**User Guide to FISH-e: FAO's tool for quantifying the greenhouse gas emissions arising from aquaculture**

Version: FISH-e v1

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We need your help!

FISH-e v1 is a test version, and we are keen to improve it. We would be grateful if you could take a few minutes to tell us what you think of it. To provide feedback, please click in the link below:<http://www.fao.org/fileadmin/user_upload/affris/docs/FISHe/FISH-e_feedback_form.docx>

# Glossary and abbreviations

*Glossary of commonly used terms*

|  |  |
| --- | --- |
| **Term** | **Definition** |
| Animal by-products | Products of slaughter not included in the carcass weight, e.g. offal, trimmings etc. |
| Carcass weight | Weight of an eviscerated carcass, including bones |
| CO2e | Carbon dioxide equivalent, i.e. the global warming potential of non-CO2 greenhouse gases, expressed in terms of CO2 |
| Cradle to gate | Processes occurring pre- and on-farm |
| Crop by-products | By-products from the processing of grains and oilseeds, e.g. rapeseed meal, wheat bran. |
| Crop residues | Stubble, straws and stovers. |
| Digestible energy/digestibility | Feed gross energy minus undigested energy excreted in faeces. |
| Dry matter | Mass of a feed material (e.g. wheat) not including its moisture content. |
| Edible protein | Mass of protein produced by livestock intended for human consumption, i.e. the protein content of meat. |
| Emission factor | The amount of emissions produced per unit of good or service, e.g. kg of CO2e per MJ of electricity. |
| Emission intensity (EI)  | The amount of emissions produced per unit of commodity output, e.g. kg of CO2e per kg of live weight |
| Feed conversion ratio | A measure of the efficiency with which livestock convert feed into outputs, e.g. kg feed in/kg of live weight gain. |
| F-gases | Fluorinated gases (such as HFCs) used (amongst other things) as refrigerants in cooling systems.  |
| Fieldwork | Ploughing, manure spreading, crop harvesting etc. |
| Gross energy | Total chemical energy in feed measured from complete combustion in a bomb calorimeter  |
| Land use change (LUC) | Conversion of land from one class to another, e.g. from grassland to cropland. |
| Life cycle analysis | Analytical approach that measures the environmental impact of a good or service over its full life cycle, including production of inputs, manufacturing, distribution, consumption, end of life disposal. |
| Manure N | The total nitrogen content of manure. |
| Methane | Greenhouse gas produced from the anaerobic decomposition of organic compounds. |
| Methane conversion factor | The rate at which organic compounds are converted to methane. |
| N excretion | Excretion of nitrogenous wastes by livestock. |
| Nitrous oxide | Greenhouse gas produced by the microbial transformation of nitrogenous compounds in soils, manure storage or ponds. |
| Nutrient use efficiency | A measure of the proportion of a nutrient that is taken up by a plant or animal, e.g. the % of applied fertiliser nitrogen that is taken up by a wheat crop.  |
| On-farm | Processes occurring on the fish farm |
| Organic N | Nitrogen content of organic compounds such as: manures, composts and feed.  |
| Post-farm | Processes occurring after the fish farm |
| Pre-farm | Processes occurring before the fish farm |
| Synthetic N | Manufactured nitrogenous fertiliser, e.g. ammonium nitrate and urea. |
| Volatile solids | Undigested organic matter excreted by fish. |

*List of abbreviations*

|  |  |
| --- | --- |
| AFFRIS | FAO's Aquaculture Feed and Fertilizer Resources Information System |
| CH4 | Methane |
| CO2 | Carbon dioxide |
| CP | Crude protein |
| CW | Carcass weight |
| DDGS | Distiller's dried grains with solubles |
| DE | Digestible energy |
| EF | Emission factor |
| EI | Emission Intensity |
| FAO | Food and Agriculture Organization of the United Nations |
| FAOstat | Food and Agriculture Organization of the United Nations Statistics |
| FCR | Feed conversion ratio |
| GE | Gross energy |
| GLEAM | Global Livestock Environmental Assessment Model |
| IPCC | Intergovernmental Panel on Climate Change |
| kgCO2e/kg CW | kg of CO2 equivalent emitted per kg of carcass weight |
| kgCO2e/kg LW | kg of CO2 equivalent emitted per kg of live weight |
| kgCO2e/kg protein | kg of CO2 equivalent emitted per kg of edible protein |
| LCA | Life cycle analysis |
| LUC | Land use change |
| LW | Live weight |
| MCF | Methane conversion factor |
| N2O | Nitrous oxide |
| NUE | Nutrient use efficiency |
| UNFCCC | United Nations Framework Convention on Climate Change |

