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Life cycle assessment of three Peruvian fishmeal plants: Toward a cleaner production

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ABSTRACT

Fishmeal and fish oil are largely used as input to several animal feed industries all around the world, but there is a lack of life cycle assessments (LCAs) on Peruvian fishmeal plants, despite their predominance in the global supply. LCAs where performed on three different types of Peruvian fishmeal plants with the objective of comparing them and suggesting ways of limiting their impacts. The LCA results can be nested into LCAs of animal feed. Two system boundaries were used: one including the fishery and another excluding it in order to enable other practitioners to use our generic life cycle inventory (LCI) data and LCI analysis. The effects of different processing rates and qualities of fishmeal on environmental impacts were compared. We used the SimaPro software, the ecoinvent 2.2 database and the ReCiPe method. In contrast to many LCA studies, the construction and maintenance phases were considered. Despite the predominant impact of the use phase, in particular consumption of fossil energy, these two phases contribute significantly (>10% using the ReCiPe single score) when fishing is excluded from the system boundaries. Furthermore, existing screening LCAs of the use phase largely underestimate (~20%) its environmental impacts. The environmental benefit of using natural gas instead of heavy fuel as energy source, in terms of reduced impacts, is huge, reaching 41% of the ReCiPe single score when fishing is excluded and 30% when included. The comparison of environmental impacts between different qualities of fishmeal shows higher impacts of residual fishmeal, intermediate impact of standard fishmeal and lower impacts of Prime fishmeal, the difference between extreme values being more than twofold. Future studies on other fishmeal and residual fishmeal plants should take into account the construction and maintenance phases, and more items in the use phase than in historical screenings. There is room to decrease the environmental impact of this industry in Peru.

1. Introduction

1.1. Rationale and objective

Food production intensification is driven by the increase of foodstuff demand, itself driven by the human population growth and the increase of per capita foodstuff consumption. For at least the two last millennia, farmed terrestrial animals (livestock) have been the first source of protein in most countries, ranking just before (or sometimes just after) wild fish. World per capita apparent consumption of meat from feedstocks and fish (wild and farmed) increased dramatically during the last decades: from an average of ~24 kg in the 1960s to ~43 kg in 2012 for meat (FAOSTAT, 2016) and from an average of ~10 kg–~19 kg for fish during the same period (FAO, 2014). From the beginning of this millennium, nearly one fish out of two used for direct human consumption, that is excluding forage fish and trash fish reduced into fishmeal and fish oil (FM, FO, FMFO when referring to both), is a farmed fish (FAO, 2014).

Abbreviations: DHC, direct human consumption; BOD_5, biological oxygen demand after five days; COD, chemical oxygen demand; FAQ, Fair Average Quality; FM, fishmeal; FMFO, fishmeal and fish oil; FO, fish oil; FU, functional unit; IVQ, Individual Vessel Quota; LCA, life cycle assessment; LCI, life cycle inventory; LCIA, life cycle impact assessment.

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Intensive or semi-intensive farming of livestock and aquatic animals (finfish and shrimps in particular) requires feeds with high protein and lipid contents, some of which must be of animal origin to supply essential amino and fatty acids. Those two ingredients are found in fishmeal and fish oil, respectively. Although the substitution of those two commodities by cheaper products of vegetal and animal origin is increasing (Tacon et al., 2011), the increase in farming of livestock and aquatic animals counterbalances these substitutions. There is also a growing demand of fish oil for human consumption (omega-3 fats). Because FMFO demand is still growing whereas the supply remains limited and variable, the prices of FMFO are increasing and volatile (Fréon et al., 2014a).

The food production intensification results in major concern regarding the environmental burden of food production (Garnett, 2014; Soussana, 2014). Environmental assessment approaches on food products, especially those using the life cycle assessment (LCA) approach, started to develop from the 1990s whereas such approaches regarding fisheries and aquaculture developed from the 2000s (Vries and de Boer, 2010; Avadí and Fréon, 2014). In the aquaculture sector, LCAs demonstrated that feed provision accounts for a large share in many of the environmental impacts in this sector (Henriksson et al., 2012, 2015). FMFO contribution within fish feed environmental impacts is substantial and usually ranks first in fish feed of carnivorous species such as salmon and trout (e.g. Pelletier et al., 2009; Avadí et al., 2015). Moreover, feeds for farmed herbivore fish such as *Cichlidae* and *Cyprinidae* often include small amounts of FMFO, thus representing a large aggregated consumption due to the large share of these families in the worlds' aquaculture output (Chiu et al., 2013; Henriksson et al., 2014a). Nonetheless the precision of FMFO impacts in most studies is hindered by the lack of a comprehensive life cycle inventory (LCI) of the FMFO production process. As far as we know, only Denmark benefits from a rough LCI of fishmeal plants, whereas Peru and Norway only benefit from an even more superficial screening. The Danish fishmeal plant LCI, available at http://www.lcafood.dk/, was performed in 2000 at the large (220,000 t of fishmeal per year) Triplenine plant, and most of its data were used as proxies for the other LCIs, in addition to few generic data for freshwater use and waste water (FAO, 1986; COWI, 2000). The Danish inventory includes only 9 inputs (including sandeel, *Ammodytidae* family, as primary material) and 8 outputs (including FMFO and three repeated outputs in different compartments). It excludes all items related to the construction, maintenance and end of life (EOL) phases. Beyond this LCI, there are only few fuel use and electricity consumption data by fishmeal plants compiled by Tyedmers (2000). These data are quite outdated whereas the technology improved substantially during the last decades, resulting in a cleaner production. According to Henriksson et al. (2014b) fishmeal environmental impacts could differ with two orders of magnitude depending upon its origin. Although Peru is the first producer and exporter of FMFO, there is still no publication of a detailed LCA on fishmeal plant but only papers that incorporate the results of such an LCA in different fish supply chain studies (e.g. Avadí and Fréon, 2014; Avadí et al., 2014a, 2015). The objectives of this work are, first, suggesting ways of limiting the environmental impact of different types of Peruvian fishmeal plants, and second, to provide Peruvian-specific and generic LCI data and LCI analysis usable by other LCA practitioners, as detailed in the Goal section.

