carp feeds[1] from six mills in India

Fish size (g)	Crude protein (%)	Digestible protein (%)	GE (MJ/kg)	DE (MJ/kg)	DP/DE (g/MJ)
1 – 49	26.8 – 31.3	21.6 – 26.1	16.2 – 18.9	10.2 – 12.9	17.9 – 25.9
50 – 99	25.0 – 31.3	18.1 – 26.1	16.1 – 18.9	8.8 – 12.9	17.9 – 26.9
100 – harvest	23.0 – 28.6	16.0 – 23.1	16.1 – 18.2	7.8 – 11.9	18.9 – 25.3

[1]The feed mill using the 50% inclusion of premix was excluded from this calculation, as the nutritional content of that premix could not be determined.

Notes: GE = gross energy; DE = digestible energy; DP/DE = digestible protein to digestible energy ratio.

Appendix 4.3.3 Viet Nam

Feed mills in Viet Nam reported the use of 14 raw materials (Table A4.9). Meat and bone meal primarily used as protein source comprised between 4 and 11 percent of the feeds, greater than the inclusion of fishmeal, which reflects the importance of these materials. The largest source of protein was soybean meal, comprising 19 – 31 percent of the feeds; other plant proteins were used in the feed from 5 to 15 percent (the latter being canola meal). Although DDGS is a good source of protein, its high price restricted its use for striped catfish feeds.

The main source of carbohydrate in the feed was cassava, which not only provided starch for energy, it also served to bind the pellets. Wheat was not a significant element in the striped catfish feeds, as cassava is locally available and is much cheaper. Quantity of vitamin and mineral premix use was highly variable ranging between 0.5 and 5.0 percent while use of other additives have not been reported in the survey except that one farm reported using 0.5 percent of salt.

The dietary requirements of striped catfish have received relatively little attention to date, and the mills therefore use information for the American channel catfish (*Ictalurus punctatus*) as a guide. The NRC (2012) report indicates that the channel catfish requires 29 percent digestible protein, and 12.6 MJ/kg digestible energy (equating to a DP/DE of 23.0 g/MJ). However, as was the case with supplying feed for the Nile tilapia and major carps, most mills producing feed for the striped catfish focussed on cost control, rather than optimising protein and energy supply for growth. Most feed mills make similar declarations of the nutritional contents for feeds for fingerlings and larger fish. This declaration is driven by Vietnamese law, which dictates the protein and oil contents for different sizes (fry-fingerling, juvenile, grower) of the striped catfish.

Table A4.10.1 shows the declared content of the feeds, as required by law in Viet Nam. These laws define the two main strategies for growth, one using higher

TABLE A4.9
Inclusion of 14 raw materials, as minimum and maximum percentages, in striped catfish feed from five mills in Viet Nam

	Minimum (%)	Maximum (%)	Number of mills using the raw material
Protein (animal sources)			
Fishmeal (55% protein)	4.2	5.9	3.0
Meat and bone meal (high fat)	4.0	11.3	5.0
Protein (plant sources)			
Soybean meal	19.4	31.3	5.0
Rapeseed meal (India)	7.5	7.5	1.0
Canola meal	4.9	15.0	3.0
Copra meal	3.6	9.1	5.0
DDGS	2.5	3.9	3.0
Carbohydrates			
Rice bran	9.7	22.5	5.0
Rice bran (de-oiled)	6.1	9.9	2.0
Wheat bran	2.0	9.9	5.0
Wheat	2.0	4.0	2.0
Cassava	16.5	18.0	5.0
Other ingredients			
Salt	0.5	0.5	1.0
Mineral and vitamin premix	0.5	4.5	5.0

(26 percent) and another using lower (22 percent) protein contents for the main grower phase. The lower protein feeds are cheaper per tonne, but bring a higher FCR, so resulting in more waste.

The feed mills in Viet Nam did not share the formulations for individual feeds during this survey, instead giving total raw material used for the year. Therefore, only the average crude protein, digestible protein, gross energy and digestible energy could be calculated (Table A4.10.2). However, these values are the weighted average over the life of the fish fed these feeds, so are still very relevant. The digestible protein and energy contents reported for the striped catfish are much lower than those required to optimise growth of channel catfish (NRC, 2012). The low protein content in particular creates an unbalanced diet, with much lower protein compared to energy than is recommended.

TABLE A4.10.1
Declared protein and oil content, and pellet size, for striped catfish feeds from five mills in Viet Nam

Fish size (g)	Declared protein (%)	Declared oil (%)	Pellet diameter (mm)
30 – 149	28.0	5.0	1.5 – 4.0
150 - harvest[1]	26.0 – 28.0	5.0 – 6.0	4.0 – 8.0
400 – harvest[2]	22.0	5.0 – 6.0	6 .0– 10.0

[1]Harvest size is about 400 g or less; [2]Harvest size is about 750 g – 1.0 kg.

TABLE A4.10.2
Calculated protein and energy contents of the feeds for striped catfish made in five mills in Viet Nam

Crude protein (%)	Digestible protein (%)	GE (MJ/kg)	DE (MJ/kg)	DP/DE (g/MJ)
24.3 – 27.7	19.7 – 23.1	16.2 – 16.9	10.0 – 11.2	19.8 – 21.7

Notes: These values represent the average values of all the raw materials used by the feed mills over the year, rather than for individual feeds for fish of different sizes as reported for the other countries.

Notes: GE = gross energy; DE = digestible energy; DP/DE = digestible protein to digestible energy ratio.

APPENDIX 4.4 FEED PRODUCTION

A range of aquaculture feed types are used in Asia, from the simple addition of single raw materials directly to the pond, to formulated feeds. Intensive aquaculture relies heavily on complete formulated feeds, supplying all of the nutrition required by the fish. Commercial companies supply feeds made by either steam pelleting or extrusion.

Steam pelleting

For several decades, steam pelleting has been used to make livestock feeds. As aquaculture has intensified, many livestock feed mills have changed their formulations, and make some simple steam pelleted fish feeds. The equipment required for this process is generally cheaper than that required for extrusion pelleting, and it requires less energy. However, steam pelleted cannot be used to make the floating pellets which are often desirable for aquaculture, (as they allow farm staff to see if all feed is eaten, thus reducing waste).

Steam pelleting equipment was reported in this survey from Bangladesh and India, but not from Viet Nam. Although electricity was a major source of energy for running all such mills, a variety of other fuels was used to provide energy for the boiler to produce steam. These other fuels included diesel, fuel oil, gas, rice husk and coal (Table A4.11).

The amount of electricity required to run the mills varied within Bangladesh, from 23.5 to 49.0 kWt/tonne of feed. In contrast, in India, the amounts of electricity were much higher, varying between 110 and 230 kWt/tonne of feed, which raised questions about these mills' energy efficiencies.

TABLE A4.11
Average electricity and fuel requirements for each mill using a steam pelleting machine

	Feed mills					
	Bangladesh				India	
	1	2	3	4	5	6[1]
Electricity kWt/tonne feed						
Electricity	23.5	44.1	36.0	49.0	110.0	230.0
Fuel source for boiler kg/tonne feed						
Diesel	-	4.8	-	4.6	-	-
Fuel oil	6.2[2]	-	-	-	-	-
Gas	-	-	2.7	-	-	-
Rice husk	-	-	-	-	135.0	565.0
Coal	-	-	-	-	-	400.0

Notes: 1 to 4 mills in Bangladesh, 5 and 6 mills in India.

[1]Mill 6 used both an extruder and a steam pelleting machine, but did not separate energy use between the machines; [2]This includes the use of fuel oil to run a generator at the factory (using 2.78 kg/tonne feed).

Extrusion pelleting

By applying more energy to the raw materials, extrusion cooks the starch in the pellets more effectively than steam pelleting, thus greatly expanding the starch. The advantages of this process are the creation of a less dense pellet, which will float, and making the raw materials more digestible. However, extrusion pelleted technology is more expensive and requires more energy than steam pelleting. The high degree of variation in energy consumption by the mills is shown in Table A4.12, and probably indicates different efficiencies in running the mills.

TABLE A4.12
The average electricity and fuel requirements for each mills using extrusion technology

	Mills										
	Bangladesh	India					Viet Nam				
	5	1	2	3	4	6[1]	1	2	3	4	5
Electricity kWh/tonne feed											
Electricity	128.6	100.0	200.0	20.0	110.0	230	92.0	85.4	93.2	91.2	75.2
Fuel source for boiler kg/tonne feed											
Diesel	9.55	0.01	-	-	-	-	-	-	-	-	-
Fuel oil	-	-	-	-	-	-	-	12.7	-	-	-
Furnace oil	68.2	-	-	-	-	-	-	-	-	-	-
Gas	-	-	-	-	-	-	-	-	-	-	-
Rice husk	-	250,0	50.0	70.0	60.0	565.0	146.4	-	-	-	-
Coal	-	-	-	-	-	400.0	-	-	-	-	-
Wood	-	-	-	-	-	-	-	-	87.6	-	-
Briquette[2]	-	-	-	-	-	-	-	-	-	108	85

[1]Mill India 6 used both an extruder and a steam pelleting machine, but did not separate energy use between the machines.

[2]Briquette made of rice husk or wood.

Losses during production

During production, most raw materials are converted into feed. However, this may not happen the first time for all of the raw material. For example, at start-up of a run of feed production, such as at the beginning of the shift, or at a change in feed formulation, the mixed raw materials are fed through the system, but during the first few minutes of production, the system is stabilizing and most of the pellets produced are diverted away from the drier and cooler, sent back to the mixer, and reworked. Similarly, at the end of a run of feed, the last kilograms of feed will not be fully processed into pellets and will be reworked later.

Later on in the production process, after drying and cooling, the pellets are normally passed over sieves to screen out large clumps of material, and remove broken pellets and dust. These materials are collected, and also returned to the process to be reworked, and are often added as a separate raw material category during formulation. Small pellets, less than 3mm, are particularly prone to increased amounts of clumping, breakage and dust, and therefore more rework is seen when making these feeds than when making larger pellets.

The values for rework were reported by each company in Bangladesh and India, but not in Viet Nam, so an approximation was reported (Table A4.13). However, it is clear that the quantity of rework in Viet Nam was much greater than in Bangladesh, which could in part be due to the use of extruders in Viet Nam compared to pellet mills in Bangladesh, and in part due to local requirements for very low dust in the feed bags in Viet Nam, which results in the feed being heavily sieved, with the collected dust sent for rework.

TABLE A4.13
Estimated amount of rework from the feed mills in the three countries surveyed (extrusion and pellet mills combined)

	Bangladesh	India	Viet Nam[1]
Minimum	0.005	1.0	0.50
Average	0.009	1.5	1.55
Maximum	0.010	2.0	2.00

Notes: Data are percentages of total production.
[1]Data for Viet Nam are approximations.

Rework itself does not result in a loss of raw materials, because they are returned to the mix and will eventually be used to make feed. However, the extra processing involved uses energy, which is reported in the total energy use by the feed mill. Reducing rework will reduce the total energy consumption of the mill.

Viet Nam also reported that losses of raw materials are recorded by the feed mills during storage. This loss is a comparison of weight of raw materials delivered to weight of raw materials used. The quantities ranged from 0.4 percent to 1.1 percent, with an average of 0.85 percent over the year. A most likely cause of the loss is the drying of the finished feed to a lower moisture content than the initial raw materials. Other possible causes include drying of raw materials during storage (i.e. loss of moisture); discarding poor quality raw material after storage (for example through development of mould); and losses due to pests and theft. Losses of weight due to loss of moisture during storage would be common in mills where raw materials are stored for a long period of time, which is common for cassava for example, where there is only one crop per year.

Although these losses of raw materials were not reported by the feed mills in Bangladesh and India, they may have been present.

Packaging

Plastic packaging of some kind was used by all feed mills surveyed (Table A14). The common usage of this material reflects that the environments in which the bags of feed are stored are commonly exposed to rain, and will also endure rough handling. Paper bags are not robust enough for these conditions.

The packaging materials used varied between countries, presumably depending on local availability of materials. Bangladesh reported polypropylene bags (PP); India used high density polyethylene (HDPE); Viet Nam used a mix of PP and PE (polyethylene). The quantity of packaging materials per tonne of feed varied between countries – depending on the quality and strength demanded by the mill.

Bag sizes varied with countries, with Bangladesh reporting only 25 kg bags, India mainly used 40 kg bags (one mill had 50 kg bags), and Viet Nam had 15 kg, 25 kg and 40 kg bags.

TABLE A4.14
Summary of feed packaging materials used

	Bangladesh	India	Viet Nam
Material	PP	HDPE	PE and PP
Bag capacity (kg)	25	40, 50	15, 25, 40
Average packing material weight per tonne feed (kg/tonne)	2.93	0.69	4.73

Notes: HDPE = high density polyethylene; PE = polyethylene; PP = polypropylene.

The average weight of packaging material used per tonne of feed varied considerably between countries (Table A14). This variation in part reflects the different strengths of

the bags. However, the value in India is so low, that it is likely that another, unknown, factor is important.

In India, some bags were poorly stitched, which lead to an increased chance of the bags splitting when handled.

APPENDIX 4.5 FEED TRANSPORT

Farms are often located at a considerable distance from the feed mills, and various modes of transport are used to bring the feed to the fish. The modes of transport used reflected the distance between the mills and the farm, the weight of feed to be carried, and also the accessibility of the farms, for example some farms only have boat access.

Bangladesh showed the greatest variety of transport modes, with choice of transport depending on the distance between mill and farm; India relied on trucks, and Viet Nam relied on trucks and boats (Table A4.15). Trucks were typically 15 to 25 tonnes, depending on availability, and on the route to be taken. The boats in Viet Nam ranged from 15 to 120 tonnes capacity for wooden vessels, and 150 to 500 tonnes for steel vessels.

Medium and large farms may buy feed directly from the mills, which will save cost. However, smaller farms may buy through traders, which are closer to the farms. The surveys showed that the use of traders was common in all three countries, and in Bangladesh, there were no direct sales from the feed mills to farmers, everything was sold through traders. Traders sent out small amounts of feed to the farmers in Bangladesh, whereas in India the traders supplied large quantities of feed to individual farmers while in Viet Nam large quantities of feed are supplied by the feed millers/ traders to the individual farms and farms under cooperative under an annual agreement between farmers/cooperatives. In majority of the cases, farmers buy feed from the feed millers on credit and pay the cost after harvest.

TABLE A4.15
Transport methods and maximum capacities reported, together with a summary of the distances travelled by each method

			Transport distance (km)		
Country	Transport method	Maximum capacity (tonne)	Minimum	Average	Maximum
Bangladesh					
	Truck	< 15.0	30	122	450
	Small pickup truck	< 3.00	20	30	45
	Van (with engine)	< 1.00	8	14	25
	Van[1]	< 0.50	5	8	15
	Tempo[2]	< 0.50	5	12	30
	Auto rickshaw	< 0.18	3	6	15
	Rickshaw	< 0.13	5	5	5
India					
	Truck	15 to 18	1	40	350
Viet Nam					
	Truck	< 40.00	1	56	290
	Boat (wood)	< 120.00	1	61	250

[1]Van without an engine are normally manually driven; [2]Tempo is a larger, shared auto-rickshaw, with a cabin in the back and is used in both rural and urban Bangladesh primarily used as a vehicle to transport human and goods.

Data on fuel consumption of the boats in Viet Nam, supplied separately from the questionnaires, as shown in Table A4.16.

TABLE A4.16
Average details for boat types used for transporting feed in Viet Nam, gathered by the country expert

Vessel type	Capacity (tonne)	Speed (km/hour)	Fuel consumption (litre/hour)	Fuel consumption (litre/km)
Wooden	15 – 120	5.0	15.0	2.4
Steel	150 – 500	6.2	10.0	2.0

Source: La Van Chung, personal communication (2014).

Losses in transport

The long transport distances and the tropical climates of the three countries, pose a risk of rain damaging the feed during transport. If the bags get wet, water soaks the feed and there is a risk of mould developing. Further damage or losses can occur through mechanical damage to the bags, such as tears allowing feed to spill, and dropping the bags may break the pellets inside, creating dust.

Feed companies and transporters try to protect against such losses. Transport vehicles are generally covered with tarpaulins, and some types of bags are lined with a thin plastic bag to prevent water getting to the feed. Workers are trained how to handle feed bags carefully to avoid dropping them from a height, which can split the bags. Workers are also taught to avoid using hooks to pull the bags.

Such losses in transport were not easy to quantify in this survey. In Bangladesh, annual losses of this type were reported as varying between 100 and 300 kg per mill per year (equating to 0.0022 percent to 0.0033 percent, with an average of 0.0026 percent). It was agreed though, that such losses were low as they were obvious and could be reduced. In India, transport losses were so small that none were reported, but some bags were damaged by rain, although double or even triple bagging helps reduce this problem; some bags were damaged by poor handling by workers. In Viet Nam no data could be obtained, as normally such losses were immediately compensated with replacement feed, often not documented.

Losses at the farm

Some losses of feed will occur at the farm due to poor storage conditions. The main issue is likely to be the feed getting damp or wet, and mould growing on it. There may also be some contamination or consumption of the feed by pests and other animals, and even some theft. Although none of these losses were reported in this survey, they are known to occur. It is most likely that these losses would be included in the farms' calculations of FCR, as this calculation would be made on feed purchased for the farm, compared to growth of fish biomass.

In India it was found that 3 or 4 bags in every 1 000 bags (50 tonnes of feed) would be damaged in some way, including damage by rodents, improper storage, over long storage (causing rancidity of oils) and bad handling of bags.

There is further losses of feed due to feed dust in the bags. This dust is created during production and transport, as pellets grind against each other and hard surfaces, wearing off a thin layer. The dust collects in the feed bags, and when the bags are opened at the farm, the dust may blow away or float at the surface, uneaten by the fish.

Among the three countries, there was a great difference in the percentage of dust in the feed that was expected and tolerated. In Bangladesh, farmers were given standards for dust content in the feed: nursery feed 5 – 8 percent, starter feed 2 – 3 percent, and grower feed 1 – 2 percent. In India, farmers accept 0.2 to 0.325 percent dust in the bags at packing, resulting in less than 1 percent at the farm. The reduction of dust in the feed would require efficient sieving at the factory, resulting in higher rework at this point. In Viet Nam, the farmers have a very assertive attitude towards dust, expecting a very low proportion in each bag (less than 0.25 percent, and preferably less than 0.18 percent).

The losses from dust at the farm will be covered by the FCR calculations for the fish, as this calculation deals with the feed purchased and fed compared to the growth in fish biomass. However, if dust is completely uneaten, then reducing it could be a way to gain a small decrease in FCR, increasing the overall efficiency of the farming system.

APPENDIX 4.6 FARMING

Farming areas

In all three countries, the farms were in lowland areas, near rivers which provided good access to fresh water. All three countries used pond aquaculture for these fish species. Pond sizes ranged from 5 000 to 600 000 m^2, with some differences in pond depths depending on the species (Table A4.17). Many farms in India had just one pond on their land, whereas in Bangladesh there were one to eight ponds, and in Viet Nam there were three to eight ponds.

TABLE A4.17
Comparison of pond size and number, and age of farms, for the three countries

		Bangladesh n = 10	India n = 12	Viet Nam n = 10
Total pond area per farm (m^2)				
	Average	30 060	126 583	45 990
	Range	4 858 – 129 554	24 000 – 600 000	25 000 – 70 000
Number of ponds per farm				
	Average	4	1	5
	Range	1 – 8	1 – 5	3 – 8
Pond depth (m)				
	Average	1.4	2.1	3.9
	Range	1.3 – 2.0	2.0 – 3.0	3.3 – 5.0
Age of farm (years)				
	Average	12	13	9
	Range	1 – 19	2 – 28	5 – 13

In each of the three countries, most of the land currently used for aquaculture had previously been farmed. The farms in Bangladesh were on land previously used for rice farming, India used general agricultural land. In Viet Nam, previous uses were either rice farms or fruit tree farms. Only Viet Nam reported a different land use prior to aquaculture, namely the building of two farms on open land covered in grass and trees next to the river bank.

The oldest farms were in India, where some farms had been established for over 20 years; there was also one new farm. In contrast, Vietnamese farms were much more recently established, where the farming of striped catfish began in the early 2000's. In Bangladesh the age of the farms was between that of India and Viet Nam.

Farming techniques

The basis of the farming varied between the three countries. Monoculture of striped catfish was practiced in Viet Nam. There was culture of only two species of major carps in India, rohu and catla; rohu was always in the majority (90 percent of the total number stocked), and catla the minority 10 percent, in all farms. There was a more diverse situation in Bangladesh. In this country, only one farm reported monoculture production, of Nile tilapia. The remainder of the farms raised a mixture of Chinese carps, rohu, catla, silver barb, stinging catfish (local name: *singh*) and striped catfish. Although some farms held only one other species, two farms had a total of five species. On the latter farms, Nile tilapia represented 70 to 90 percent of total number of fish

stocked, with the other species being equally distributed. Although the present survey focussed on the Nile tilapia production for these farms in Bangladesh, some of the feed would probably have been consumed by the secondary fish species.

Prior to stocking, and occasionally during production, farms in Bangladesh and India used manures to promote the production of natural food in the ponds (algae, zooplankton, and other fish which would be consumed by the target aquaculture species) (Table A4.18). The manures were mainly cow dung (dried or fresh) and poultry manure. In contrast, manure was not used in Viet Nam, as the striped catfish were moved to artificial feeds at a very small size, which allowed much more intensive farming.

TABLE A4.18
Use of manures in Bangladesh and India

	Bangladesh	India	
	Cow dung	Cow dung	Poultry manure
Farm use (number farms manures/total)	3/10	7/12	11/12
Average (kg/m^2 water area/year)	0.10	0.72	0.76
Range (kg/m^2 water area/year)	0.08 – 0.12	0.25 – 1.33	0.25 – 1.11

Notes: Manures were not used in Viet Nam.

Farms in Bangladesh and India also reported the use of fertilisers, to promote production of natural food in the ponds. Focus was on the provision of nitrogen and phosphorus through urea and phosphates, and some other minerals were also added (Table A4.19). In Bangladesh, if fertilizers were added, only urea or TSP used. In India, a greater variety of materials were used to fertilize the ponds. Notably, the dose used per square metre of water in the ponds varied greatly in both countries. Fertilisers were not reported from grow out ponds in Viet Nam.

TABLE A4.19
Use of six different fertilisers in Bangladesh and India

All fertilizer categories		Bangladesh	India
	Farms using any type of fertilizer	8/10	11/12
Urea	Farm use	6/10	3/12
	Average	26	21
	Range	3 – 79	19 – 25
Triple super phosphate (TSP)	Farm use	5/10	0/12
	Average	13	-
	Range	2 – 30	-
Super phosphate (SP)	Farm use	0/10	9/12
	Average	-	64
	Range	-	<1 – 250
Double ammonia phosphate (DAP)	Farm use	0/10	8/12
	Average	-	32
	Range	-	<1 – 52
Potash	Farm use	0/10	2/12
	Average	-	9
	Range	-	4 – 13
Micro minerals	Farm use	0/10	1/12
	Average	-	0.1
	Range	-	0.1 – 0.1

Notes: Farm use is number of farms using fertilizers compared to total number of farms. Amount of fertilizer used (average and range) is reported as total weight, per m^2 of water area per year.

* Fertilizers were not reported from grow-out ponds in Viet Nam.

Most farms used commercially produced feeds, mainly extruded pellets, but also steam pelleted feed. Some farms had only recently changed to these feeds. The widespread use of commercially produced feeds indicates progression towards a more developed aquaculture industry. Some farms in Bangladesh and India still used farm-made feeds such as mashes (Table A4.20). None of the farms surveyed reported using moist pellets.

TABLE A4.20
Use of three different types of feed in the three countries

	Bangladesh n = 10	India n = 12	Viet Nam n = 10
Mash	0	25	0
Extruded pellet (floating)	60	83	100
Steam pellet (sinking)	70	17	0

Notes: Data are presented as percentage of farms using each type of feed.

The main sources of energy were diesel and petrol to run pumps, generators and motorbikes, and mains electricity for pumps and lighting (Table A4.21). Energy use varied greatly between farms, primarily depending on how much water had to be pumped, and the height to which it had to be lifted.

Farms in Viet Nam required very regular water exchange, as they carried fish at very high stocking densities. Although many of the farms in Viet Nam had to use pumps to carry out these water exchanges, some of the farms could occasionally use tidal differences in the river height to flood the ponds, so having much lower energy requirements than farms using pumps. One farm in Viet Nam reported no use of energy, presumably using tidal flow only to change water.

TABLE A4.21
Comparison of use of four types of energy in farms in the three countries

		Bangladesh	India	Viet Nam
Diesel (litres/tonne fish harvested)				
	Farm use	3/10	8/12	2/10
	Average	26.4	12.9	0.75
	Range	6.4 – 36.8	0.6 – 40.0	0.50 – 1.00
Petrol (litres/tonne fish harvested)				
	Farm use	0/10	9/12	0/10
	Average	-	3.6	-
	Range	-	0.6 – 10.0	-
Electricity (kWh/tonne fish harvested)				
	Farm use	8/10	10/12	7/10
	Average	150	76.3	80.7
	Range	74.3 – 360	9.5 – 150	50 – 115
Tidal water exchange				
	Farm use	0/10	0/12	3/10

Notes: Farm use is the number of farms using energy compared to total number of farms.

Fish production

In Bangladesh and India, the polyculture nature of the ponds makes it more difficult to calculate the production efficiencies of individual species. In some farms, fish were regularly stocked and harvested throughout the year, with small crops of harvest-sized fish being removed as they were caught, and small fish being returned to the pond to grow on. Although this practice makes it hard to define the productivity, reasonable

estimates were provided by the farmers. The impact of these practices on the ability to assess production efficiencies is reflected in the variation seen in Table A4.22. The production of the tilapia and major carps was usually efficient, although some of the maximum values for eFCR were very high for major carps.

The monoculture nature of the Vietnamese striped catfish industry allows for a relatively straight forward assessment of the production system. Ponds are managed on an "all in, all out" system: fingerlings are stocked at 20 to 30 g, and the grown fish harvested at 750 to 1 020 g. This management practice allows for calculation of the eFCR of each pond. The monoculture of the striped catfish enabled a much greater production of fish than would be achievable from a polyculture from the same area, and the use of the commercial feeds facilitated production with a good eFCR.

Survival of the fish in Bangladesh and Viet Nam ranged from 70 to 95 percent, showing opportunities for improvement, which when achieved would help to improve the eFCR. The values for survival reported in India were often 100 percent, a high rate that is related to the use of much larger fish at stocking than in the other two countries. Larger fish are more robust and diseases resistant compared to smaller fish, and thus are better able to withstand the stress of transfer and the new environment on the farm. However, the apparent 100 percent survival rate should be interpreted with caution, as farmers may not property count the numbers of fish while stocking the pond, yet provide accurate numbers when counting the fish out at sale.

TABLE A4.22
Production and efficiencies of farms in the three countries

	Bangladesh	India		Viet Nam
	Nile tilapia	Rohu	Catla	Striped catfish
Stocking size (g)	15	160	210	27
	1 – 50	50 – 300	50 – 600	20 – 30
Harvest size (g)	310	1 240	2 340	880
	180 – 750	1 000 – 2 000	1 350 – 3 000	750 – 1 020
Annual harvest per year (tonne/year)				
	52	135		1 480
	10 – 300	22 – 700		1 125 – 2 160
Annual harvest per square metre of water (kg/m^2)				
	1.93	1.00		34.90
	0.37 – 3.53	0.78 – 1.57		22.30 – 60.00
Grow out time (days)				
	184	230		220
	120 – 270	180 – 300		190 – 245
eFCR				
	1.6	1.8		1.7
	1.1 – 2.0	1.0 – 5.0		1.6 – 1.9
Survival (%)[a]				
	88.5	98.3		80.1
	70 – 95	90 – 100		75 – 90

Notes: Data presented are means above, and range below.
[a]Survival was estimated from the number of fish stocked and the number harvested.

APPENDIX 4.7 FISH HARVESTING AND MARKETS

At the end of the growth phase, the fish are harvested from the ponds and sent to market. In Bangladesh and India, some farms net through the ponds, catching the large fish ready for market, and returning the small ones to grow on. The main markets in these two countries are for whole fish, mainly dead on ice, although in Bangladesh

some live fish are also sold. In contrast, in Viet Nam, where harvesting is done on an "all in, all out" basis, and the pond is emptied, live fish are taken by boat to a processing plant where they are killed and processed.

Due to the differences between the markets and the processes, information for each country will be summarised separately below.

Appendix 4.7.1 Bangladesh

The main markets for the fish from the farms are domestic. Most are sold whole, dead on ice. Up to 20 percent of the harvest are sold live, in particular the striped catfish and tilapia farmed together are both sold live, transported in drums of water (about 900 fish per truck in 30 drums), or in tanker trucks carrying 1 000 to 1 400 fish.

Fish transported on ice are packed in plastic boxes using 450 – 600 g ice per 1 000 g fish. The boxes are reused, with a life of approximately three years, depending on how heavily worn they are. The fish are transported from the farm to the markets by engine van, mini truck or truck, depending on the size of the harvest (0.5 tonne, 2.5 tonne and more than 1 tonne respectively).

If the harvest is large (greater than 1 tonne), a truck will come directly to the farm from the main markets at Dhaka, Gazipur, Sylhet or Tongi, which are 80 to 180 km distant from the farms. For smaller harvests, fish will be moved to local markets, such as Baro Bazar, Jamalpur, Kulauru, Mesua Bazar, Nandina Bazar, Shambuganj Bazar, Shamganj Bazar, Srimangol, Tarakanda Bazar, or Trishal, which are 3 to 15 km from the farm.

As the fish are sold whole (either on ice or live) to consumers, estimation of losses are not possible.

Appendix 4.7.2 India

Once packed at the farm, fish in India are moved a short distance (10 – 100 km) by truck (10 to 17 tonnes) to assembling centres such as Akiveedu, Bhimavaram, Eluru, Kaikaluru, and Narayanapuram. The first part of the journey, from the farm to a local market, is made by truck, with the fish packed in plastic boxes with ice and the total weight of approximately 65 kg of ice and fish. A ratio of approximately 850 g ice per 1 000 g fish is used in the plastic boxes, to ensure that the fish are still well iced on arrival at the markets. These heavy boxes (4 500 g) are reused, and sending them back to the farms costs additional money for transport. At the local markets, the fish are repacked in the thermocole boxes, and are then sent to the large markets in Assam, Howrah, Kolkata, and Siliguri in 17 – 21 tonne trucks; journeys which range from 1 100 to 1 425 km. These thermocole boxes weigh only 700 g each, and are discarded at the end of the journey. The thermocole boxes require less ice than the plastic boxes, due to their better thermal properties (a ratio of 625 g of ice per 1 000 g fish in summer, and 450 g of ice per 1 000 g fish in winter).

The fish are sold whole in the markets, and no estimates of waste from later processing were made.

Appendix 4.7.3 Viet Nam

Fish are transported live from the farms to the processing plants in boats. Each boat can carry 6 to 30 tonnes of fish, held in large wells which let water flow from the river through the boat (Table A4.23). Survival in these boats is high, with less than 1 percent of the fish dying or arriving in a very weak condition. High survival is important, as dead fish are either rejected by the processing companies or are bought at a much lower price than the live fish.

TABLE A4.23
Information on the three main types of boats used for carrying live striped catfish from the farms to the processing plants in Viet Nam

	Fish weight/holding capacity (tonne)	Water volume (m^3)	Fish density (kg/m^3)
Type 1	60	36 – 42	140 – 170
Type 2	200	120 – 140	142 – 167
Type 3	300 – 400	180 – 210	142 – 167

Journeys from the farms to the processing plants on the rivers were of distances of 20 to 100 km, requiring about 1 litre of diesel for 1 km distance for a 200 tonnes capacity boat. The processing plants are often separate companies to the farms, although they can also be the farm owners. At the processing plants, the fish are killed, and most are filleted; the minority are just gutted, and some may be left whole. Most are exported, only a very small percentage is sold in the local market.

