Life cycle assessment of co-culture of *Clarias gariepinus* and *Oreochromis niloticus* in the whedos of Ouémé delta in Benin

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Abstract

The development of the fish farming with regard to environmental sustainability is nowadays a serious alternative to satisfy the needs of the population in quality animal protein and to reduce imports in Benin. In this study we assessed the environmental impacts of co-culture of *Clarias gariepinus* and *Oreochromis niloticus* systems in the whedos of Ouémé delta in Benin. Life Cycle Analysis (LCA) which is a systemic method that assesses all potential environmental impacts of global and regional product, service, company or process has been used according to the CML baseline 2000 method. However, that method was adapted for fish farming system. The estimation of nitrogen (N) and phosphorus (P) wastes in production systems (T1: imported feed, T2: local feed and T3: mixed feed), was performed according to the nutritional balance method; and calculation of impact categories was conducted with environmental analysis software, SimaPro® 8.0.5.13. For all the environmental impact category considered (non-renewable energy, climate change, eutrophication, freshwater ecotoxicity, terrestrial ecotoxicity and potential acidification), the T1 system recorded the lowest values of impacts compared to T2 and T3. Except the eutrophication dominated by the production process, the feed production process is the major contributor of other impact categories. To optimize fish productivity and sustainability of fish farming, the T1 system would be advisable.

Keywords: Life Cycle Assessment, happa, Ouémé, fish farming, whedos

INTRODUCTION

Fish is the most accessible animal protein for a large part of the world population. It contribute for about 20% to the protein supply for about 3 billion of people and about 15% for 4.3 billion of people in the world. In some countries, fish is an important resource. FAO (2011) reported that the fish ensures at least 50% of animal protein in some Asian countries (such as Cambodia, Indonesia, Sri Lanka) and some African countries (such as Sierra Leone, Gambia and Ghana). In Sub-Saharan Africa (SSA), the fish ensures about 22% of animal protein consumption. In some SSA countries, the fish contribution to animal protein consumption would be about 50% (Brummet *et al.,* 2008; FAO, 2008, 2020). In Benin, the fish is the most important animal protein source (Agbohessi *et al.,* 2018). It ensures about 31.9% of animal protein and about 5.5% of all proteins (FAO, 2020). The continental fishing (in streams, lakes, lagoons, plain liable to flooding) contributes for about 75% to the national halieutic production (Lalèyè *et al.,* 2003). Unfortunately, the halieutic production is increasingly decreasing these last year because of the overexploitation of the natural streams, especially with the using of forbidden fishing engines and technics (Imorou Toko, 2007). Since 2005, the fish import in Benin is higher than the domestic halieutic production. Then it is necessary to promote the development of fish farming in order to ensure a large availability of halieutic products and to decrease the overexploitation of natural halieutic resources and the fish import (Elègbè *et al.,* 2015a; Agbohessi *et al.,* 2019). Despite the classical fish farming in Benin, the traditional fish farming, especially in *whedos* is the most developed form in the country. The existence of *whedos* in Benin (in the regions such as Sô-ava and Ouémé valley) go back to more than a century (Chikou, 2006). The *whedos* are traditional fish farming form developed by fishers to profit from the succession of flood and fall in plains liable to flooding (Imorou Toko, 2007). The development of that fish farming system faces today several constraints. The feeding which represents about 50% of the fish farming expenses is the principal constraints (Gourène *et al.,* 2002; Agbohessi *et al.,* 2018). Then it is important today to develop technics optimizing the fish feeding in this system. Researches on the co-culture of *Clarias gariepinus* and *Oreochromis niloticus* in the Ouémé delta in Benin allowed reducing the breeding expenses and to breed several species together, better profiting from the symbiosis of these species (Elègbè *et al.,* 2015a and b; Agbohessi *et al.,* 2018). However, the environmental and ecological sustainability of these fish farming systems is still to prove. In fact, the fish farming systems produce gases which require attention because of their effects on environment. The level of these emissions is an indicator of the efficiency of systems, their capacity to produce fish using the mobilized inputs (Effolé, 2011). The assessment of these effects on environment require the using of multi-criteria tools. The Life Cycle Analysis (LCA) is a global method which assesses the whole potential environmental impacts related to a product from its source to its recycling or its final waste (Guinée *et al.,* 2002). This method was identified as pertinent for the environmental assessment of the agricultural production systems (van der Werf and Pe-

tit, 2002) with some references in fish farming (Casaca, 2008; Effolé *et al.*, 2012; Aubin, 2014 and 2015; Abdou, 2017). The present paper uses the LCA to assess the environmental impacts of the co-culture of *C. gariepinus* and *O. niloticus* in *Ouémé* delta in Benin.

MATERIAL AND METHODS

Study area

The study was carried out in the village of Ayizè in the upper *Ouémé* delta, municipality of Ouinhi, department of Zou in southern Benin. This village is located between the 6°57 and 7°11 of North latitude and 2°23 and 2°33 of East longitude (Figure 1). Data were collected during 56 days (from 30 July to 24 September 2014). According to Adam and Boko (1993), the climate of the area is of sub-equatorial type characterized by 4 seasons: one big rainy season (March to July), one small dry season (July to August), one small rainy season (September to November) and one big dry season (December to March). In the *Ouémé* delta, there is one upper water season (with high amplitude from end of July to beginning of November) and one low water season (December to June) is noted in the year. In flood season, there is flooding in the delta. However in the fall season (low water season) the water level considerably decreases in the river bed, all plains liable to flooding dry allowing crops production (Welcomme, 2002; Imorou Toko *et al.*, 2007; Lalèyè *et al.*, 2007).
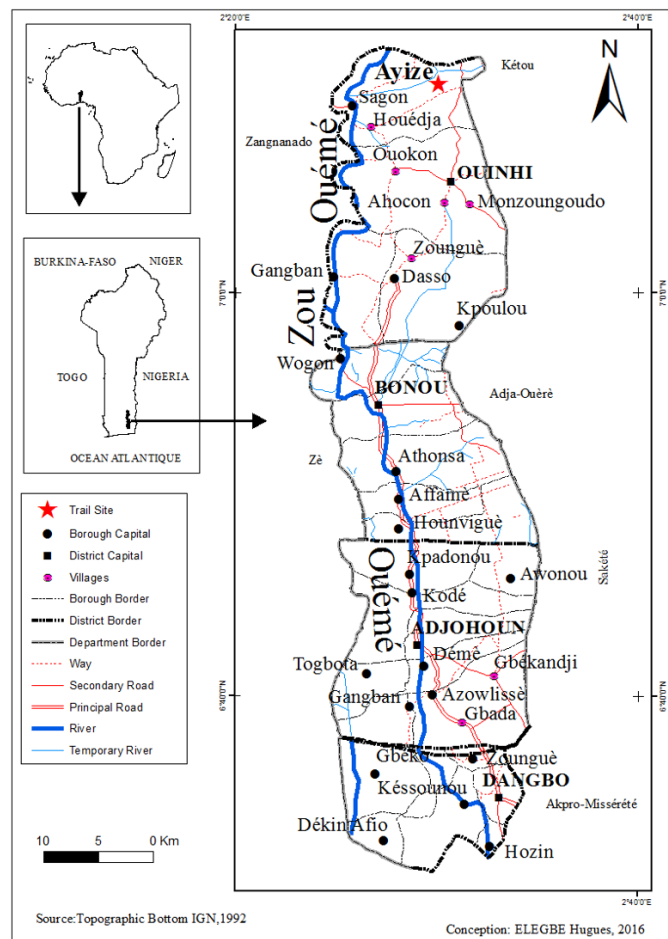

Figure 1: Geographic situation of study area (Ouémé delta)

Animal material

The fry of *C. gariepinus* (initial average weight: 6.74 ± 0.27g) and *O. niloticus* (initial average weight: 8.11 ± 0.14g) used for the experiment were bought at the Center of Fish Farming Research and Incubation in Benin (CRIAD) in Cotonou. The density was 30 *C. gariepinus* per m² and 5 *O. niloticus* per m².

Description of the studied production systems

Based on food breeding three systems of *C. gariepinus* and *O. niloticus* installed in *whedos* were analyzed (Figure 2). These feed were included in arrangements of double happas (2.5*2.5m for *O. niloticus* and 1*1m for *C. gariepinus*). System 1 used imported food; system 2 used local food and system 3 used mixture of both imported and local food.
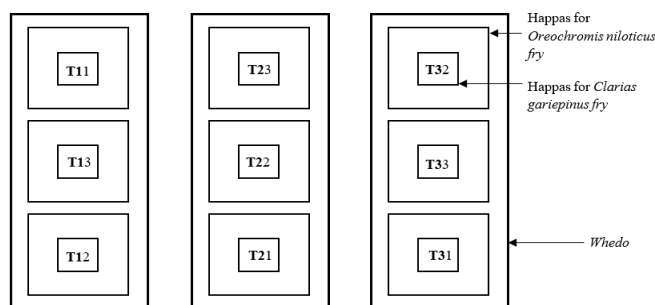

Figure 2: Schematic systems evaluated for co-culture of Clarias gariepinus and Oreochromis niloticus

At total 3 rectangular *whedos* were used. The surface of each *whedos* was 127 m². These *whedos* were provided in water by the ground water with average water height which varied from 0.47 to 0.59 m. The lost water in the *whedos* was replaced each 2 weeks by pumping the river water.

Experiment conduct

Three categories of food were used in *triplicat*. 3 happas were introduced in each experiment *whedos*. Each happa contained *O. niloticus* and *C. gariepinus*. The fishes of each *whedos* received one category of food as follow:

• *Treatment 1 (T1) for system 1:* imported food containing 45% of protein (the commercial name is Skretting) ;

• *Treatment 2 (T2) for system 2:* local food (produced in Benin) containing 37% of protein;

• *Treatment 3 (T3) for system 3:* mixed food containing 50% of imported food and 50% of local food 41% of protein.

Only fry of *C. gariepinus* were fed ad libitum 3 times per day (at 8', 13' and 18') during 2 months. The *O. niloticus* profited from the rests and throwing out from happas with *C. gariepinus* and/or primary production from the mineralization of excrements and non-apprehended feed. The final average weights of *C. gariepinus* varied from 30.7 ± 3.04 g to 42.6 ± 2.26 g. The average weights of *O. niloticus* varied from 18.4 ± 4.99 g to 19.6 ± 0.83 g.

The food quantity used during the experiment is mentioned in table 1. The data in the farm were obtained by direct measures (characteristics of equipment; water quality) and quantify (food quantity; water bulk) during the experiment (Table 1).

Life Cycle Analysis

The limits of each fish farming system analyzes in this paper include the process of breeding equipment construction (happas), food production for the fishes, the fry and commercial fish production, the transport at all stages from the cradle to the farm door (Aubin *et al.*, 2009) (Figure 3). The inventory data collection concerned one production cycle. The LCA was done following the CML2 baseline 2000 version 4.2. method (Guinée *et al.*, 2002). However, that method was adapted to the fish farming considering its previews application in different fish farming systems (Aubin *et al.*, 2006; Casaca, 2008; Roque d'Orbcastel *et al.*, 2008; Aubin and van der Werf, 2009a; Effolé, 2011; Aubin, 2014 and 2015; Abdou, 2017) on production cycle using:

• The economical allocation based on the average market price of the study area during the year 2014;

• One ton of fresh fish produced at the exit of the farm as functional unit,

• The secondary data on the energy, the transport, the minerals, … from the Ecoinvent LCA inventory database (Eoinvent, 2007).

The calculation of nitrogen (N) and phosphorus (P) quantity in the food was made using chemical analysis of the dry matter of the food (total N and P). The level of N and P loss was calculated using the nutritional balance method (Cho and Kaushik, 1990). The impacts were calculated using the environmental analysis software SimaPro ® 8.0.5.13 (Pre Consultants, Netherlands). The impact categories retained for this study were: the non-renewable energy (EU expressed in MJ); the climate change potential (CC expressed in kg CO_2); the toxicity of fresh waters (TED) and the earth eco-toxicity (ET expressed in kg 1.4 DB); the potential acidification (AP expressed in kg SO_2) and the eutrophication (E expressed in kg PO_4). To put the studied systems in a global context, their environmental impacts were compared to those of other previews studies using the same method in Brazil (Casaca, 2008), in France (Aubin *et al.*, 2009a), in Canada (Nathan *et al.*, 2008), in Cameroon (Effolé *et al.*, 2012) and Ivory Coast (Ngongang Nganso, 2015) (Tables 2 and 3).

The effect of the different treatments (T1, T2 and T3) on the environment was tested comparing the impacts (EU, CC, TED, ET, AP and E) using one-way Analysis of Variance (ANOVA1). The HSD test of Turkey was used to compare the means of the impacts of the different treatments at the threshold of 5%. The statistical analysis was done using the STATISTICA 6.0 (Statsoft, Inc.) software.

Table 1: Characteristics of studied production systems

Species	Systems	Surface (m²)	Water deep (m)	Food quantity (Kg)	Fish density (ind/m²)	Duration production Cycle (month)	Yield (t/ha/year)
Clarias gariepinus and *Oreochromis niloticus*	T1	6.25	0.53	3.39	60	2	14.88
	T2	6.25	0.53	3.10	60	2	10.2
	T3	6.25	0.53	4.45	60	2	15.6

T1: imported food; T2: local food; T3: mixture of imported and local food
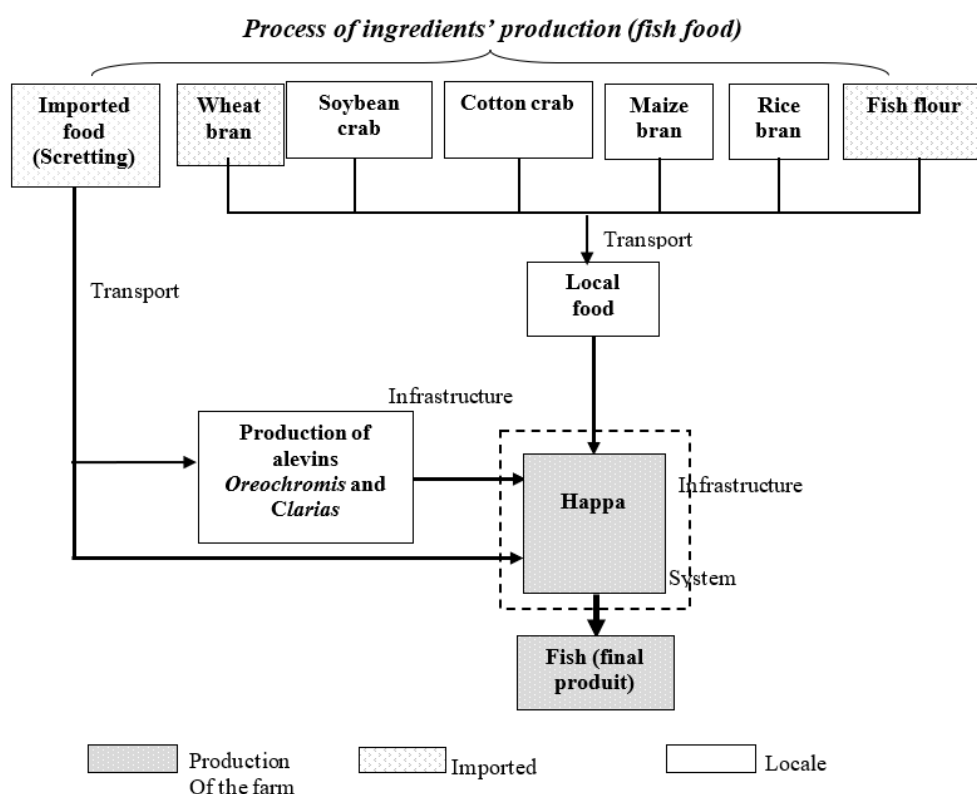
Figure 3: Limits of the studied systems

RESULTS

The table 4 presents the results of the potential environmental impacts per ton of fish in the co-culture system of *C. gariepinus* and *O. niloticus*. This table showed that lowest impacts values of different impacts category considered (EU, CC, TED, ET, AP and E), was obtained with T1 system. The highest level value recorded in T2 system.

The ANOVA1 analysis showed that there is significant difference ($p < 0.05$) at the threshold of 5% among the different impact category values (EU, CC, E, TED, ET and AP) following the treatment. Moreover, the HSD test of Turkey showed that the values of EU, CC, E, TED, ET and AP were significantly ($p < 0.05$) different from each other at the threshold of 5%.

Table 2: Characteristics and environmental impact of different fish farming system studied in other countries

	Casaca (2008)	Aubin and van der Werf (2009a)	Nathan et al. (2008)				Efflolé et al. (2012)			
Countries	**Brazil**	**France**	**Canada**				**Cameroon**			
Production systems	Integrated semi-intensive	Intensive in poly-tank with water recirculation	Net-pen	Cage	Pond with opened circuit	Pond with closed circuit	Integrated pig-fish (F1)	Intensive (F2)	Semi-intensive (F3)	Pig and excrement (F4)
Types	Polyculture	Monoculture	Monoculture				polyculture			
Species	*Ctenopharyngodon idella, Hypophthalmichthys molitrix*	*Oncorhynchus mykiss*	Salmon				*Oreochromis niloticus Clarias gariepinus*			
Food	Plante forage	Concentrated	Industrial food				Pig Lisier	Wheat bran	Lisier, excrements and cropping co-products	Lisier and excrements
Yield (t/ha/year)	7	241	3600	416	96.2	46.2	7.5	6.2		3.4
Impacts environnementaux potentiels des différents systèmes par tonne de poisson produit										
Eutrophication (kg of PO_4)	23	66	35.3	31.9	31	11	908	318	401	157
Climate change (kg of CO_2)	1200	2700	2073	22.50	5410	10.3	5100	1600	800	600
Acidification (kg of SO_2)	8	19	17.9	18	33.3	72.5	22	7	3	3
Used energy (GJ)	11.6	78.2	12.1	13.9	38.1	72.5	17.1	4.0	1.8	1.7

Table 3: Potential impacts per tonne of fish produced in an extensive fish farming pond in Central west region of Côte d'Ivoire (Ngongang Nganso, 2015)

Species	Systems	EU (MJ)	CC (Kg CO_2)	AP (Kg SO_2)	E (Kg PO_4)
Oreochromis niloticus	**SR**	50 948	4735	35.9	507.7
	SRC	26 240	2191	14.4	404.8
	SRB	65 109	5366	32.6	648.0
	SRO	30 047	2607	15.8	370.2
	SRT	25 817	2180	14.8	324.1

SR= Bass rice flour; SRC = Bass cooked rice flour; SRB = Bass flour of fermented rice with bangui ; SRO = Bass flour of fermented rice with water; Bass flour of roasted rice

Table 4: Potential impact per tonne of fish produced in *whedo*, semi-extensive fish farming in the delta of the Ouémé in southern Benin

Species	Food categories	Impact categories					
		EU (MJ)	CC (Kg CO_2)	TED (Kg 1,4 DB)	ET (Kg 1,4 DB)	AP (Kg SO_2)	E (Kg PO_4)
Clarias gariepinus and Oreochromis niloticus	T1	30839 ± 4419[a]	2071 ± 128[a]	35.7 ± 1.77[a]	2.75 ± 0.11[a]	9.34± 0.54[a]	16.3 ± 1.43[a]
	T2	9769429 ± 337449[b]	100124 ± 3480[b]	8060 ± 285[b]	2291 ± 81[b]	766.7 ± 26.9[b]	518.5 ± 19.4[b]
	T3	480637 ± 18645[c]	48838 ± 1928[c]	3893 ± 158[c]	1103 ± 45.0[c]	372 ± 14.9[c]	260.9± 10.1[c]
Probability (p)		0.0021	0.0023	0.0004	0.0001	0.0003	0.0001

EU= Energy Use; CC = Climate Change; TED = Toxicity of fresh water; ET = Earth Eco toxicity; AP = Potential Acidification; E = Eutrophication. The values are expressed in: mean ± standard deviation. The values of the same column are not significantly different (P > 0.05). T1= imported food; T2 =local food; T3 = mixture of local and imported food

The average relative contribution of the system processes to the different impact categories showed that apart from the eutrophication impact dominated by the production process, the food processing is the major contributor of the other impact categories (Figure 4).

DISCUSSION

The high values of potential environmental impacts for the eutrophication category of the system 2 (related to the treatment T2: local food) in comparison with the system 3 (related to the treatment T3: mixture of local and imported food) and the system 1 (related the treatment T1: imported food) could be explained by the low assimilation of the local food due to its physical characteristics in comparison with the imported food. In fact, the resistance of the local food to the water is relatively low. Accordingly, if the food is not caught by the fish, few minutes after it leaks in the water, disintegrates and becomes inaccessible to the fishes. Therefore, the environment gets richer in biogenic nutrients than their assimilation by the fishes (Yakupitiyage *et al.,* 2007; Aubin, 2014). These results are in accordance with the process of nutrient repartition in a pond ecosystem (Nathan *et al.*, 2006 and 2007; Abdou, 2017).

Moreover, the low value of the eutrophication impact of the system 1 (imported food) can be due to the form of the diet (pellet). In fact, these pellet are more floating than T2 and available for the fishes. In addition, their quality in relation with their high digestibility and the protein rate (45%) (Aubin *et al.,* 2009b; Effolé *et al.,* 2012). Nevertheless, the values of eutrophication obtained with T3 system were lower than those obtained by Ngongang Nganso (2015) in extensive *O. niloticus* fish farming in Ivory Coast and those obtained by Efolé et al. (2012) in semi-intensive pond system integrating both fish and pig

in Cameroon (Tables 2, 3 and 4). These differences can be justified by the relatively low yield of these systems (1 to 7t/ha/year) in comparison with the production systems of *whedos* analyzed in this study (14.9 t/ha/year; 10.2 t/ha/year and 15.6 t/ha/year).

Furthermore, the high values of the eutrophication in the systems 2 and 3 in comparison with those obtained by Casaca (2008) and Nathan *et al.* (2008) in pond semi-intensive system could be explained by the low number of species in the co-production system (Table 2). In fact, the poly-culture systems developed in Brazil uses a large number of species even with low growing capacity but with important ecological roles which enable optimizing the nutrients.

The values of impact categories such as the non-renewable energy (EU) (976942 ± 33744 MJ; 480636 ± 18645 MJ), the climate change (CC) (100124.25 ± 3480.07 Kg CO_2; 48838 ± 1928 Kg CO_2) and the potential acidification (AP) (respectively obtained for systems 2 and 3) were high relatively to system 1 (Table 4). This fact could be explained by the source and the origin of the inputs (Aubin and van der Werf, 2009a; Aubin *et al.,* 2009b; Effolé, 2011). Aubin *et al.* (2009b) reveal that the agricultural input production and transportation would contribute to the acidifying substances emission for about 10 to 17%. Therefore, the usage of imported products from Europe in the local food production combined with their weak optimization justifies the high level of these impacts. The exclusive usage of local by-products can contributes to reduce these impacts (Effolé *et al.,* 2012). The values of EU, CC and AP obtained in the frame of this study are higher than those obtained in other fish farming systems (Casaca, 2008; Nathan *et al.,* 2008; Aubin and van der Werf 2009a; Effolé *et al.,* 2012; Ngongang Nganso, 2015) (Tables 3 and 4). These differences could
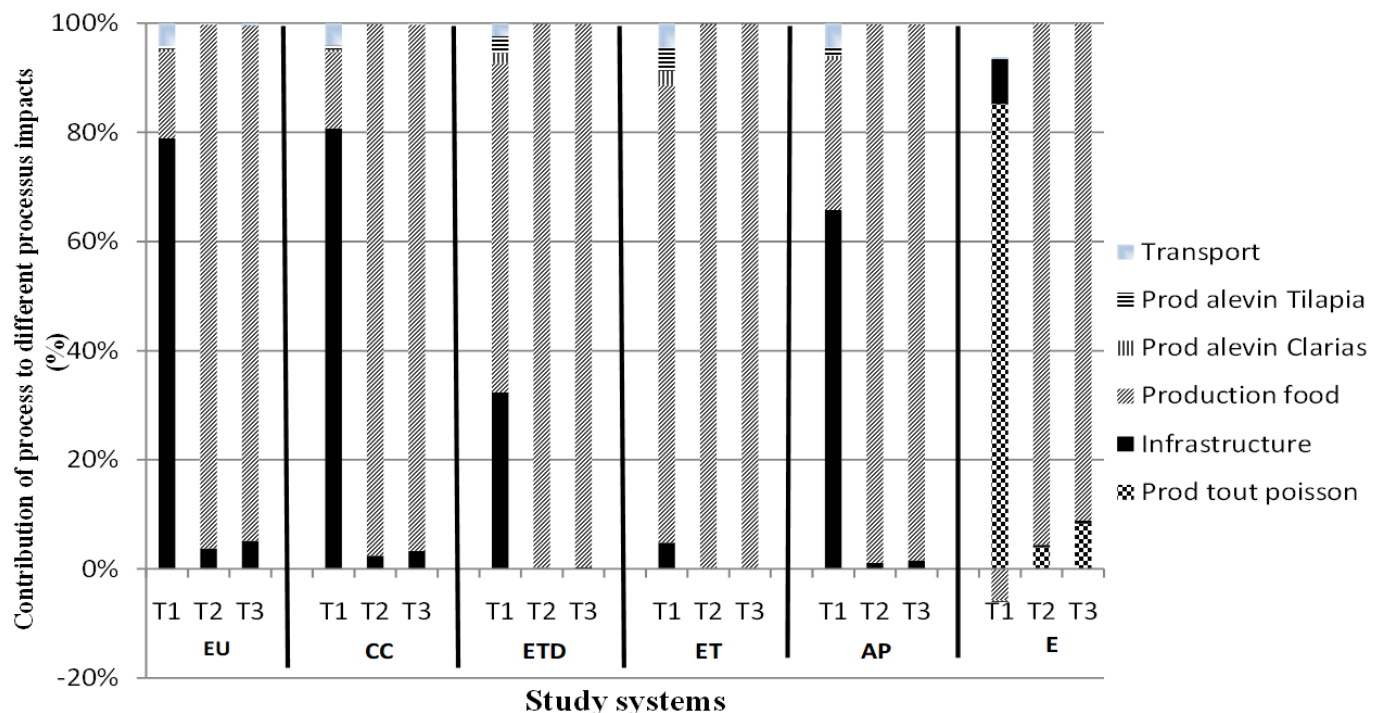
Figure 4: Relative contribution (%) of process to different impacts categories per ton of fish produced

Eu = Non renewable energy; CC = Climate change; ETD = Toxicity of fresh water; ET = Earth Eco toxicity;
AP = Potential Acidification; E = Eutrophication

menly be justified by the origin of the ingredients used in local food processing and the low yield of the local crop production systems. The same raisons explain the high values of TED and in the studied systems.

CONCLUSION

The semi-intensive whedo T2 system recorded the highest environmental impact level. Food processing, origin and source of ingredients where determinant. Life Cycle Analysis is adapted to the fish farming system with low level of inputs. The less impact level recorded with the T1 system are link to the digesbility of the imported food

The improvement of local food processing and diversification of species can lead to less environmental impact level and a better optimization of studied systems.

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