1.2. The Peruvian FMFO sector

The Peruvian FMFO sector produces in average (2006–2015) 1.183 million t of fishmeal and 230,000 t of fish oil per year, which represent 24% and 23% of the global production, respectively. Peru exports most of this production which relies on the extremely high abundance of the Peruvian anchovy (*Engraulis ringens*), commonly referred to as 'anchoveta'. This species is also characterized by its high variation in abundance and condition (which is reflected by its oil content) at different time scales. The inter-annual volatility is mostly due to El Niño Southern Oscillation (ENSO) events, which can dramatically decrease the production and the fish condition (in the accepted biological sense) and, to a lesser extent, to La Niña events, which favour abundance and condition but often decreases catchability (Bertrand et al., 2004). Abundance cycles over decades and centuries are more pronounced than inter-annual variability, even in the absence of exploitation (Gutiérrez et al., 2009).

The production of FMFO is mostly supplied by the Peruvian industrial fleet of purse-seiners, which by law consists of vessels whose holding capacities are over 32.6 m^3 and land their catches exclusively for reduction into FMFO. This huge fleet subdivides into two major segments: steel vessels and wooden hull vessels (Fréon et al., 2014b). As of 2012, the wooden industrial fleet, nicknamed "Vikingas", consisted of nearly 700 vessels with holding capacities ranging between 32.6 and 110 m^3, whereas the steel industrial sub-segment consisted of 660 vessels with holding capacities ranging between ~90 and 870 m^3. There is also a Peruvian wooden small- and medium-scale (SMS) fleet of purse-seiners with holding capacity under 32.6 m^3. This fleet is subdivided by legislation into two sub-segments: small-scale proper, featuring up to 10 m^3 holding capacity, and medium-scale from 10 to 32.6 m^3 holding capacity and with an overall length of less than 15 m. SMS vessels are allowed by legislation to land anchoveta exclusively for direct human consumption (DHC), but from 2012, 10% of the small-scale anchoveta landings and 40% of the medium-scale one can be legally redirected to reduction under certain conditions. Up to 2008 the industrial fishery was regulated by a single quota whereas the SMS fishery benefited from a full open access. From 2009, an Individual Vessel Quotas (IVQs) system was fully implemented for the industrial fleet. From 2015, by law, a single quota should be implemented for anchoveta aimed at DHC but this measure is still not effective. Illegal, unreported, and unregulated (IUU) fishing is a recurrent problem in Peru (although improving), and in the SMS fleets operations it reached 200% over the officially reported figures. The most of the landing of the SMS fleet used also to be sent to fishmeal plants (324,000 t $year^{-1}$). As a result, the SMS fleet landings for FMFO reduction represented ~6% of total anchoveta catches in the period 2005–2010 and at that time it was fully illegal (Fréon et al., 2014b). In the meantime this figure is likely to have decreased due to new regulations and enforcement.

Three different categories of fishmeal were produced in Peru during the study period (2008–2012), where quality depends mainly on protein, lipid and salt content (Supplementary Material):

1) Standard fishmeal, also are referred to as "fair average quality" (FAQ), usually produced using direct hot air during the drying phase ("flame drying" or "direct-fire drying"), including the so-called "residual fishmeal", often of poor quality, produced from fish residues,
2) Prime fishmeal,
3) Super Prime fishmeal; for producing Prime fishmeal and Super Prime fishmeal, special driers are needed, where typically hot air is produced by circulation of steam in coils or tubes located inside the dryer ("indirect steam drying").

There is no clear definition of fish oil categories in Peru, except for the recent (2009) European sanitary regulation on fish oil importation. This UE regulation deals mostly with freshness of the raw material, and storage and hygiene conditions along the supply chain.

There are three main types of fishmeal plants operating in Peru: