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Eco-designing Aquaponics: a case study of an experimental production system in Belgium.

Andrea Alberto Forchino[a], Vincent Gennotte[b], Silvia Maiolo[a]*, Daniele Brigolin[a], Charles Mélard[c], Roberto Pastres[a]

[a]Department of Environmental Sciences, Informatics and Statistics (DAIS),University of Ca' Foscari, Via Torino 155, Venice, 30172, Italy
[b]CERER Pisciculture, Chemin de la Justice 10, Tihange, 4500, Belgium
[c]Aquaculture Research and Education Centre (CEFRA),University of Liège, Chemin de la Justice 10, Tihange, 4500, Belgium

* Corresponding author. Tel.: +39-338-108-5905. *E-mail address:* silvia.maiolo@unive.it

Abstract

Aquaponics is receiving a growing interest as an emerging technology that combines recirculating aquaculture practices and hydroponics to produce fish and vegetables. However, a proper eco-design is essential to limit the environmental burdens and to enhance the economic profitability. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) were here combined to estimate the environmental and economic impacts of a designed pilot indoor aquaponic system in Belgium. Results showed that energy consumption, infrastructure and water consumption represent the main critical issues to achieve both the environmental and economic sustainability of this aquaponic system.

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Keywords: Aquaponics, Eco-design, Life Cycle Thinking, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), Sustainability

1. Introduction

In the last 30 years, the scientific community [16], has developed tools to assess the sustainability of food products. To this regard, "eco-design" can be defined as the integration of environmental considerations into a planned or actual productive process in order to improve the resulting products – and possibly to help in the development of new ones – by reducing the environmental burdens throughout their life cycle [4]. One of the most accepted tools to get eco-design information about a process is the LCT approach, subdivided into three types of analyses: LCA, LCC and SLCA. However, while LCA and LCC are internationally accepted tools, SLCA is not totally developed yet. Concerning the aquaculture field, LCT approaches – mostly in the form of LCA – had an exponential growth in the last year, with studies focusing on different species, management condition and rearing systems [1,17,8,23].

However, the eco-design approach has never been applied to aquaponics, that is an innovative practice which integrates the culture of aquatic animals (mainly fish) with the hydroponic production of plants [26]. Aquaponics allows to farm fish and plants at high density, minimizing water consumption and reducing emissions [6,7].

Nomenclature

LCT	Life Cycle Thinking
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
SLCA	Social Life Cycle Assessment
NFT	Nutrient Film Technique
GRP	Glass-Reinforced Plastic
DWC	Deep Water Culture

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Although this technique seems to be sustainable, neither its environmental nor economic burdens have been deeply investigated as yet: in fact, only few studies are available in literature [2,10]. In the present study, we combined LCA and LCC to analyse the project of a future aquaponic facility located in the "Centre des Technologies Agronomiques" (CTA) in Modave (Belgium), in order to get an overview of its environmental and economic burdens and thus propose less impacting technical solutions prior to its actual building.

2. Material and methods

2.1. System description

The scheme of the pilot aquaponic system is provided in Figure 1 and its technical features reported in the Appendix section (Table A.1). The system will be hosted inside an insulated room constructed in aerated concrete blocks, while fish culture equipment will be composed of 6 rearing tanks. The mechanical filtration will be provided by a drum filter, complemented by a swirl separator. The water exiting the fish culture is conveyed to the mechanical filtering station (swirl separator + drum filter) to remove most of the suspended solids discharged from the system as sludge. Hydroponic cultures are arranged on 3-level shelves lighted by artificial LED lighting. Grow beds will be composed of NFT structures and DWC tanks, with a total surface of 50 m^2. The building is equipped with a double flow ventilation system.

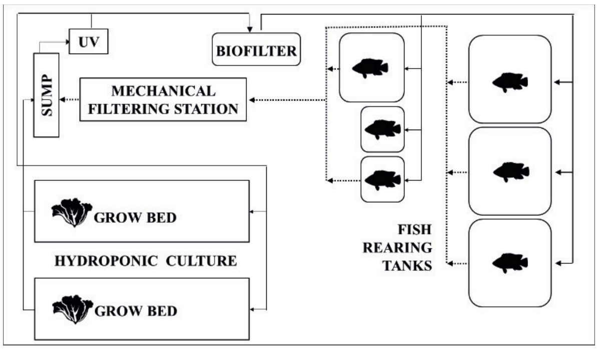

Fig. 1 Scheme of the aquaponic facility. Black arrows show the water flow.

2.2. LCA and LCC

2.2.1 System boundaries and functional unit

The system is designed to farm tilapia (*Oreochromis niloticus*) and lettuce (*Lactuca sativa*) with an expected yearly production of 0.7 and 4 tons of fish and vegetable, respectively. According to Hunkeler et al. [13], LCA and LCC have been performed on the same model of the productive system (e.g. same system boundaries, functional unit, allocation method) and a cradle-to-gate approach was adopted for both the analyses. The processes included in the analysis are the ones taking place within the productive cycle, namely: raw materials (used to build the facility and to run the production), consumptions (energy and water) and transportation. The outputs are represented by the two products (lettuce and tilapia) and their derived wastes (i.e. dead biomass and fish sludge in water) (Figure 2). The functional unit was set as 1 kg of produced lettuce and tilapia was considered as co-product. The allocation was calculated proportionally to the total amount of produced biomass (lettuce = 85.11%; tilapia = 14.89%).

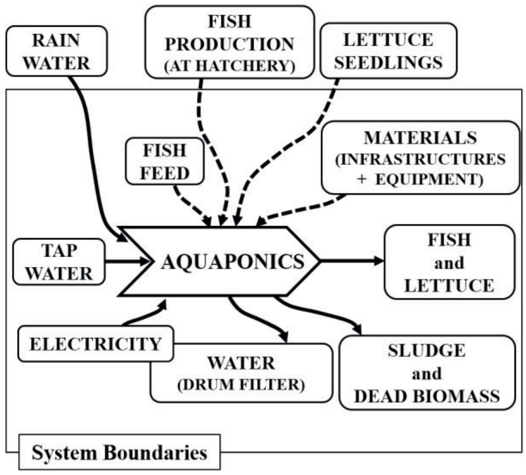

Fig. 2 System boundaries of the considered aquaponic system. Dot arrows indicate processes for which transportation was considered.

2.2.2 Life Cycle Inventory

The main system features and consumptions are reported in Table 1.

Table 1. Aquaponic system design and main yearly expected fluxes of energy and matter.

Energy	
Water pumping + LED (kWh)	63,000
Heating (kWh)	15,000
Water	
Input - Tap water (m³)	870
Input - Rain water (m³)	200
Output - Water evaporation (m³)	70
Output - Drum filter backwashing (m³)	1,000
Production	
Input - Fish feed (kg)	840
Output - Fish production (kg)	700
Output - Plant production (kg)	4,000

Production wastes (dead fish and lettuce) were considered in terms of nitrogen and phosphorous content in the disposed dead biomass, assuming a landfill disposal scenario. Removed suspended solids were quantified in terms of nitrogen and phosphorous released in the sewer system. Concerning LCC, the main inputs are reported in Table 2.