The processed fish are frozen, packed in plastic, and then boxed in cardboard boxes (Table A4.24). The boxes are kept frozen, and transported by truck in refrigerated containers to the local ports; a journey of 80 to 220 km. From the ports, the products are exported all over the world by ship. Although the processing companies did not supply details of their customers, official Vietnamese figures give an average for these markets (Figure A4.1).

TABLE A4.24
Packaging use for the processed fish products in Viet Nam

Packaging	Average (kg/tonne fish)	Minimum (kg/tonne fish)	Maximum (kg/tonne fish)
Cardboard	49	45	50
PE*	1.47	0.75	2.0

* Polyethylene.

Waste from the fish processing is very well used. Parts of the viscera are removed by hand, cleaned, and sold as food products for export. Skin and trimmings of meat are reclaimed, and sold as food for export. The remainder (the rest of the viscera, head, bone and un-reclaimed parts) are ground up into fishmeal for use in the animal feed industry. Sometimes oil is also extracted from the remainder of the fish, but the oil is quite heavy and its industrial uses are limited.

Information on the energy use for processing was difficult to obtain in Viet Nam, with only four of the ten plants sharing this information, resulting in a very wide spread of values (Table A4.25). This limited data highlights the need to get more extensive data in future studies.

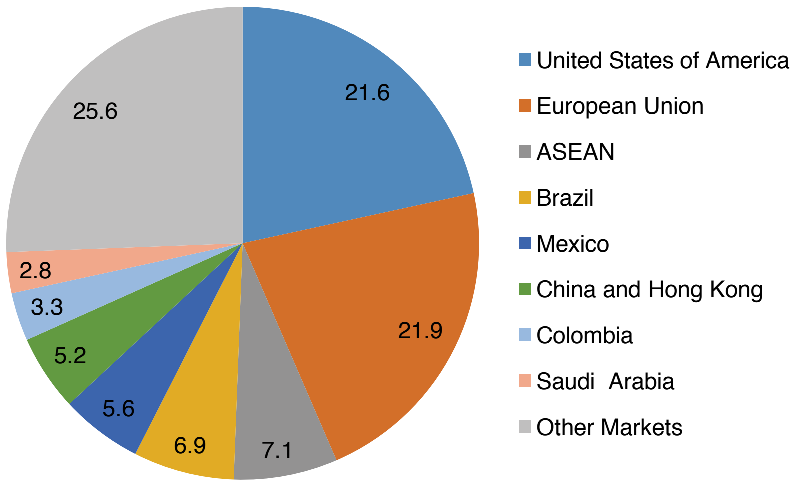
TABLE A4.25
Power requirements (kW/tonne whole fish processed) provided by 3 fish processing plants in Viet Nam

	Processing plant			
	A	B	C	Average
Processing power	1	120	120	80
Waste treatment	7	20	15	14
Refrigeration	0.3	40	60	33
Freezing	0.4	45	60	35

The final markets for striped catfish are spread globally (Figure A4.1). Although data on the volumes of fish exported are not published, the values of the exports to

the different markets are known, and they give a guide to the proportional transport routes. The freight is generally frozen, and carried in containers by ship. Once at the destination country, the containers may be split or moved whole to the next customer in the value chain, normally as road freight.

FIGURE A4.1
Global markets for striped catfish raised Viet Nam, according to per cent of total export value



Source: VASEP (2014).

Trucks are the major mode of transport for carrying fish, feeds and other materials in India (courtesy of FAO/R. Ramakrishna)

Feed is transported to an integrated enterprise farm by a mechanized boat, Mekong Delta, Viet Nam (courtesy of FAO/Mohammad R. Hasan)

Appendix 5. Raw material: protein and energy contents, and relative digestibilities

Crude and digestible protein, and gross and digestible energy content, of commonly used feed ingredients of different origins are presented in Table A5.1.

TABLE A5.1
Crude and digestible protein, and gross and digestible energy content, of commonly used feed ingredients of different origins

	Crude protein (%)	Digestible protein (%)	GE (MJ/kg)	DE (MJ/kg)
Animal protein meals				
Fishmeal	60.9	57.9	16.6	15.0
Fish trimmings meal	19.1	18.1	5.6	4.8
Dry fish	38.2	32.5	11.2	9.5
Blood meal	81.5	65.2	22.0	14.5
Meat and bone meal - low fat	51.5	41.2	13.7	10.8
Meat and bone meal - high fat	50.5	37.9	14.9	11.3
Poultry meal	65.5	59.0	14.8	14.3
Single cell protein	41.0	43.7	20.0	15.0
Plant protein meals				
Soybean - full fat	37.5	33.7	19.7	14.8
Soybean meal - de-oiled	46.0	40.5	17.7	10.9
Canola meal	35.5	29.5	15.7	8.3
Rapeseed	35.5	29.5	15.7	8.3
Copra meal	20.5	16.1	17.9	6.4
Cottonseed meal	39.0	26.6	16.5	10.0
Groundnut oil cake	49.0	40.7	21.7	13.2
Guar meal	42.0	35.7	20.5	11.1
Mustard oil cake	34.9	22.7	20.3	12.3
Mustard oil cake - de-oiled	26.0	16.9	18.7	11.3
Maize gluten	65.0	57.9	20.1	16.8
DDGS	27.4	17.8	19.2	9.1
Cereals, starches and by-products				
Cassava	2.4	0.6	15.0	10.6
Rice polish	12.53	8.3	17.8	10.6
Molasses	3.9	2.0	11.3	8.0
Maize	8.1	6.6	16.0	12.6
Rice bran - full fat	8.1	3.2	16.6	6.6
Rice bran - de-oiled	21.7	16.3	13.2	5.3
Wheat	11.7	9.6	16.1	11.8
Wheat flour	13.5	10.8	16.2	12.3
Wheat bran	11.3	5.0	17.5	7.0
Rice (polished)	7.3	4.3	16.6	8.4
Oils and fats				
Fish oil	0.0	0.0	39.0	38.5
Poultry fat	0.0	0.0	37.7	34.7

Notes: GE = gross energy; DF = digestible energy; DDGS = distillers' dried grains with solubles.

Data sources: The data used for these estimations were sourced from NACA (2008), Feedipedia (2014) and AFFRIS (2014, www.fao.org/fishery/affris/en/).

Farmed Nile tilapia (*Oreochromis niloticus*) harvested from a pond in Jamalpur, Bangladesh (courtesy of FAO/Jayanta Saha)

Appendix 6. Emissions intensities of feed materials at their point of production (PoP)

TABLE A6.1
Total emissions intensities of 12 sub-categories of feed materials at PoP (no LULUC). Within each sub-category, the materials are presented in ascending order of emission intensities (EI)

Feed sub-category (bold) and name of feed ingredients	Total EI at PoP ($g\ CO_2e/kg$ DM)
Grain by-products	
Feed material 1_wheat flour	260
Feed material 12_rice bran	312
Feed material 20_deoiled rice bran	312
Feed material 39_deoiled rice bran Andhra Pradesh	312
Feed material 40_deoiled rice bran West Bengal	312
Feed material 41_deoiled rice bran Chhattisgarh	312
Feed material 55_rice bran Andhra Pradesh	312
Feed material 57_deoiled rice bran Uttar Pradesh	312
Feed material 63_deoiled rice bran Odisha	312
Feed material 65_rice bran Tamil Nadu	312
Feed material 70_rice bran Odisha	312
Feed material 2_rice polish (grade-A)	312
Feed material 25_fine wheat bran	388
Feed material 35a_wheat bran	388
Grain by- products, high EI	
Feed material 34_DDGS	982
Feed material 35c_DDGS (India)	982
Feed material 42_DDGS Andhra Pradesh	982
Feed material 43_DDGS Nandigama, Andhra Pradesh	982
Feed material 61_DDGS Maharashtra	982
Feed material 64_maize gluten	1 693
Fish products	
Feed material 7_fishmeal	1 210
Feed material 35_fishmeal 55% protein	1 210
Feed material 46_fishmeal Karnataka	1 210
Feed material 29_fishmeal sardine and tuna trimmings	1 636
Feed material 50_fish oil Karnataka	2 090
Feed material 5_dry fish	7 110
Feed material 28_pangasius trimmings	9 480
Grain	
Feed material 18_wheat	374
Grain, high EI	
Feed material 11_maize	834
Feed material 48_maize_Andhra Pradesh	834
Feed material 49_broken rice Andhra Pradesh	1 368

TABLE A6.1 CONTINUED

Feed sub-category (bold) and name of feed ingredients	Total EI at PoP (g CO_2e/kg DM)
Animal by-products	
Feed material 6_meat and bone meal	334
Feed material 15_poultry meal	334
Feed material 16_meat and bone meal	334
Feed material 24_meat and bone meal high fat	334
Feed material 30_meat and bone meal low fat	334
Feed material 44_meat and bone meal Tamil Nadu	334
Feed material 45_meat and bone meal Delhi	334
Feed material 58_poultry meal Andhra Pradesh	334
Animal by-products, high EI	
Feed material 59_poultry fat Andhra Pradesh	818
Feed material 31_blood meal	1 217
Other oilseeds/meals	
Feed material 60_groundnut oil cake Gujarat	354
Feed material 62_groundnut oil cake Karnataka	354
Feed material 71_groundnut oil cake Andhra Pradesh	354
Feed material 27_copra meal	468
Feed material 3_rapeseed meal	532
Feed material 19_mustard oil cake	532
Feed material 26_canola meal	532
Feed material 35b_rapeseed meal (India)	532
Feed material 47_deoiled mustard oil cake Rajasthan	532
Feed material 51_rapeseed meal Rajasthan	532
Feed material 52_rapeseed meal Odisha	532
Feed material 53_rapeseed meal Chhattisgarh	532
Feed material 68_mustard oil cake Rajasthan	532
Feed material 17_guar meal	663
Other oilseeds/meals, high EI	
Feed material 54_cottonseed meal Maharashtra	943
Feed material 56_cottonseed meal Andhra Pradesh	943
Feed material 69_cottonseed oil cake Madhya Pradesh	943
Other feed materials	
Feed material 8_protein concentrate 60%	11
Feed material 9_single cell protein	11
Feed material 32_salt	18
Feed material 10_molasses	250
Feed material 23_cassava	395
Feed material 67_premix	
Other feed materials, high EI	
Feed material 33_mineral and vitamin premix	5175
Soybean/meal	
Feed material 21_soybean meal Argentina	531
Feed material 22_soybean meal United States of America	531
Feed material 14_soybean full fat	537
Feed material 4_soyabean meal (de-oiled)	663
Feed material 13_soybean meal 44%	663
Feed material 36_soybean meal Andhra Pradesh	682
Feed material 37_soybean meal Maharashtra	682
Feed material 38_soybean meal Madhya Pradesh	682
Feed material 66_soybean meal Gujarat	682

Notes: please see section 4.2 for an overview of the method used to determine the emission intensities; LULUC = land use and land use change.

Appendix 7. Emission factors for energy and transport use

TABLE A7.1
Energy emissions factors used in the calculation of feed mill energy emissions

	Bangladesh	India	Viet Nam	Units	Source and comments
Energy					
Electricity	0.59	0.90	0.42	kg CO_2e/kWh	IEA (2013)
Gas	7.65	7.65	7.65	kg CO_2e/m^3	GLEAM default (de Boer, 2009)
Fuel oil boiler	3.14	3.14	3.14	kg CO_2e/kg	Ramachandra and Shwetmala (2009)
Fuel oil generator	3.14	3.14	3.14	kg CO_2e/kg	Ramachandra and Shwetmala (2009)
Diesel	3.19	3.19	3.19	kg CO_2e/kg	Ramachandra and Shwetmala (2009)
Coal	1.76	1.76	1.76	kg CO_2e/kg	Ramachandra and Shwetmala (2009)
Furnace oil	3.14	3.14	3.14	kg CO_2e/kg	Ramachandra and Shwetmala (2009)
Rice husk	0.00	0.00	0.00	kg CO_2e/kg	Assuming net GHG = 0[1]
Wood	0.00	0.00	0.00	kg CO_2e/kg	Assuming net GHG = 0
Petrol	3.01	3.01	3.01	kg CO_2e/kg	Carbon Trust (2013)

[1]Note that FeedPrint has an EI for rice husk meal of 0.314 kg CO_2e/kg DM.

TABLE A7.2
Feed mill to farm transport assumptions for distance and emissions factor

	Truck/small pickup/van	Tempo/rickshaw	Boat	Source
Weighted average (km)				
Bangladesh	112	11	0	Feed survey
India	44	0	0	Feed survey
Viet Nam	66	0	130	Feed survey
Emissions factor				
kg CO_2e/t.km	1.082	0.62	0.049	Truck/van/tempo[1] and boat[2]

[1] Ramachandra and Shwetmala (2009); [2] La Van Chung, personal communication (2014).

TABLE A7.3
Feed mill to farm transport emission factors (EF)

Country	EF (g CO_2e/kg)
Bangladesh	127.3
India	47.5
Viet Nam	78.0

Harvest of Indian major carps (rohu, catla and mrigal) and exotic carps (silver, grass and common) carps from a semi-intensive polyculture pond, Rajshahi, Bangladesh (courtesy of FAO/Mohammad R. Hasan)

Appendix 8. Percentage of each sub-category of feed material in the rations of the three farmed species

TABLE A8.1

Percentage of each sub-category of feed material in the rations of the three farmed species

	Grain by-products	Grain by-products, high EI	Fish products	Grain	Grain, high EI	Animal by-products	Animal by-products, high EI	Other oilseeds/ meals	Other oilseeds/ meals, high EI	Other feed materials	Other feed materials, high EI	Soybean/ meal
Nile tilapia												
Ration 1_tilapia_nursery	15	0	7	19	1	0	6	19	0	3	0	30
Ration 2_tilapia_starter	17	0	6	18	3	0	8	21	0	0	0	26
Ration 3_tilapia_grower	21	0	6	16	7	0	6	26	0	0	0	18
Ration 4_tilapia_finisher	14	0	6	32	0	0	5	24	0	1	0	17
Major carps												
Ration 9_carp_nursery	24	4	4	0	18	0	2	10	5	0	0	34
Ration 10_carp_starter	29	4	2	0	19	0	2	11	6	0	0	28
Ration 11_carp_grower	31	3	2	0	20	0	1	11	5	0	0	26
Striped catfish												
Ration 5_catfish	27	2	3	1	0	0	11	11	0	17	1	26
Ration 6_catfish	21	0	0	2	0	0	9	23	0	19	1	24

Harvest of striped catfish, Mekong Delta, Viet Nam
(courtesy of FAO/T.P. Nguyen)

Appendix 9. Summary of the opportunities and priorities for expanding the emission categories included, and for refining the emissions calculation methods

Table A9.1 provides a summary of potential refinements to the emissions calculation method, and expands on Table 25 of the main report, which lists only the priorities for future action.

TABLE A9.1
Summary of potential refinements to the emissions calculation method

Emission category	Priority for future inclusion or refinement?
Biomass burning	No, reliable data on biomass burning not readily available.
Biological fixation of nitrogen	No, IPCC (2006) method excludes N_2O from biological fixation.
Land use (LU), i.e. changes in carbon stocks from land use under constant management practices	No, reliable data on CO_2 emissions from land use not readily available.
Transport of feed materials and feed	
Road/rail/ship transport from port, or place of production, to feed mill	Yes, refinement of domestic road and ship EFs.
Compound feed from mill to fish farm	Yes, refinement of domestic road and ship EFs.
On farm	
Embedded energy related to manufacture of on-farm buildings and equipment	No, unlikely to be a major source of GHG, PAS2050-2:2012 excludes these (BSI, 2012).
Production of cleaning agents, antibiotics and pharmaceuticals	No, unlikely to be a major source of GHG.
Hatcheries/nurseries	Yes, approximate quantification [based on the energy and feed consumption reported by Pelletier and Tyedmers (2010)] indicates that this could be significant for some systems, Bosma *et al.* (2011) considered hatchery impacts to be "negligible compared with grow-out farming", but the present survey shows that they are considerable for major carps at least.
On-farm energy use	Yes, there is a marked difference between the energy use in this study and other studies.
Fish health and mortalities	Yes, improving fish health will improve eFCR and reduce mortalities. Improving health through good management should be low EI and low cost, and the benefits should be great, making the likelihood for change high.
Enteric fermentation	No, unlikely to be a major source of GHG.
Anaerobic decomposition of organic matter (excreted volatile solids and uneaten feed)	No, lack of agreed method - the rates of anaerobic decomposition should be significantly lower than rice paddies [for which IPCC (2006) provide a method], as ponds should be better oxygenated.
Direct and indirect N_2O from excreted N and uneaten feed	Yes, pond N_2O EF is important, and requires further investigation (including how and why it varies between different systems and locations).

TABLE A9.1 CONTINUED

Emission category	Priority for future inclusion or refinement?
Emissions arising from the addition of (organic and synthetic) fertiliser to ponds	Yes, see above (full nutrient budget required, including other N inputs and allocating emissions to outputs, such as sediment, water used for fertilising crops).
N_2O from the animal (invertebrates only?)	No, unlikely to be a major source of GHG.
LUC from pond construction	Yes, should be quantified if the pond was constructed within 20 years, see BSI (2012).
Pond cleaning and maintenance	No, unlikely to be a major source of GHG?
CO_2 sequestered in carbonates	Not applicable to finfish.
CO_2 sequestered in pond sediments	No, but merits further investigation. Boyd *et al.* (2010) have suggested significant amounts of C could be sequestered in sediments, but this is no consensus on this yet.
Transport of fish and products	
Live fish and products to slaughter and processing plant	Not a major source of emissions, but boat transport in Viet Nam requires clarification.
Fish and processed products to retail point (including chilling)	Yes, particularly where chilled transport is used.
Allocation to by-products	
Emissions related to co-products e.g. offal, skin, bones, heads and trimmings.	No, although economic allocation (based on the values In Henriksson *et al.* (2014b) could be used to enable comparison with other processed products.
Retail	
Energy use	Yes, could make a significant impact on the emissions intensity of the consumed product due to refrigeration.
Packaging	Possibly, packaging unlikely to be a significant source of emissions, but can influence retail and post-retail loss rates.
Losses and waste disposal	Yes, could make a significant impact on the emissions intensity of the consumed product due to refrigeration.
Post-retail	
Energy use	No, potentially significant, but not easily quantified.
Losses and waste disposal	No, potentially significant, but not easily quantified.

In order to estimate the possible scale of greenhouse gas emissions in aquaculture in Asia, a study was carried out on three aquaculture systems: Nile tilapia in Bangladesh, Indian major carps in India and striped catfish in Viet Nam. The analysis was intended to improve the understanding of where and how GHG emissions arise in Asian aquaculture, whilst highlighting weaknesses in the currently available data. This results of this study will guide future studies on where to improve the data and on how to develop cost-effective ways of improving aquaculture performance and reducing emissions. This report highlights the variation within each farming system at every stage of the three Asian aquaculture systems. The report makes some suggestions for methods which potentially could reduce emission intensities related to the farming systems, but applying best practices uniformly on farms and thus increasing efficiencies appear to be major factors for improvement.

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