LIFE CYCLE ANALYSIS TO EVALUATE THE PRODUCTIVE CHAIN OF FISH CONSUMED IN THE BAHIA STATE (BRAZIL)

Eduardo Rômulo Nunes RODRIGUES[1*], Diego Lima MEDEIROS[2], André de Almeida MENDONÇA[3], Catarina da Rocha MARCOLIN, Ricardo Castelo Branco ALBINATI[5], Carlos Roberto FRANKE[6]

ABSTRACT

We evaluated the productive chain of fish consumed in the State of Bahia using Life Cycle Analysis (LCA). We estimated the inputs and outputs from logistics and fish processing. For every kg of processed and transported fish we calculated the Global Warming Potential (GWP) based on the amount of Greenhouse Gases (GHG) given in kg of CO_2eq, as follows: 0.020 – electricity; 0.003 – water consumption; 0.002 – wastewater; 0.160 and 1.495 – waste from the gutted and filleted fish, respectively; 0.871 and 1.007 – refrigerated transportation of gutted and filleted fish, respectively. The sum of GHG emissions were 1.058 and 2.592 kg of CO_2eq per kg of gutted and filleted fish, respectively. LCA results indicate that it is possible to reduce the GWP associated with refrigerated transportation by increasing local fish production and decreasing importation, especially given the available water potential of Bahia. However, to achieve a sustainable production it is imperative to adopt and develop technologies that promote environmental impact reduction from solid residues.

Key words: Life Cycle Analysis (LCA); Greenhouse Gases (GHG); food delivery; aquaculture.

ANÁLISE DO CICLO DE VIDA PARA AVALIAR A CADEIA PRODUTIVA DO PESCADO CONSUMIDO NO ESTADO DA BAHIA (BRAZIL)

RESUMO

Avaliamos a cadeia produtiva do pescado consumido no estado da Bahia utilizando a Análise de Ciclo de Vida (ACV). Estimamos os consumos e emissões associados à logística e ao processamento do peixe. O Potencial de Aquecimento Global (PAG) foi calculado com base na quantidade de Gases Efeito Estufa (GEE) indicadas por kg de CO_2eq para cada kg de peixe processado foram: 0,020 - eletricidade; 0,003 – consumo de água; 0,0029 – efluentes; 0,160 e 1,495 – resíduos sólidos para os peixes eviscerados e filetados, respectivamente, e 0,871 e 1,007 – transporte refrigerado dos peixes eviscerados e filetados, respectivamente. O somatório do impacto das emissões de GEE foram 1,058 e 2,529 kg de CO_2eq por kg de peixe eviscerado e filetado, respectivamente. Os resultados indicaram que é possível reduzir o PAG do transporte refrigerado com o aumento da produção local de peixe e redução das importações, especialmente considerando o potencial hídrico da Bahia. Entretanto, a produção sustentável requer a adoção e desenvolvimento de tecnologias para reduzir os impactos ambientais do tratamento dos resíduos sólidos da etapa de processamento.

Palavras-chave: Análise do Ciclo de Vida (ACV); Gases Efeito Estufa (GEE); distribuição de alimentos; aquicultura.

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[1,2,5,6]*Federal University of Bahia, Av. Adhemar de Barros, 500, Ondina, Salvador - BA, 40170-110, Brazil*
[3]*Bahia Pesca S/A Av. Adhemar de Barros, sn, Ondina, Salvador - BA, 40170-110, Brazil*
[4]*Universidade Federal do Sul da Bahia. BR 367, km 10. Campus Sosígenes Costa. Porto Seguro, BA, 45810-000, Brazil.*
[1*]*erodrigues659@gmail.com (autor para correspondência); 2diegomedeiros350@gmail.com;* [3]*andre.mendonca@outlook.com, 4catmarcolin@gmail.com; 5albinati.piscicultura@gmail.com;* [6]*franke@ufba.br*

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INTRODUCTION

The fish produced in the world by capture fisheries and aquaculture was 158 million (t) in 2012, from which 136 million were intended to human consumption in a rate of 19.2 kg per capita (FAO, 2014). In addition, the Brazilian fish production is lower than its consumption. At the Bahia State, in 2010 the fish production was 119,601 tons (BRASIL, 2011). In addition, the fish importation was 3,343 tons *in natura* and 32,606 tons as processed fish, and the exportation was 534 tons (BRASIL, 2010). The average annual consumption rate is 11 kg per person at the Bahia State.

In Brazil 50% of waste from fish processing are reused, whereas the rest is wasted during canning or in other stages of production, such as filleting and gutting (STEVANATO *et al.,* 2007). In the south of Brazil, 68% of residue from the fish processing industry goes to the fishmeal industry, 23% goes to municipal landfills and 9% are discharged into rivers (STORI *et al.,* 2006). VALENTE *et al.* (2014) affirms that composting is an efficient alternative of waste management from fish processing. Another source of waste from fish processing is the discharge of wastewater without treatment into water bodies, increasing the amount of nutrient in the environment (KUMMER *et al.,* 2011). The wastewater discharge, if not properly treated prior to its release on the aquatic environment, may result into severe damages, including eutrophication and the death of fish fauna (FLAHERTY and KARNJANAKESORN, 1995; KAUTSKY *et al.,* 2000; KUMMER *et al.,* 2011). The use of antibiotics and pesticides may also lead to soil and water quality deterioration (PRIMAVERA, 1993; LE and MUNEKAGE, 2004).

The increase in fish consumption elevates the pressure on both fishing and aquaculture activities over natural resources, which demands a rearrangement of the entire productive chain associated to the fish (KIMPARA *et al.,* 2010). The definition of fish production boundaries, supported by capacity models and environmental monitoring, are key to sustain the increasing fish demand. In addition, the regionalization of trade, such as production, transport and processing must be seen in detail to improve supply chain ecoefficiency. Life Cycle Assessment is a suitable method to identify the environmental impacts associated with a product from the extraction of raw material to the waste disposal. Life Cycle Analysis (LCA) is used to evaluate specific impact categories, such as Global Warming Potential (GWP) based on greenhouse gases emissions (GHG) associated with resources consumed in one or more stages of its life cycle. Previous studies have used LCA to evaluate the impacts on specific stages of the fish production chain (PAPATRYPHON *et al.,* 2004; TYEDMERS, 2004). HENRIKSSON *et al*. (2015) evaluated the GHG emissions of catfish (*Pangasius* spp.) farms in Vietnam and the average GWP were 6.7 and 5.9 kg CO_2eq per kg of fish for small and large scales, respectively. YACOUT *et al*. (2016) assessed tilapia production in Egypt and the GWP were 0.96 and 6.12 kg CO_2eq per kg of fish for intensive and semi-intensive systems, respectively.

We used the Bahia State as a case study to evaluate the global warming potential associated with the supply chain (transport and processing) of the imported fish from different national states, using the LCA for this purpose. We discuss our results in terms of public policies to promote sustainability along the fish supply chain.

MATERIAL AND METHODS

The Life Cycle Analysis (LCA) methodology was based on ISO 14044 (2006) and the study covered the fish supply chain from gate-to-gate.

Scope

The fish production chain involves three steps: production, processing, and delivery. We evaluated the greenhouse gases from gate-to-gate related to processing and distribution stages, as shown in Figure 1.

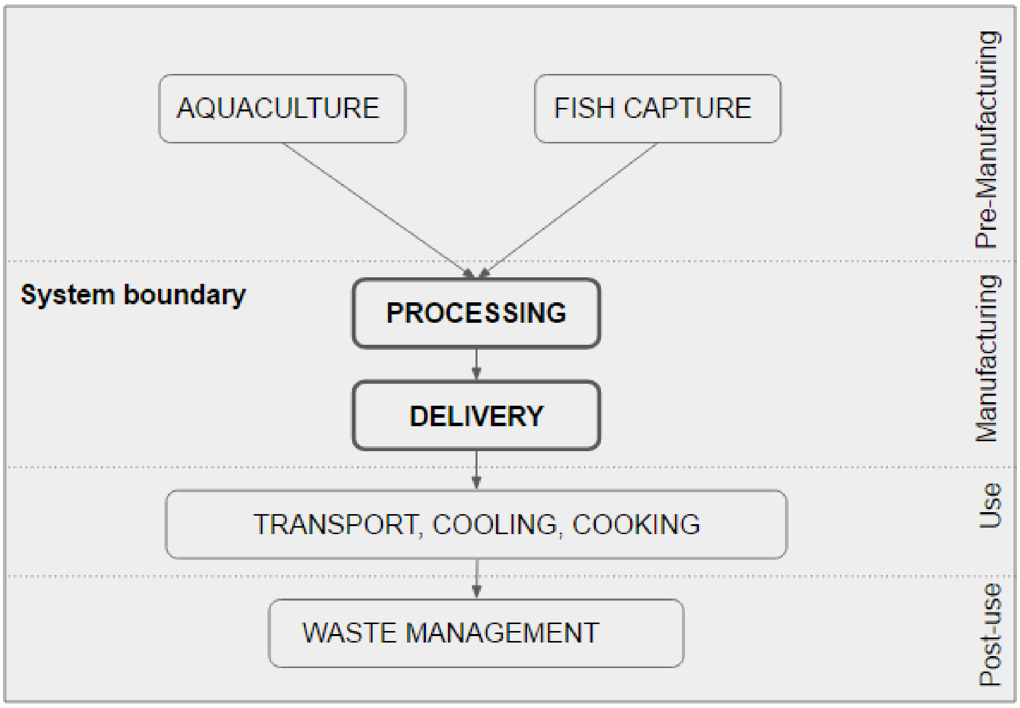


Figure 1. Fish supply chain and study system boundary.

In this study, the production stage associated to fish larvae production, fish farming growth, or capture during fishing activities of the national imported fish was not included. The processing stage corresponds to washing, peeling, gutting, filleting, freezing and storage. Afterwards, the processed fish is transported to the costumers. The fossil fuels and electrical energy demands for freezing increase according to the distance between the production and consumption locations. We used the kg of processed and transported fish as a reference flow and compared the Global Warming Potential (GWP) of gutted and filleted fish.

Life Cycle Inventory - LCI

We defined the amount of the entire fish that is necessary to obtain one kg of gutted and filleted fish, as well as the amount of water, energy spent during both fish processing, transport to collect the waste and deliver the product, and the amount of waste and wastewater generated to treatment. The amount of tap water necessary to process one kg of fish was estimated in 5.36 L (SOUZA *et al.*, 2008; THRANE *et al.*, 2009). The average electricity consumption during processing was 0.09 KWh kg^{-1} of processed fish, considering a production scale of 312.5 kg h^{-1} (SHIROTA *et al.*, 2000; ROCHA *et al.*, 2010).

The average distance traveled for product transportation, considering only road transportation by refrigerated truck, was 1455 km. The distance traveled by the imported fish was obtained at the Secretary of the State of Bahia (SEFAZ). We considered one way of refrigerated transport and the way back with no refrigeration. The waste transport distance to the landfill was 25 km. The residue production at fish processing facilities, especially in those specialized in tilapia filleting represents 62.5 – 66.5% (BOSCOLO *et al.*, 2001) and 54 – 86% (KUBITZA and CAMPOS, 2006) of the entire fish. Given the variability in residue in relation to the weight and the species of fish, we estimated an average of 20% and 70% of loss for gutted and filleted fish (Table 1).

Table 1. Waste generation of fish processing.

Fish processing waste	Fish in general*	Gutted fish	Filleted fish	Unit
Gut	8 – 16	16	16	%
Skin	2 - 6	-	3	%
Scale	2 - 4	4	3	%
Head	12 - 25	-	18	%
Fishbone, with adhered meat	30 – 35	-	30	%
Sum of waste	54 – 86	20	70	%
Entire Fish	-	1.25	3.3	Kg Kg^{-1} of product
Processing waste	-	0.25	2.3	Kg Kg^{-1} of product

* KUBTIZA and CAMPOS (2006)

We estimated the amount of wastewater as 5.25 L kg^{-1} of processed fish based on the generation rate of 98% of the consumed water (SOUZA *et al.*, 2008). Table 2 presents the gate-to-gate LCI of gutted and filleted fish. The background input and output environmental data were taken from ecoinvent LCA database (WERNET *et al.*, 2016) version 3.2 (MORENO-RUIZ *et al.*, 2015).