#

# Introduction

In order to reduce greenhouse gas emissions (GHGs) we need to understand how and why they arise. To help meet this challenge, FAO has developed a user-friendly tool that quantifies aquaculture emissions called FISH-emissions (or FISH-e for short). It calculates the emission intensity (sometimes referred to as the carbon footprint - the kg of GHG per kg of live weight) for the main aquaculture commodities, i.e.: catfish; cyprinids; Indian major carps; salmonids; shrimp; and tilapia. Users can change key parameters (such as species, location, ration composition and feed conversion ratio, and on-farm energy and fertiliser use) and explore how these influence the emissions intensity.

The emissions intensity of fish farming is intimately linked to the mix of feed materials in the ration (and, of course, the efficiency with which these are then converted to live weight gain). Default rations are included in FISH-e for the most common aquaculture commodity/location combinations. However in order to achieve a more accurate calculation of emissions intensity, users can also enter specific ration compositions. They can also specify their energy and fertiliser consumption, which can be important sources of GHGs in some systems. Once the information is entered, FISH-e calculates the emission and provides a graphical breakdown of the emissions by source, thereby enabling users to quickly identify the main sources of GHGs in their system.

This guide provides a brief overview of FISH-e and an explanation of how to use it. FISH-e v1 (a test version of the tool, which will be revised in light of feedback form users) can be downloaded using the following link: <http://www.fao.org/fileadmin/user_upload/affris/docs/FISHe/FISHe_v1_test_public.xlsm>

The system boundary of FISH-e v1 is shown in Figure 1. It 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 stages:

• Production of feed raw materials;

• 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.

The system boundary of FISH-e v1 is therefore “cradle to farm-gate”. As with any model, FISH-e has to make trade-offs between scope, accuracy and use-ability. It is recognised that significant emissions (and losses of product) can occur post-farm during transport, processing and distribution. However, aquaculture products have many routes to market and including post-farm processes would therefore require a more complex tool. In order to provide a relatively straightforward and user-friendly tool, with broad geographical scope, it was decided to exclude post-farm processes from this (initial) version of the tool.

*Figure 1. The system boundary of FISH-e v1 is indicated by the dashed red line. The flow diagram is taken from Henriksson et al. (2014a).*

The major GHGs associated with aquaculture production are:

* **N2O** arising from the microbial transformation of N (mainly from applied fertilisers) in soils during the cultivation of feed crops. Significant amounts of N2O may also be emitted from ponds as a result of the microbial transformation of nitrogenous compounds in ponds (e.g. synthetic fertilisers, manures, composts, uneaten feed and excreted N), although the magnitudes of these emissions are less readily quantified.
* **CO2** arising from energy use *pre-farm* (primarily associated with feed and fertiliser production), *on-farm* (e.g. for pumping water) and during *post-farm* distribution and processing. CO2 emissions also arise from changes in above and below ground carbon stocks induced by land use and land use change (primarily driven by increased demand for feed crops, which can lead to the conversion of forest and grassland to arable land).
* **CH4** arising mainly from the anaerobic decomposition of organic matter during flooded rice cultivation. May also arise during fish farm waste management.
* **F-gases** - small amounts of these potent greenhouse gases are leaked from cooling systems on-farm and post-farm.

The sub-categories of GHG included in FISH-e v1 are summarised in Table 1.

*Table 1. Summary of the GHG categories included in FISH-e v1.*

|  |  |
| --- | --- |
| **Name** | **Description** |
| Feed: fertilizer production | Emissions arising from the production of synthetic fertilisers applied to crops |
| Feed: crop N2O | Direct and indirect nitrous oxide from the application of (synthetic and manure) N to crops and crop residues management  |
| Feed: crop energy use | CO2 from energy use in field operations, feed transport and processing, and fertiliser production. |
| Feed: crop LUC | CO2 from land use change arising from soybean cultivation. |
| Feed: rice CH4 | Methane arising from flooded rice cultivation |
| Feed: fishmeal | CO2 from energy use in the production of fishmeal |
| Feed: animal by-products | CO2 from energy use in the production of animal by-product feeds |
| Feed: blending & transport | CO2 from energy use in the production and distribution of compound feed |
| Feed: other | Emissions from the production of a small number of "other" feeds (including lime and synthetic amino acids) |
| Juvenile fish production | Emissions arising in hatcheries during the production of fingerlings |
| Pond fertilizer production | Emissions arising from the production of synthetic fertilisers applied to increase aquatic primary productivity |
| Grid electricity | Emissions arising from the production of electricity used on the fish farm |
| On-farm fuel use | Emissions arising from the use of fuels on the fish farm |

Table 2 lists the sources of GHG not included in FISH-e v1. Most of these are unlikely to be a significant source of emissions, apart from pond N2O and carbon sequestration, which are discussed briefly below.

*Pond N2O*

According to Hu *et al.* (2012) N2O 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). Because of this, pond N2O is not usually included in aquaculture GHG studies, however Robb et al (2017) provided preliminary estimates of N2O in their analysis of three Asian systems.

*Carbon sequestration in pond sediments*

Pond carbon sequestration was excluded from the present study, however it has been suggested (see Verdegem and Bosma (2009), and Boyd *et al.* (2010)) that ponds could act as net carbon sinks if primary productivity is stimulated. However other studies (such as the SEAT project, see Henriksson *et al.* 2014a,b) exclude these sinks 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). In addition, stimulating the growth 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 the fish welfare in such conditions, as the nutrient additions significantly change the water quality, which may not suit some species of fish.

*Table 2. GHG sources falling within the cradle to farm-gate system boundary, but not included in FISH-e v1*

|  |  |  |
| --- | --- | --- |
| **Process** | **Gas** | **Comment** |
| Energy in the manufacture of on-farm buildings and equipment (including packaging) | CO2 | Difficult to quantify, unlikely to be a major source of emissions |
| Production of cleaning agents, antibiotics and pharmaceuticals | CO2 | Unlikely to be a major source of emissions |
| Anaerobic decomposition of organic matter in ponds  | CH4 | Difficult to quantify, unlikely to be a major source of emissions |
| Pond N2O | N2O | Difficult to quantify, potentially significant |
| N2O from the animal | N2O | Possibly significant for invertebrates, but difficult to quantify |
| LUC arising from pond construction | CO2 | Difficult to quantify, unlikely to be a major source of emissions |
| Pond cleaning maintenance | CO2 | Difficult to quantify, unlikely to be a major source of emissions |
| CO2 sequestered in carbonates | CO2 | Possibly significant for invertebrates? |
| CO2 sequestered in pond sediments | CO2 | Difficult to quantify, potentially significant |
| Leakage of coolants | F-gases | Difficult to quantify, potentially significant (particularly post-farm) |

# Using FISH-e

FISH-e consists of a series of sheets that hold data, perform calculations and report results (Table 3). The blue sheet are visible to users.

*Table 3. Overview of the sheets in FISH-e v1*

|  |  |
| --- | --- |
| *Name* | *Function* |
| Read me | File info and version control |
| START | Introductory sheet where user inputs the location, commodity and system. |
| INPUTS | Sheet where user inputs details about their fish farm production, rations, energy use and fertiliser use. |
| RESULTS | Provides results, i.e. total emissions and emissions intensity, and compares against benchmarks |
| References | List of references used in the tool |
| Feed EFs | Calculates the feed emissions per kg of dry matter |
| Electricity EFs | Emission factors for electricity by country |
| Fuel EFs | Emission factors for fuels |
| Fert EFs | Emission factors for fertilizers and lime |
| Fingerling EF | Emission factor per kg of juvenile fish imported into the farm |
| Processing | Factors to convert from liveweight to carcass weight |
| Country list | Full list of FAO countries |
| Conversions | Unit conversions |

*General instructions*

Values should be entered into the white cells only. For each white cell, enter the appropriate information or, when provided, choose one of the options in the drop down menu.

***START*** *sheet*

1. Select the country, commodity and system of the fish farm from the drop down menus. Note that in v1, “System” does not affect the results.
2. Click “NEXT”

***INPUTS*** *sheet: PRODUCTION*

1. Enter the fish weights and % of fingerlings harvested. Length or growing period may also be entered but is not used in the calculations in v1.
2. Enter the annual fish production and feed consumption into the white cells. Users can also enter their actual feed conversion ratio (FCR) if it is different from the implied or default FCR. FISH-e will use the actual FCR (E19) in the subsequent calculations if a value is entered. If no value is entered it will use the implied FCR (E18) or the regional default FCR (E20) if the total fish production and consumption have not been entered (see RESULTS, cell D14).

***INPUTS*** *sheet: RATION COMPOSITION*

Default rations are included in the model for the most common commodity/location combinations, however in order for a more accurate calculation of emissions intensity, users can enter their specific ration composition.

FISH-e distinguishes between two types of aquafeed as follows: (a) commercial aquafeed which are compound feeds purchased from specialised feed companies and/or feed merchants. The feed is comprised of materials sourced nationally and internationally, which are formulated and blended into high quality compound feed and (b) farm made/semi-commercial aquafeeds made on the fish farm or produced by small-scale feed manufacturers from locally sourced feed materials.

***Instructions***

1. Enter the % of the total ration comprised of commercial feed (E42).
2. Select the main commercial feed materials (users can choose up to ten) and estimate the % each comprises of the total commercial feed. The "Commercial total" in cell C58 should be equal to 100% (or 0% if no commercial feed is used).
3. Repeat for non-commercial feed (if non-commercial feed is used) - it should also add up to 100% (or 0% if no non-commercial feed is used).



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*Figure 2. Screenshot of the Ration Composition part of the INPUTS sheet.*

***INPUTS*** *sheet: ON-FARM ENERGY USE*

*Grid electricity*

1. Under “Activity” users can select ALL if they want to enter the total electricity consumption, or enter the consumption by activity, if this information is available.
2. Enter the annual consumption and select the units consumption is measured in.

*Fuel use*

1. Select the fuel (cells B79:B83). Note that the same fuel can be entered more than once, if the user wishes to specify the amount of fuel used by activity.
2. Select the activity, then enter the amount of fuel used each year, and the units.

***INPUTS*** *sheet: POND FERTILISATION*

On some fish farms fertilizers and lime are added. The purpose of this section is to quantify the emissions arising during the production of these inputs. The results do not include the N2O emissions from ponds that may arise from the addition of nitrogenous fertilisers.

*Instructions*

1. Select the main fertilizers added to the fish ponds, and enter the amount added each year in the white cells.
2. Enter the amount of lime added each year.
3. Click “To RESULTS”.

***RESULTS*** *sheet*

This sheet provides the following results for the fish farm:

1. Annual fish production.
2. Total annual emissions disaggregated by emissions category. Feed emissions are further disaggregated into nine subcategories (Figure 3).
3. The emissions intensity, in terms of the total emissions (kgCO2e) for each kg of live weight at the farm gate.
4. A sample of the emissions intensity of seafood and livestock commodities reported in other studies is provided, to put the results in context.

**

*Figure 3. Screenshot of part of the RESULTS sheet*

*Table 4. Summary of the effect of changing different parameters*

|  |  |
| --- | --- |
| **Parameter** | **What changes?** |
| *START sheet* |
| Location | Changes: default ration, default FCR, feed material EFs, electricity EFs, fertilizer EFs. |
| Commodity | Changes: default ration, default FCR.  |
| System | Does not change the calculations in the current version.  |
| *INPUTS sheet* |
| Length of the growing period | Does not change the calculations in the current version. |
| Juvenile fish weight at input and mature fish weight at harvest | Changes the amount of harvested LW and emissions occurring on the grow out farm. |
| % of fingerlings harvested as mature fish | Changes emissions arising during fingerling production. |
| Total fish production and Total feed consumption | Determines FCR and hence feed emissions. |
| Proportion of commercial feed and ration composition | Changes the proportion of each feed material in the specified ration and hence the feed emissions. |
| On-farm energy use | Changing the type and amount of electricity and fuel used changes the energy emissions. |
| Pond fertilization | Changing the type and amount of synthetic fertilizer (and lime) changes the pond fertilization emissions. User can also specify the amount and type of organic fertilizers used, but these do not change the emissions at present. This information would be required to calculate pond N2O. |

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# Data used in FISH-e

*Default rations and feed conversion ratios*

Default rations and FCRs were derived from a range of sources including: AFFRIS (FAO 2017a), journal articles (e.g. Tacon, Metian and Hasan, 2009; Tacon and Metian, 2008, 2015), technical reports (e.g. Robb *et al.,* 2017), grey literature (e.g. White, 2013) and expert opinion.

*Emissions factors for feed*

The EFs for crop feed materials were based on the values derived using GLEAM (FAO 2017b). EFs for additional feeds were derived from Feedprint (fishmeal, poultry meal, feather meal, meat and bone meal, blood meal, lime and groundnut meal, see Vellinga *et al.,* 2013) and Pelletier and Tyedmers (2010) (fish oil).

*Emission factors for fuels and grid electricity*

Country specific EFs for grid electricity were taken from UK BEIS (2016). Regional EFs were used for countries without national EFs. Note that the generation EFs in UK BEIS (2016) are taken from IEA (2013). EFs for fuels were taken from UK BEIS (2016); these are not country-specific.

