Evaluation of Different Aquaculture Feed Ingredients in Indonesia Using Life Cycle Assessment

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Abstract

Indonesia's aquaculture industry has grown by almost 25% annually over the last five years, an achievement enabled through the increased use of commercial aquaculture feeds, made from agricultural, capture fisheries and livestock resources. The reliance of aquaculture on capture fisheries has, however, attracted criticism, as has the land use consequences of imported Brazilian soybeans. Sourcing more sustainable resources has thus become part of maintaining a good environmental image and to secure long-term growth. In the present study we applied LCA to a number of feed ingredients used by the Indonesian aquaculture industry, including local fishmeal, rice and maize, as well as imported soybean, wheat and livestock byproduct meal (BPM). The impact categories global warming, acidification, eutrophication, land occupation and freshwater consumption were evaluated. Shrimp byproduct meal was generally associated with the largest emissions, followed by poultry byproduct meal. Wheat bran from Australia was the agricultural product with the largest acidification impacts, while rice bran had largest freshwater requirements. Overall, however, a shift is needed away from the overexploited local fish stocks towards alternative substitutes.

Keywords: *Indonesia, LCA, feed, aquaculture, agriculture*

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1. INTRODUCTION

Aquaculture in Indonesia has a history dating back to the 15th century[1]. Production practices have however intensified over the last decades, moving from extensive systems relying on local resources to semi-intensive or intensive production systems sourcing resources form across the planet. This intensification has allowed Indonesia to increase its production of farmed fish (finfish, crustaceans and mollusks) from 0.6 million tons (Mt) in 1994, to 1.1 Mt in 2004, to 4.3 Mt in 2014[2]. Today it provides Indonesians with a cheap source of animal proteins and a source for export incomes[3]. Farmed fish has, as part of this increase, grown to become more popular than chicken, with an annual per capita consumption in excess of 10 kg fish capita^{-1} yr^{-1}.

The expansion of Indonesian aquaculture has, however, also brought with it environmental concerns, including its reliance on wild fish in fishmeal production, eutrophication of lakes and destruction of mangroves[4],[5]. In addition to these, several studies have highlighted the lifecycle related impacts of aquaculture using life cycle assessment (LCA)[6]. A common outcome across these studies is that the provision of feed is responsible for the largest share of most LCA impacts. Two LCA studies, one focusing on tilapia monoculture as well as one on tilapia farmed with carp in Indonesia, reached similar conclusions for the impacts global warming, cumulative energy demand, acidification, water dependence, land occupation and biotic resource use[4],[7]. Only for eutrophication did the actual grow-out account for the bulk of the impacts, but these were in turn driven by the amount of feed used on farm [4],[7].

The Indonesian government has ambitious targets to further expand aquaculture in the country. However, even more modest growth scenarios have been projected to exceed environmentally sustainable levels before 2030[8]. Thus, identifying more environmentally friendly feed ingredients will be essential for allowing Indonesia to intensify production, thereby avoiding the destruction of more virgin forests, without escalating environmental impacts. The present study therefore set out to benchmark common aquafeed ingredients using LCA.

2. METHODS

2.1. Goal and scope

The current research is based on data collected as part of an initiative financed by the Gordon and Betty Moore Foundation and the CGIAR Research Programs. The overarching goal of the present research was to provide guidence to the Indonesian Department of Fisheries on how fish production could be increased most sustainably. The ingredients explored in the research were selected based upon the outcomes of fieldwork carried out in Sumatra and Java in 2014. During the fieldwork, feed millers were interviewed with regards to the raw materials used to produce their feeds and their origins. Once the most relevant feed materials were identified, secondary data were collected from literature (for full sets of data on feeds and grow-out farms, please see Henriksson et al. *in review*).

The LCA models were established using the CMLCA v5.2 with life cycle inventory (LCI) models supported by the ecoinvent v2.2 database. Overall dispersions around different LCI flows were quantified using the protocol presented by Henriksson et al[9]. The system boundry was set to include the grow-out of feed ingredients (incl. field emissions), fuel used, electricity used, transportation, fertilizer production, mineral production (e.g. limestone) and other inventory flows linked to these production chains as described in Henriksson et al. 2015[10].

With respect to available data representative of Indonesia, the impact categories global warming, acidification and eutrophication were explored[11],[12]. Alongside these were land occupation and freshwater consumption estimated by aggregating the sqaure meters occupied annually (m^2a) and cubic meters (m^3) of freshwater made unavailable for other uses (evaporation, discharge to sea, etc). Once the LCA model was established, Monte Carlo simulations (1,000 iterations) were run to evaluate the range of environmetal impacts scaled to a functional unit of one tonne of raw material at feed mill in Indonesia.

Allocation, the subdivision of environmental impacts accross several products originating from the same process were solved using primarily mass allocation and secondarily economic allocation to allow for a sensitivity analysis. In the case of straw, which can greatly influence mass allocation depending upon if it is seen as a coproduct or waste, the present study assumed all staw as waste, except for rice straw. This as rice straw has estalished uses and in most cases a market price.

2.2. Unit process data

With regads fisheries products, Indonesia has some domestic production of fishmeal (22% of overall consumption) and oil (37%) but is largely dependent upon imported products (Table 1)[2],[13]. While data were available on the Peruvian anchoveta fishery[14], Vietnamese mixed fisheries[10], and the Chilean fishery could be assumed as similar to

Peruvian, inventory data remained missing for Korean and Mexican fisheries. Consequently, 40% of the fishmeal and oil were modeled based upon Avadí et al[14], 25% based upon the average of the values presented by Tyedmers[15], 22% as domestically produced assuming 100 kg diesel per tonne fish (CV=1.443), and 13% originating from Vietnam based upon Henriksson et al[10].

Table 1. Origin of Indonesian fishmeal imports. Data from BPS (2012; bps.go.id)

Country of origin	Fish-meal, total	Fish-meal, <60% protein	Fish-meal, >60% protein	Other
Peru	33%	12%	68%	0%
Korea	24%	58%	0%	25%
Vietnam	13%	10%	7%	18%
Mexico	9%	2%	19%	5%
Chile	7%	1%	9%	9%
Total, ktonnes	97.0	20.2	31.6	45.1

As for agricultural products, rice and maize are mainly produced domestically, while soybeans and wheat are imported[17]. USA was the predominant source of soybeans, while most of the wheat was improted from Australia. Both of these LCI models were sourced from Henriksson et al[10].

Table 2. Production, exports, imports and origin of agriculture cropts to Indonesia. Data from FAOStat.

	Paddy rice	Soybeans	Maize	Wheat
Production	6,57E7	8,44E5	1,76E7	0
Export	0	5,70E2	1,27E4	0
Import	5,94E3	2,09E6	3,21E6	5,60E6
Origin of imports:	CN (70%)	US (88%)	IN (39%)	AU (67%)
	IN (29%)	MY (6%)	AR (33%)	CA (18%)
	PH (1%)	AR (3%)	US (13%)	US (13%)

CN = China, IN=India, PH=Philippines, US=United States, MY=Malaysia, AR=Argentina, AU=Australia, CA=Canada.

Domestic farming was based upon an average consumption mix of inorganic fertilizers in Indonesia[18]. Rice is the most important cereal crop to Indonesia and farmers generally get two harvests per year, with some regions achieving three harvests. It is also common to rotate rice with other crops, such as maize, soybean or peanuts [19]. Data on rice farming were derived from Maraseni et al., Sato and Uphoff, Boling et al. and FAOStat[17],[20],[21],[22],[23]. Maize is the second most important cereal crop to Indonesia, with about half of the production centered in central and eastern Java[19]. Data on maize farming were sourced from Swastika et al., Rosas and FAO[17],[19],[23],[24].

Most livestock BPMs used in Indonesia originate from poultry. In the present study, poultry farming was modeled according to Pelletier, Boggia et al., Castellini et al. and Prudêncio da Silva et al.[25],[26],[27],[28]. Emissions from manure management were modeled according to IPCC[29] and byproduct processing according to Ramirez[30].

3. RESULTS AND DISCUSSION

LCIA results are presented as box and whisker plots indicating the median, the 25th and the 75th percentiles (box) and the 5th and 95th percentiles (whiskers). Given the large dispersion, the results were plotted against a logarithmical y-axis.

3.1. Global warming

Shrimp BPM had by far the largest global warming impact, followed by the other protein sources. Soybeans was the protein source with the lowest global warming impact, but controversial land use change in Brazil was not accounted for[31]. The large GHG emissions from shrimp BPM production mainly originated from shrimp feed production, coal burning for dehydrating the shrimp byproducts and diesel burned on farm. As for fishmeal, emissions mainly originated from the burning of fuel on fishing boats; for poultry BPM, from byproduct rendering and methane from manure; and from corn gluten meal and feed, from fossil fuels used to power the wet-milling and dinitrogen monoxide emissions from farms. Cassava had the lowest global warming impact, but also one of the most limited nutritionous profiles.

