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# Inferred equations for predicting cumulative exergy extraction throughout cradle-to-gate life cycles of Pangasius feeds and intensive Pangasius grow-out farms in Vietnam

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ABSTRACT

Intensive Pangasius aquaculture in Vietnam has attracted concerns about the sustainability of its resource use. However, the assessment of the latter, using Life Cycle Assessment (LCA), is a time-consuming and complex task. To establish a simplified approach, especially relevant for certification incentives, as an alternative to a full LCA, we first highlight key parameters in resource use of the system to provide a better understanding of the variability in LCA results, and second present inferred equations that allow for an easy estimation of the resource footprint using some of these key parameters.

A representative sample of 10 certified (i.e., ASC and GLOBALG.A.P.) and 10 non-certified intensive Pangasius farms in the Mekong Delta was investigated. Detailed LCA results, resulting in resource consumption in terms of the Cumulative Exergy Extraction from Natural Environment (CEENE), showed that pond water renewal and feed production, particularly agriculture-based feed ingredients, were the hotspots.

Inferred equations, in fact linear regression models, were successfully set up and have proven to be useful to estimate the resource footprint of Pangasius feeds and aquaculture using parameters identified as the resource use hotspots. The CEENE over the cradle to feed mill gate per tonne feed could be predicted from the mass share of agriculture-based ingredients ($R^2 \geq 0.90$, n = 12 feeds). The CEENE over the cradle to farm gate per tonne Pangasius fish in the certified farms and/or non-certified farms can be explained by the amount of water and feed inputs ($R^2 \geq 0.98$, n = 20 farms), which highlights the relevance of managing these resources in intensive Pangasius farming, and subsequent equations were also set up.

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## 1. Introduction

Whereas catches from wild capture fisheries levelled off since the mid-1980s, aquaculture has remained one of the fastest-growing food producing sectors with an average annual growth rate of 8.3% worldwide in the period 1970–2008 (FAO, 2010). Aquaculture now provides almost half of all fish for human consumption and this share is projected to rise to 62 percent by 2030 (FAO, 2014). As this sector has emerged as a significant food production system on a global scale, concerns about its environmental impacts have emerged as well. Life cycle assessment (LCA) has proved to be a valuable tool to assess overall environmental performance of aquaculture and to identify environmental hotspots for process optimization (Cao et al., 2013; Pelletier and Tyedmers, 2008). Aquaculture LCAs have, however, mostly focused on production systems in developed countries (Henriksson et al., 2012) whereas Asia contributed around 88% of world aquaculture production by volume (FAO, 2014).

*Pangasius Hypothalamus* (here referred to as Pangasius), with a global annual production of 1.3 million tonnes, mainly in Vietnam, has achieved a very fast supply growth at a global level, along with tilapia and carp (FAO, 2014). International markets, especially the United States and the European Union, were eager to introduce Pangasius fillets as a cheap substitute for the more expen-

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sive generic whitefish from classic fisheries (Belton et al., 2011; FAO, 2014). However, important resources, e.g., land, water, and energy, are finite and competed between aquaculture and other sectors (e.g., agriculture, livestock, etc.). This may cause a conflict between resource users and constrain the future growth of Pangasius aquaculture. Local Pangasius producers presently follow several sustainability certification schemes recognized by international markets, typically the Aquaculture Stewardship Council (ASC) and the Global Partnership for Good Agricultural Practice (GLOBALG.A.P.). These standards set criteria to ascertain that aquaculture practices at a farm are reasonably environmentally and socially sustainable. By August 2015, Vietnam has 42 Pangasius ASC-certified farms and 15 other farms under ASC assessment (ASC, 2016) while 27 Pangasius producers have achieved the GLOBALG.A.P. certification (GlobalGAP, 2016).

The resource use efficiency has been studied of the Vietnamese Pangasius production, comprising of non-certified intensive pond farming (Huysveld et al., 2013), fish processing, transportation (to Europe) and reprocessing (Nhu et al., 2015). Using the LCA approach, these authors highlighted the hotspots in resource use throughout the cradle-to-gate life cycle of two Pangasius fillet products, i.e., frozen fillets and modified atmosphere packaging (MAP) fillets. Aquaculture, particularly its farm feed and water inputs, were the highest contributors to the resource footprint even though the fillets were transported overseas over a distance of about 12000 km. In light of the need for environmentally sustainable practices, Pangasius producers, would benefit from being able to easily quantify the resource use efficiency on their own. In addition to resource use, emission-related indicators (e.g., global warming, toxicity impacts) of such production were also considered in the LCA literature (Bosma et al., 2011; Henriksson et al., 2015a; Henriksson et al., 2015b). However, full LCAs require complex modelling and time-consuming data collection (Horne et al., 2009). An easy calculation tool could hence simplify this task, consisting of a methodological framework in which equations/models are used to estimate the resource footprint of intensive Pangasius aquaculture using limited input data. A similar framework was established to quantify the resource footprint of pharmaceuticals (De Soete et al., 2014), greenhouse gas impacts of wind electricity (Padey et al., 2012), and environmental assessment (e.g., global warming, non-renewable energy, etc.) of an agricultural region (Avadí et al., 2016).

The first objective of the study is to identify the resource consumption hotspots of intensive Pangasius aquaculture relying on LCA for 10 certified (i.e., ASC and GLOBALG.A.P.) and 10 non-certified farms in the Mekong Delta (Vietnam). While different impact methods exist that account for or assess the resource consumption/usage, the selection of the impact assessment method depends on the type of production system (Swart et al., 2015). Since Pangasius is a biological product, accounting of biotic resources and land, and their related energy flows, are of the essence. We applied the Cumulative Exergy Extraction from the Natural Environment (CEENE) (Dewulf et al., 2007), which is considered one of the two best thermodynamic resource indicators (Liao et al., 2012). The CEENE method covers all resource types (i.e., the biotic and abiotic resources) through the following eight categories: renewable resources, fossil fuels, nuclear energy, metal ores, minerals, water resources, land and biotic resources and atmospheric resources. All resources were expressed in one common unit: Joules of exergy (Jex). Exergy, defined as the amount of maximum useful energy obtained from a resource when bringing it to a predefined reference state, accounts for both the quality and quantity of material and energy flows (Dewulf et al., 2008). We only focus on resource consumption and not on emissions. Secondly, based on this platform knowledge, the authors then derive straightforward equations to estimate resource consumption of Pangasius feed and fish production, based on the linear correlation between the resource footprint and certain predictor variables (e.g. amount of water use, derived out of the hotspot identification) of Pangasius intensive farms.

## 2. Materials and methods

### 2.1. Hotspot identification through LCA

#### 2.1.1. Goal and scope

Resource use analysis of intensive Pangasius aquaculture, including certified and non-certified farms, was obtained by performing a cradle-to-farm gate LCA according to the ISO 14040/14044 guidelines (ISO, 2006a, 2006b). Infrastructure, maintenance, and labour were excluded while transport of ingredients from origins to feed mills and of inputs to the farms were accounted for. No primary data were available on fingerling stocking in certified farms. The contribution of fingerling production was quantified based on the primary data of 7 fingerling production systems with an average weight of 52 ± 29 g per fingerling studied by Huysveld et al. (2013) (see Section 3.2.2) since there is very little detailed (data) information available for the hatchery production of Pangasius. The functional unit (FU) was set at one tonne live-weight of Pangasius delivered at the farm gate. The functional unit (FU) was set at one tonne live-weight of Pangasius delivered at the farm gate.

#### 2.1.2. Life cycle inventory (LCI)

Foreground data of Pangasius aquaculture were obtained from 10 certified farms (CFs) and 10 non-certified farms (NFs). A survey was conducted in 2013 by administering a questionnaire to the producers of 20 farms in the Mekong Delta in Vietnam, of which 10 CFs (CF1 to CF10) and 3 NFs (NF1 to NF3) provided enough data which were recorded in the first half 2013. In total, these farms used 7 different types of feed, i.e., F1 to F7, of which ingredient compositions were provided by the producers. The 10 CFs achieved both ASC and GLOBALG.A.P. certifications. This study also considered the four farms (NF4 to NF7) studied by Huysveld et al. (2013) and Nhu et al. (2015), and the three farms (NF8 to NF10) studied by van der Heijden et al. (2012). The average composition (Fa) of feeds F1 to F7 was applied to the three farms NF8, NF9 and NF10 since neither feed types nor compositions were presented for these farms. All CFs and NFs met the following criteria: (i) intensive pond farming, and (ii) their water input was measured throughout the production, and not estimated as done in other studies (Bosma et al., 2011; Phan et al., 2009). Water input is here the water removed from the body and introduced into the farm (i.e., water exchange through the pond). Land occupation ($m^2$ year $kg^{-1}$) of the production processes of agriculture-based inputs was calculated by the average 10-year (2003–2012) data of crop productivity (kg $ha^{-1}$ $year^{-1}$) (FAOSTAT, 2016). Chemicals for farming (except lime) were assumed as organic chemicals because of unavailability of detailed information (i.e., list of chemicals, quantity used of each type). Rainfall quantity was taken from the dataset produced by the Climatic Research Unit (CRU) of University of East Anglia (UEA) for Vietnam at Cai Be in the 1990–2012 period (World Bank group, 2016).

Moreover, this study considered 12 different feed types, including F1 to F7 from the survey (2013), F8 from Huysveld et al. (2013) mentioned above and other four types (F9 to F12) studied in Bosma et al. (2011) to identify resource hotspots for feed production, and also considered for the subsequent simplification, though feeds F9 to F12 were not used by the 20 studied farms. These 12 feeds were all commercial feeds. In addition to the feed compositions, other inputs of feed production (i.e., electricity, diesel, water use), origins of feed ingredients and transportation distances of feed ingredients to the feed mills and of farm inputs (e.g., chemicals, feed, etc.) to the

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