Resources, Conservation and Recycling 102 (2015) 27–38

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Resource usage of integrated Pig–Biogas–Fish system: Partitioning and substitution within attributional life cycle assessment

Trang T. Nhu[a,*], Jo Dewulf[a], Pieterjan Serruys[a], Sophie Huysveld[a,b], Cong V. Nguyen[d], Patrick Sorgeloos[c], Thomas Schaubroeck[a]

[a] Research Group EnVOC, Department of Sustainable Organic Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Gent, Belgium
[b] Institute for Agricultural and Fisheries Research (ILVO), Burg. Van Gansberghelaan 115, B-9820 Merelbeke, Belgium
[c] Laboratory of Aquaculture & Artemia Reference Center, Ghent University, Rozier 44, B-9000 Gent, Belgium
[d] College of Environment and Natural Resources, Can Tho University, 3-2 Street, Can Tho, Viet nam

ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 20 May 2015
Accepted 22 June 2015

Keywords:
Life cycle assessment
Resource footprint
CEENE
Pig–Biogas–Fish
Vietnam

ABSTRACT

The integration of agriculture and aquaculture with anaerobic digestion is a popular practice at small Asian farms as a way of producing energy and fish, i.e. providing a better nutrient balance and resource recycling. Concerns are raised whether the resource efficiency of such system is better or worse relative to the monoculture system. In this study, we focused on quantifying the resource demand of two integrated Pig–Biogas–Fish farms in Vietnam. The analysis was performed by using the exergy concept: exergy flow analysis (ExFA) at process level and Cumulative Exergy Extraction from Natural Environment (CEENE) at life cycle level.

Results showed that such integrated systems considerably relied on land (68% farm A and 54% farm B, mainly for pig feed production) and water (28% farm A and 42% farm B, mainly for aquaculture). It can also be concluded that the intensive aquaculture practice had a higher feed input than the semi-intensive one integrated with pig and biogas production; however, the latter system had a higher CEENE value to deliver a similar mass (i.e. one kilogram) of product at farm gate. This is mainly caused by a dramatically low areal yield of the integrated aquaculture, corresponding to an inefficient water use (16 m^3 kg^{-1} fingerlings and 10 m^3 kg^{-1} fish) therefore identified as the resource hotspot.

Improvements could be achieved through a better water management in aquaculture and an increased biogas utilization, preventing any leakages. Fertilizing the fish pond with manure-based digestate instead of fresh manure and/or rising the application rate might be a more efficient way to reduce pelleted fish feed consumption, although further research on such options are needed.

1. Introduction

Following the onset of industrialization and population growth, the buildup of waste has globally caused a rapid deterioration of sanitation and human life quality, in addition to fast resource depletion. In this context, more environmentally sustainable activities are currently encouraged, resulting in, for example, a shift away from traditional waste disposal (i.e. landfill) to integrated resource recovery (IRR) from waste flows. In the IRR concept, 'waste' is seen as a potential resource that can be valorised into useful products through reuse, recycling and/or recovery. This approach potentially leads a to a lower damaging impact on human and ecosystem health due to less resource extraction and less pollution by waste streams. IRR is of great value and has been applied in various fields, such as agriculture, aquaculture, chemical industry, food industry, etc.

Animal products serve an important role in the human diet as they have a high energy density and they are good sources of high-quality proteins, crucial minerals and vitamins (Gibson, 2011). In 2005, livestock products contributed around 27.9% of protein consumed worldwide and 47.8% in developed countries (FAO, 2009). Additionally, through applying the IRR approach livestock, manure has multiple usages as fertilizer for crop production, household fuel, construction material, feedstock for biogas production and fertilizer in aquaculture (FAO, 2011). One among such promising waste management strategies is the application of integrated agriculture-aquaculture (IAA) in developing countries, particularly

* Corresponding author. Fax: +32 9 264 62 43.
E-mail address: Trang.nhuthuy@ugent.be (T.T. Nhu).

http://dx.doi.org/10.1016/j.resconrec.2015.06.011
0921-3449/

in Asia. This strategy implies integration of crop production, vegetable cultivation, livestock breeding and/or fish culturing, for example: rice-fish, water hyacinth-fish, pig-fish, poultry-fish, etc. The IAA system hence induces a nutrient balancing through recycling waste outputs of a subsystem as inputs of another subsystem (Nhan et al., 2007; Prein, 2002). In Vietnam, IAA is a traditional and well-developed practice (Luu et al., 2002). A common IAA form in the Mekong Delta is the 'Vuon, Ao, Chuong — Garden, Aquaculture, Animal husbandry (VAC)', typically including a pond stocked with fish; livestock or poultry pens situated near or over the pond to provide an immediate source of organic fertilization; and gardens for both annual and perennial crops. Recently, Vietnamese livestock production has rapidly grown. Particularly the pig sector had a high annual growth rate (around 6%) over the 1990–2010 period (FAOSTAT, 2014). This expansion will likely lead to more environmental pollution accompanied with a poor utilization of nutrients and energy present in the manure. To solve these problems, anaerobic digestion has been recommended and introduced in the conventional VAC, termed as VACB (B stands for biogas). In VACB system, livestock manure is anaerobically digested to produce biogas, which is then burned for daily household cooking. Meanwhile, digestate can be used as a base fertilizer for fish culturing. Pond sediments can be used as a fertilizer for crops or orchards. Literature has focused on the pros of the traditional IAA system. Such an approach lessens the adverse environmental impacts and improves economic viability relative to intensive monoculture aquaculture systems (Kluts et al., 2012; Murshed-E-Jahan and Pemsl, 2011; Phong et al., 2010). Kluts et al. (2012) compared a monoculture system with an IAA system for Pangasius Hypophthalmus production in terms of nine impact categories: global warming, acidification, ozone depletion, photochemical oxidation, eutrophication, fossil depletion, human toxicity, freshwater ecotoxicology and marine aquatic ecotoxicology. For all impacts, except eutrophication and freshwater ecotoxicology, the integrated system performed better than the monoculture system. Little attention has been paid to the benefit of biogas production in IAA systems. Compared to the conventional agriculture system, such an integrated system with biogas shows a better ecological economy under good operational conditions over a period of at least 8 years (Wu et al., 2014) and a greenhouse gas reduction benefit (Yang et al., 2012). These studies, however, did not quantify the savings in resource consumption through integration. Questions have been raised about how efficient the IAA combined with biogas production, e.g. VACB, consumes resources relative to specialized mono-aquaculture. Further research is needed to quantify the (potentially improved) resource efficiency of the VACB systems.