3.2. Eutrophication

Shrimp BPM was also the feed ingredient with the largest eutrophication impact, mainly consisting of nutrient run-off from shrimp ponds (Fig. 2). Rice bran and poultry BPM also had large eutrophying emissions, primarily from ammonia from nitrate run-off from paddies and ammonia emissions from manure, respectively. Cassava again had the lowest impact, followed by soybean meal and oil.

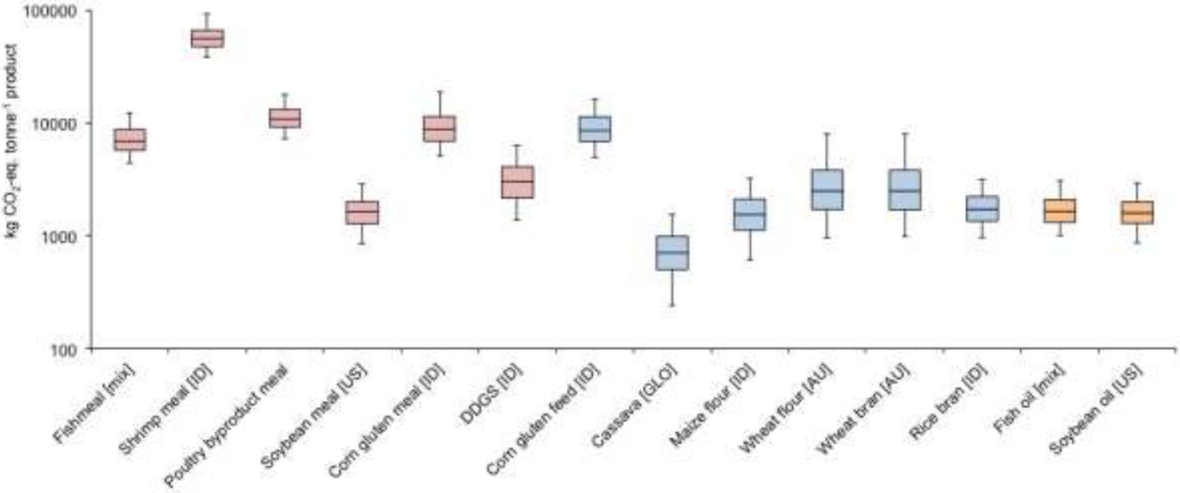

Fig. 1. Global warming impacts per tonne of aquaculture feed ingredient used in Indonesia using mass allocation. Boxes represent the median and the 50% confidence interval; whiskers the 90% confidence interval; red = protein sources; blue = carbohydrate sources; orange = oils

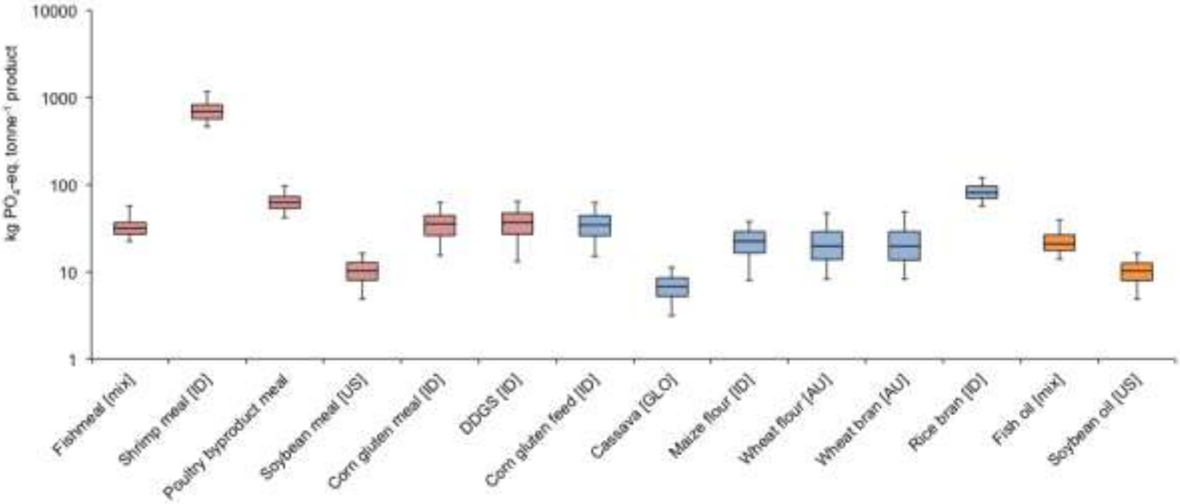

Fig. 2. Eutrophication impacts per tonne of aquaculture feed ingredient used in Indonesia using mass allocation. Boxes represent the median and the 50% confidence interval; whiskers the 90% confidence interval; red = protein sources; blue = carbohydrate sources; orange = oils

3.3. Acidification

Shrimp meal again performed the worst with regards to acidification, a result of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions from the burning of fossil fuels (Fig. 3). Poultry BPM were the second most polluting feed ingredients with most emissions again associated to ammonia from manure management. Cassava had the lowest impact, followed by rice bran fish oil and soybean meal and oil. Accross all agriculture, ammonia and nitrogen oxides from fields were the dominant emissions.

3.4. Land occupation

Shrimp BPM was again the most demanding in terms of land occupation, followed by poultry BPM (Fig. 4). Most of the agricultural products required less than a magnitude of order less land. Fishmeal and fish oil were, however, far less land demanding.

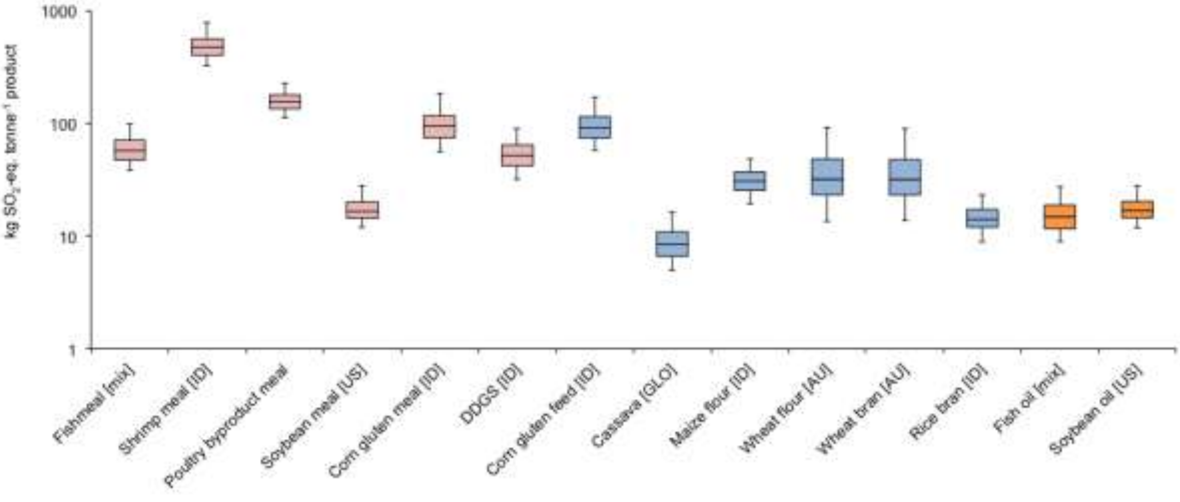

Fig. 3. Acidification impacts per tonne of aquaculture feed ingredient used in Indonesia using mass allocation. Boxes represent the median and the 50% confidence interval; whiskers the 90% confidence interval; red = protein sources; blue = carbohydrate sources; orange = oils

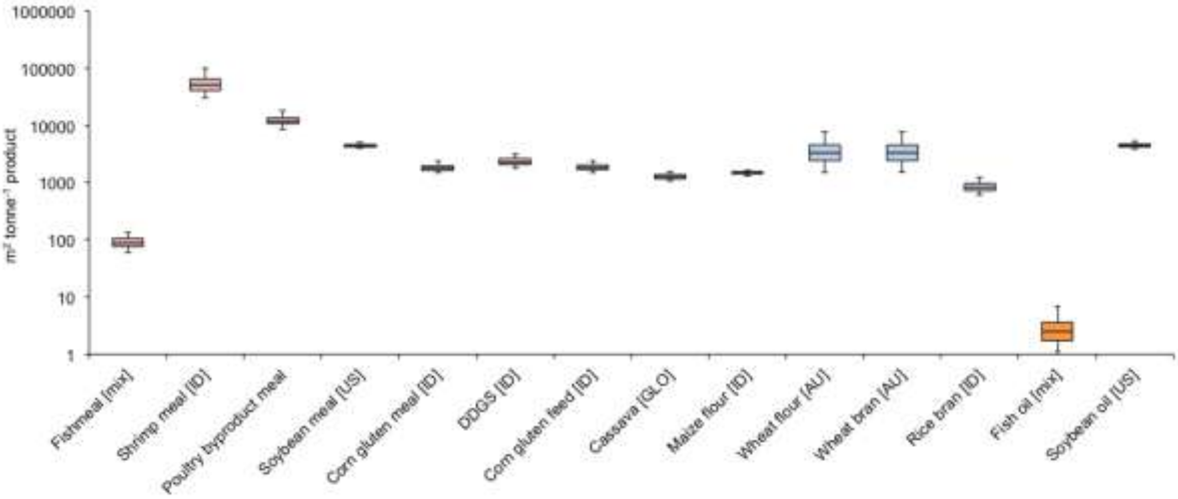

Fig. 4. Land occupation per tonne of aquaculture feed ingredient used in Indonesia using mass allocation. Boxes represent the median and the 50% confidence interval; whiskers the 90% confidence interval; red = protein sources; blue = carbohydrate sources; orange = oils

3.5. Fresh water consumption

In terms of freshwater demand shrimp meal and rice bran performed the worst (Fig. 5). Apart from shrimp BPM, where a substantial amount of water was used to dilute marine water to brackish water, most of the fresh water was consumption in irrigation. Fishmeal and fish oil consequently had much lower fresh water requirements, as only required some water in refineries, on fishing boats and in processing. Cassava, however, consumed the least amount of water as it generally is not irrigated.

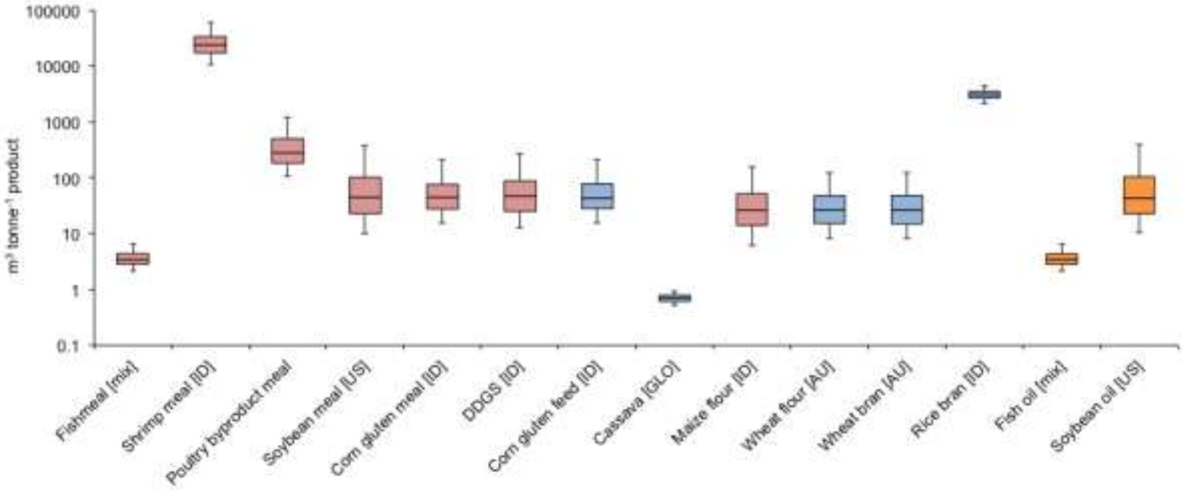

Fig. 5. Freshwater consumption per tonne of aquaculture feed ingredient. Boxes represent the median and the 50% confidence interval; whiskers the 90% confidence interval; red = protein sources; blue = carbohydrate sources; orange = oils.

3.6. Sensitivity analysis

Among the many pivotal choices made, coproduct allocation was one with large influences on outcomes. A sensitivity analysis was therefore conducted comparing mass allocated results with results using economic allocation (Fig. 6). The sensitivity analysis showed little difference between allocation factors for cassava, maize flour, fish oil, wheat flour and corn gluten meal. However, fishmeal, rice bran, poultry BPM, DDGS, corn gluten feed and shrimp BPM all had much lower impacts using economic allocation. The reason for this, apart from corn gluten feed, is that the feed industry is making use of co-product streams that otherwise would be waste. In the case of corn gluten feed, it is simply its lower value compared to the other productions from maize wet-milling, namely corn gluten meal, corn oil and ethanol. Soybean oil, in the meantime, was associated with larger impacts when economic allocation was used. This since the value of soybean oil is higher than that of soybean meal.