*Emission factors for fertilisers*

EFs for fertilisers were derived from Kool *et al.* (2012), which provides EFs for each fertiliser for 5 geographic regions: Western Europe; Russia and central Europe; North America; China and India; rest of the world.

# References

Bosma, R., Thi Anh, P., & Potting, J. 2011. Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. International Journal of Life Cycle Assessment, 16: 903-915.

Boyd, C.E., Wood, C.W., Chaney, P.L. & Queiroz, J.F. 2010. Role of aquaculture pond sediments in sequestration of annual global carbon emissions. Environmental Pollution, 158 (8): 2537–2540.

FAO. 2017a. Aquaculture Feed and Fertilizer Resources Information System <http://www.fao.org/fishery/affris/affris-home/en/>

FAO. 2017b. Global Livestock Environmental Assessment Model (GLEAM) <http://www.fao.org/gleam/en/>

Henriksson, P.J.G., Zhang, W., Nahid, S.A.A., Newton, R., Phan, L.T., Dao, H.M., Zhang, Z., Jaithiang, J., Andong, R., Chaimanuskul, K., Vo, N.S., Hua, H.V., Haque, M.M., Das, R., Kruijssen, F., Satapornvanit, K., Nguyen, P.T., Liu, Q., Liu, L., Wahab, M.A., Murray, F.J., Little, D.C. & Guinée, J.B. 2014a. Final LCA case study report. Results of LCA studies of Asian aquaculture systems for tilapia, catfish, shrimp, and freshwater prawn. SEAT Deliverable Ref: D 3.5. Stirling, United Kingdom, SEAT Project. 164 pp.

Henriksson, P.J.G., Zhang, W., Nahid, S.A.A., Newton, R., Phan, L.T., Dao, H.M., Zhang, Z., Jaithiang, J., Andong, R., Chaimanuskul, K., Vo, N.S., Hua, H.V., Haque, M.M., Das, R., Kruijssen, F., Satapornvanit, K., Nguyen, P.T., Liu, Q., Liu, L., Wahab, M.A., Murray, F.J., Little, D.C. & Guinée, J.B. 2014b. Final LCA case study report. Primary data and literature sources adopted in the SEAT LCA studies. SEAT Deliverable Ref: D 3.5. Annex report. Stirling, United Kingdom, SEAT Project. 121 pp.

Hu, Z., Lee, J.W., Chandran, K., Kim, S. and Khanal, S.K. 2012. Nitrous Oxide (N2O) Emission from Aquaculture: A Review. Environmental Science and Technology, 46: 6470−6480.

IEA. 2013. CO2 Emissions from Fuel Combustion Highlights Paris: IEA/OECD

Kool, A., M. Marinussen and H. Blonk. 2012. LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization GHG Emissions of N, P and K fertilizer production Gouda: Blonk Consultants

Pelletier, N. & Tyedmers, P. 2010. A life cycle assessment of frozen Indonesian tilapia fillets from lake and pond-based production systems. Journal of Industrial Ecology, 14: 467–481.

Robb, D.H.F., MacLeod, M., Hasan, M.R. & Soto, D. 2017. *Greenhouse gas emissions from aquaculture: a life cycle assessment of three Asian systems.* FAO Fisheries and Aquaculture Technical Paper No. 609. Rome, Italy, FAO. 92 pp.

Tacon, A.G.J. and Metian, M. 2008. Global overview on the use of fishmeal and fish oil in industrially compounded aquafeeds: Trends and future prospects *Aquaculture*, 285 146–158

Tacon, A.G.J. and Metian, M. 2015. Feed Matters: Satisfying the Feed Demand of Aquaculture, Reviews in Fisheries Science & Aquaculture, 23:1, 1-10.

Tacon, A.G.J., Metian, M. & Hasan, M.R. 2009. *Feed ingredients and fertilizers for farmed aquatic animals: sources and composition.* FAO Fisheries and Aquaculture Technical Paper. No. 540. Rome, FAO. 209 pp.

UK BEIS. 2016. Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors. September 2016. London: UK Department of Business, Energy & Industrial Strategy

Vellinga, Th. V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. & Starmans, D. 2013. Methodology used in FeedPrint: a tool quantifying greenhouse gas emissions of feed production and utilization. Report 674. Lelystad, the Netherlands, Wageningen UR Livestock Research.

Verdegem, M.C.J. & Bosma, R.H. 2009. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. Water Policy, 11(S1): 52-68.

White, A. 2013. A Comprehensive Analysis of Efficiency in the Tasmanian Salmon Industry. PhD thesis, Bond University