This paper, therefore, presents the quantification of resource efficiency of two VACB systems in the Mekong Delta of Vietnam. As pig farming is the most important animal husbandry activity in this area, the studied farms are both 'Pig–Biogas–Fish' systems. By using exergy flow analysis (ExFA) and the Cumulative Exergy Extracted from the Natural Environment (CEENE) method, we quantified the natural resource demand at two levels, process and cradle-to-farm gate life cycle, for the two respective farms. At life cycle level, the resource usage was allocated to different products and byproducts through partitioning and substitution within an attributional approach (Fig. 1; explained in Section 2). Moreover, we show the pros and cons of the integrated system relative to the monoculture system, regarding resource efficiency.

2. Materials and methods

The two studied farms were described before introducing the applied methodologies.

2.1. Description of the production systems

The selected farms were the first farms applying the VACB model in Can Tho in 2008, funded by the 'Clean Development Mechanism' project of Can Tho University (CTU) and the Japan International Research Center for Agricultural Sciences (JIRCAS). Later on, they have been considered as role models to expand this technology to neighbourhood farmers.

The two farms consisted of four similar components: a pigsty, an anaerobic digester, an aquaculture pond and a garden. Crossbred swine, obtained by interbreeding Landrace and Yorkshire pigs, were cultivated continuously. Each sow delivered 10–15 (average 12) piglets per cycle that were fed with sow's milk and commercial feeds in approximately 150 days to deliver pigs of 100 kg each to the local market. Different pig feeds were used for gestation, lactation, nursery, and growing (Supporting information A). Groundwater was used as drinking water for swine and for cleaning the pigsty (three times per day). Sows were kept for about 5 cycles and new sows were selected out of the cultivated pigs. Pig manure, along with the wastewater from cleaning, was discharged into the anaerobic digester. Plastic-bag digesters were used in these farms for biogas production. The obtained biogas was burned for daily household cooking; the excess biogas was stored in plastic bags or emitted to the atmosphere through an automatic valve when the pressure is too high. In this integrated system, Snakeskin gourami (Trichogaster pectoralis) larvae were cultivated to fingerlings in an average 60-day cycle (excluding 0.5 months for pond preparation and nursing). In addition to pelleted feed, primary in situ biomass (e.g. phytoplankton, algae, etc.), taking advantage of fertilization by manure or digestate, served as additional fish feed. Pond water was daily renewed at a low rate with water from a branch of the Mekong River. Pond sediment was used as a fertilizer for vegetable production at farm A or for fruit cultivation in the garden at farm B. Vegetables were grown and used as food for the farmer's family while fruits were sold on the local market.

There were differences in the way of reusing intermediate flows and the final products of aquaculture in the two studied farms (Fig. 1). In detail, farm A used manure as digester feedstock (89%) and as input in fish culturing (11%), while digestate was totally disposed to the environment (Fig. 2). In contrast, manure was fed to the digester in farm B and afterwards the digestate was fully recycled as an input for the fish pond (60%) and the broodstock pond (40%) (Fig. 3). The dosage of manure and digestate added into the fish pond depended on subjective experience of the farmers: water color observation, growth and mortality of fish and fingerlings, etc. Farm A had annually four batches of fingerlings. Farm B had 3 batches of fingerlings where two were harvested after 60 days (fingerlings) but one was kept for ongrowing up to market-sized fish (210 days). Manure and digestate were fed into ponds for the last 30 days of the fingerling crops and during the entire fish-ongrowing period. Different commercial feeds were used for the fingerling and the ongrowing fish (Supporting information B). Harvested fingerlings and fish were sold to other grow-out farms and processing factories, respectively. Every 2 years, farm A selected some fingerlings that were grown to be kept as new broodstock, while farm B used the mature fish harvested in the last cycle for reproduction.

2.2. Exergy flow analysis (ExFA)

In Exergy flow analysis (ExFA), the exergy content of each flow within the production system is quantified and efficiencies are calculated to pinpoint process inefficiencies. Exergy is the maximal amount of work that a system can deliver when brought in equilibrium with its environment through reversible processes. The exergy content of the product flows was calculated based on com-