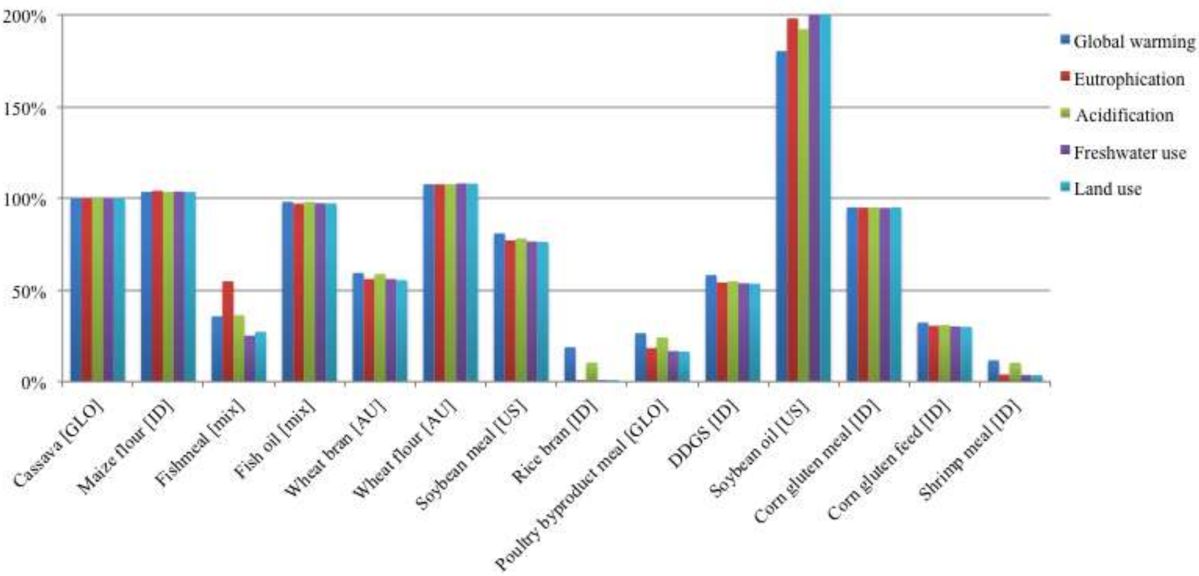

Fig. 6. Sensitivity analysis comparing results using mass allocation with results using economic allocation (economic allocation/mass allocation)

4. CONCLUSIONS

Across the ingredients studied, protein sources generally had higher impacts than carbohydrate sources and oils, using mass allocation. Cassava was associated with the lowest global warming, acidification and eutrophication impacts. However, using economic allocation, rice bran had the lower impacts. Both these ingredients are unfortunately low in protein and of limited nutriontional quality. Animal derived protein souces (fishmeal, poultry BPM and shrimp BPM) were in the meantime often associated with larger environmental impacts, apart from fishmeal with regards to freshwater consumption and land occupation. Capture fisheries are, however, related to many other environmental consequences not covered by the impact categories in this LCA (e.g. overexploitation and seafloor destruction) and should therefore be minimized. This especially since several Indonesian fishstocks used for reduction already are overexploited[32]. Thus, herbivorous and omnivorous fish should be promoted in place of carnivorous species.

Distance from origin had limited influence on the different impacts. Indonesia’s reliance on imported feed ingredients, however, makes the country vulnerable to fluctuations on world markets. Thus, domestic alternative feed resources should be identified and promoted. More sustainable alternatives should therefore be explored, such as e.g. fish byproduct meal, insect meals, yeasts, aquatic plants, etc.

Feed ingredients from aquatic plants might hold especially large potential in Indonesia, given its extensive shorelines. Algae could help substitute animal derived feed ingredients, given that they can be rich in both protein and carbohydrates[33]. Shortcomings in the supply of fishmeal with overall increasing demand for protein rich ingredients will also likely improve the financial gains of algae farming[33]. However, different algae species and farming systems should be reviewed using LCA to identify the most sustainable practices.

The large dispersion around results and strong influence of allocation highlights the danger of comparing LCA results and product footprints accross studies. Comparisons should instead be kept study specific [34].

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