Table 2. Life Cycle Inventory of processed and transported fish.

	Gutted fish	Filleted fish	Unit	Comment
Inputs				
entire fish	1.25	3.33	Kg	This study
water	5.36	5.36	Kg	SOUZA *et al.*, 2008; THRANE *et al.*, 2009
electricity	0.09	0.09	KWh	SHIROTA *et al.*, 2000; ROCHA *et al.*, 2010
transport, refrigerated, way to	1455.00	1455.00	Kg*Km	SEFAZ (2012)
transport, way back	1455.00	1455.00	Kg*Km	SEFAZ (2012)
Outputs				
waste, landfill	0.25	2.33	Kg	BOSCOLO *et al.*, (2001); KUBITZA e CAMPOS 2006
wastewater	5.25	5.25	L	SOUZA *et al.*, 2008
transport of waste	12.50	116.50	Kg*Km	Estimated
product	1.00	.00	Kg	This study

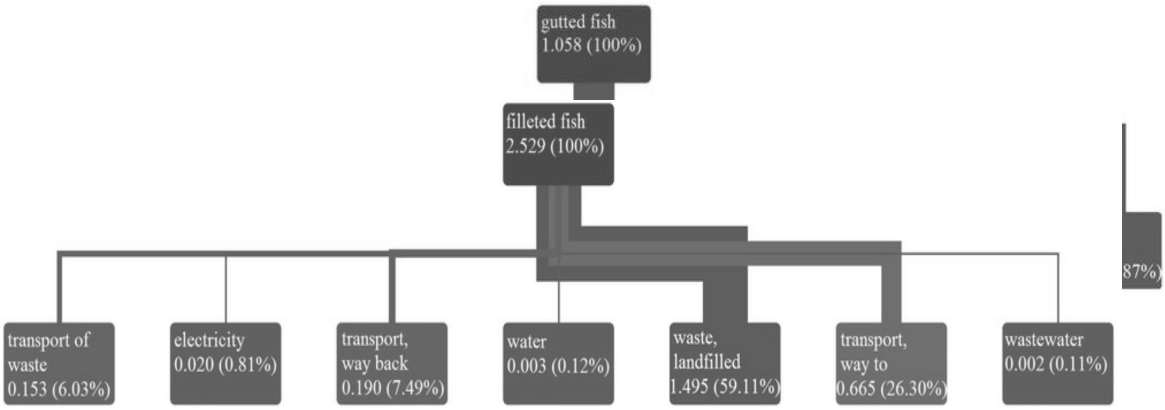
Impact Assessment - LCIA

We used the LCIA method IPCC 2013 100 years to measure the Global Warming Potential (GWP) of Greenhouse Gas (GHG) emissions. GWP impact is indicated in equivalent carbon dioxide (CO_2eq), resulted from the conversion of each GWP of the GHG to equivalents of carbon dioxide. The results are expressed in kg of CO_2eq kg^{-1} of delivered gutted or filleted fish. We used the software OpenLCA version 1.4.2 to calculate the LCIA.

The LCIA results indicated that the highest GHG occurred during refrigerated transport and solid waste treatment (Figures 2 and 3). The GWP impact of gutted and filleted fish were 1.058 and 2.529 kg of CO_2eq kg^{-1}.

Figure 2. Global Warming Potential from gate-to-gate of gutted fish in absolute and relative quantities. The line width represents the proportion of the GHG impact contributions. Source: Adapted from OpenLCA 1.4.2.

Figure 3. Global Warming Potential from gate-to-gate of filleted fish in absolute and relative quantities. The line width represents the proportion of the GHG impact contributions. Source: Adapted from OpenLCA 1.4.2.



RESULTS

The main source of GHG emissions of the gutted-fish chain was the refrigerated transportation. When the transport is coming back, it does not need refrigeration, providing relatively lower emissions. The main source of GHG emissions of filleted fish was the waste treatment in sanitary landfills, followed by the refrigerated transportation. For both production chains, the remaining inputs and outputs such as electricity, water, wastewater, and waste collection had lower contributions.

The main GHG contributions were from fossil carbon dioxide and biogenic methane, as shown in Figure 4. The main fossil carbon dioxide source in Figure 4 was the transportation processes and the main biogenic methane source was the sanitary landfill.

Marine species provided the highest importation budget to the Bahia State. Table 3 shows the rank of the most fish national importer states and its distance, quantity, and respective GWP impact of traveling and final products. It is important to highlight that the transportation impact factor increases according to the distance from the consumer market. The main importer States were Santa Catarina and Rio de Janeiro, which are coastal States. Their geographical locations are favorable to transportation by water, which consumes less fuel but takes longer and leads to a higher energy consumption with refrigeration. The State of Bahia imports 32,606 t of fish, but species were only identified for 11,662 t. The fish was then categorized just as frozen fish or fresh fish. Therefore, we could not perform a detailed analysis that considered the type of processing per specie for each Federal State.

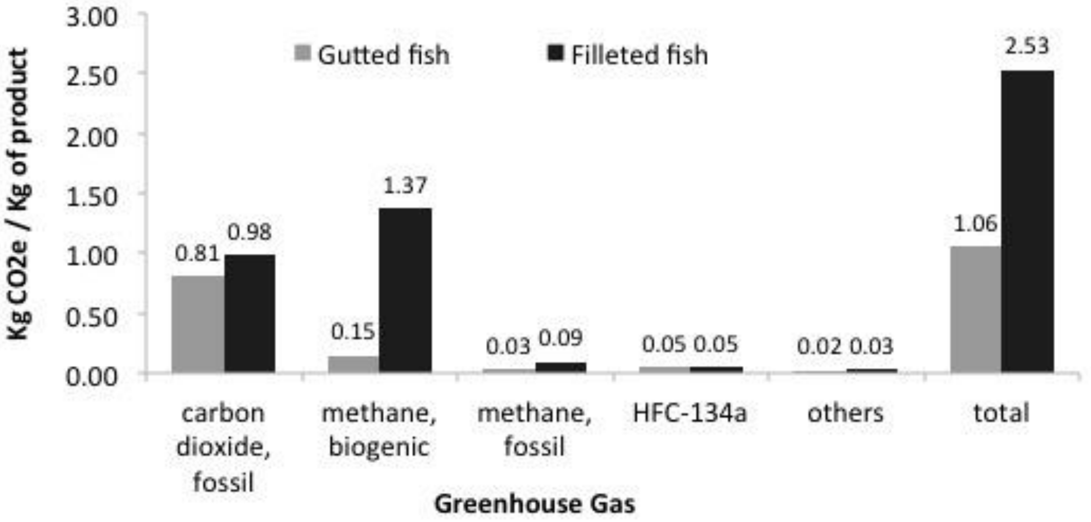


Figure 4. GHG contribution per substance from gate-to-gate of gutted and filleted fish.

Table 3. National importer States for the fish consumed at the Bahia State and their respective production, distance from consumers, and GWP impacts. The distances were calculated based on State capitals.

State	Distance to Salvador (km)	Import (t)	Transport (kg CO_2eq kg^{-1} of product)	Gutted fish distributed (kg CO_2eq kg^{-1} of product)	Filleted fish distributed (kg CO_2eq kg^{-1} of product)
Santa Catarina	2,682	15,172	1.576	1.779	3.250
Pará	2,100	10,973	1.234	1.437	2.908
Rio de Janeiro	1,649	2,692	0.969	1.172	2.643
Espírito Santo	839	999	0.493	0.696	2.167
Rio Grande do Sul	3,090	608	1.816	2.019	3.490
Pernambuco	839	473	0.493	0.696	2.167
Rio Grande do Norte	1,126	451	0.662	0.865	2.336
São Paulo	1,979	391	1.163	1.366	2.837
Amazonas	5,009	306	2.943	3.146	4.617
Sergipe	356	125	0.209	0.412	1.883
Ceará	1,389	102	0.816	1.019	2.490
Amapá	2,004	73	1.178	1.381	2.852
Piauí	994	68	0.584	0.787	2.258
Distrito federal	1,446	51	0.850	1.053	2.524
Minas Gerais	1,372	45	0.806	1.009	2.480
Maranhão	1,323	37	0.777	0.980	2.451
Paraná	2,385	31	1.401	1.604	3.075
Alagoas	632	4	0.371	0.574	2.045
Goiás	1,643	2	0.965	1.168	2.639
Acre	4,457	2	2.619	2.822	4.293
Tocantins	1,454	1	0.854	1.057	2.528

DISCUSSION

The filleted fish processing produces more waste compared to gutted fish. The Brazilian fish processing industry still produces a considerable amount of residue and lacks proper technology to turn waste into valuable products, as only half of the fish residue is reused (STEVANATO *et al.*, 2007). Fish feed production and energy consumption are the major environmental issues on the tilapia production, then ecofriendly fish feed and energy efficiency are key to lower environmental impacts of fish production

(YACOUT *et al*., 2016). The residue usage to produce ration, fertilizers, biofuels, or silage to directly feed the farming fish may reduce the environmental impacts of fish processing residues and fish feed production.

The wastewater may be similarly reused as fertilizers in agriculture, which would reduce the costs with nitrogen and phosphorus, and reduce pollution and the GWP. Indeed STEPHEN *et al.* (2015) points out that few agricultural regions with high application rates of nitrogen and phosphorus are the main contributors to the transgression of the planetary boundaries. The nutrients for agriculture are increasingly more expensive. Therefore, it is imperative to implement strategies to use the wastes that contain these nutrients as new products and contribute to stability of the biogeochemical cycles.

An elevated contribution of GHG emissions from fish transportation was previously presented by ZIEGLER *et al.* (2003) and THRANE (2006). On the other hand, PENA (2012) analyzed the GHG emissions of salmon production from fisheries in Portugal and demonstrated that the type of ship used to capture the salmon did not influence significantly the GHG emissions. Long-distance air transportation of product contributed more to the GHG emission, followed by terrestrial transportation, and the lowest emissions were observed on railroad transportation. This author argues that high-load means of transportation could reduce the GHG emissions per kg of fish. The present study found that the transportation is one of the main GHG contributors, but it should be interpreted with caution since the coverage did not include the production stage, which is relevant to aquaculture production.

The parcel of GHG emissions derived from transportation may also influence the bulk of emissions for several kinds of food. According to GONZÁLEZ *et al.* (2011) the transport of 1 kg of meat from Argentina to Gothenburg, Sweden, represents 7% of the total energy and 1.3% of the GWP impact. On the other hand, the authors found that the transportation of grains or beans from Brazil or Argentina to Sweden may achieve 60% of the total energy and GWP impact. This means that meat production has a higher impact compared to vegetables and the transportation is less relevant for the meat. If the meat is not produced, but it is taken directly from nature, such as fish capture, then the transportation can be relevant as shown in the present study.

The GWP impact of catfish production stage presented by HENRIKSSON *et al*. (2015) were 7 to 9 times the ones of processing and delivery stages in current case study. The GWP impact of intensive tilapia production systems presented by YACOUT *et al*. (2016) was lower than the processing and distribution stages from this study. Our results provided a still unusual way to associate the consumed fish and the GWP impact caused by its processing and transportation. The translation of inventory data into GHG emissions and GWP impacts allow a more concrete rationalization of which aspects from production should be a priority in terms of management to reduce its carbon footprint. We also argue that proper management of electricity, water, transport, solid waste, and wastewater generation during processing are key to effectively reduce the current impact of aquaculture and fisheries supply chains as they can have higher impacts than fish production.

CONCLUSIONS

The reduction of the current GWP impact associated with long-distance refrigerated transportation and the development of economic alternatives to reuse solid waste and wastewater are crucial to promote a sustainable fish supply in the Bahia State. The promotion of local fish industry closer to the consumer market would reduce costs with transportation and GHG emissions. In addition, the solid waste has a potential to produce ration, fertilizers, and biofuel, whereas the processing wastewater has the potential to be used as fertigation in agriculture, which would reduce the costs with fertilizers, such as nitrogen and phosphorus. The adoption of these practices is crucial to reduce the greenhouse gas emissions associated with the fish production chain. Nevertheless, the evaluation of the entire cycle and the inclusion of other environmental aspects such as eutrophication are crucial to provide a realistic picture of the environmental issues associated with fish production chain.

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