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Integration of energy audits in the Life Cycle Assessment methodology to improve the environmental performance assessment of Recirculating Aquaculture Systems

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ABSTRACT

In Recirculating Aquaculture Systems (RAS), water is continuously treated and recirculated as opposed to being discharged untreated into the environment as in other type of fish production systems; the design and production parameters will determine the overall energy consumption. This energy-intensive nature hampers their sustainability and cost-effectiveness. This paper proposes a combination of two methods (i.e. Life Cycle Assessment (LCA) with energy audits) to: improve environmental performance of RAS, identify energy consumption and thus, its environmental and monetary effects in order to seek cost reduction. The proposed methodology was proved with a case study focused in a pilot-scale RAS unit used in codfish (*Gadus morhua*) production, located in the Basque coastal area (northern Spain). Feed and juvenile production/transportation, oxygen transportation and energy consumed during the whole experiment were considered as inputs for the assessment. Energy consumption was measured both continuously by an energy meter embedded in the RAS unit as well as with a portable energy analyzer to measure each of the energy-consuming devices independently. Although the system required an average of 29.40 kWh/kg fish for successful system operation, the energy consumption varied by season presenting maximum and minimum periods of 40.57 and 18.43 kWh/kg fish, respectively. Main consumers included the heat pump, followed by the main and secondary pumps, respectively. Energy audit's results show the success in identifying the devices that consumed the largest amount of energy, and recorded data served to feed the Life Cycle Inventory and perform a more complete and precise LCA. Fossil fuel based on-farm electricity for the on-growing of fish was shown to be the most environmentally unfriendly input; it was the major impact producer in the assessed impact categories. It showed a temporal variability depending on the water temperature, which resulted to be the main factor linked to the energy use. This aided performing a precise assessment including system-specific scenarios. The combination of LCA and on-farm energy audit represents a useful tool to secure a more complete assessment with a periodic assessment to design a less energy intensive, profitable and sustainable system; likewise, it increases the speed and transparency of governance and decision-making, taking into account the time-based fluctuation of the energy consumption throughout the production cycle.

1. Introduction

Water pollution is one of the biggest challenges European aquaculture is facing (AQUAeTREAT, 2003). Thus, current policies created for aquaculture's development highlight the need of an industry that minimizes its impact on the environment (COM, 2002; COM, 2009); in this scope Recirculating Aquaculture Systems (RAS) are proven to be a viable solution (Masser et al., 1999; Timmons and Ebeling, 2010; Martins et al., 2010; Dalsgaard et al., 2013). RAS started to develop in the 70s based on sewage treatment plants (Asche, 2008). RAS are technologically advanced systems, where several devices treat the water in order to achieve the right parameters for fish to be reared. They are designed specifically to: reduce the amount of water required and waste produced from traditional flow-through systems (known as raceways or tanks where the same amount of water is taken and discharged) (Blancheton, 2000), isolate the culture environment from surrounding ecosystems reducing the proximate ecological impacts

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(i.e. surrounding water bodies pollution, habitat interactions) typically associated with more open production systems, such as net-pens and raceways (Ayer and Tyedmers, 2009), and ensure the prevention of inclusion of pathogens guarantying chemical-free productions (Badiola et al., 2014a). Nevertheless, RAS are up to 1.4–1.8 times more energy intensive than traditional flow-through systems (d'Orbcastel et al., 2009a,b), fact that hinder their environmental sustainability. Moreover, in the last year, more efficient products to reduce energy and resource consumption are on demand, requiring the improvement of the energy efficiency and eco-design of products (COM, 2016). Hence, on-farm energy use (i.e. fossil energy) should be also quantified (i.e. time-based quantification) and taken into account when eco-designing and/or assessing their design and operations for further development of the RAS industry and increased production volumes from these systems (Ang et al., 2010).

Life Cycle Assessment (LCA) is generally accepted internationally as a strong tool for providing inputs to be considered while assessing the environmental sustainability of a product or process, including those of aquaculture such as salmonid feeds (Papatryphon et al., 2004; Boissy et al., 2011), characterization of turbot farming (Iribarren et al., 2012), the carbon footprint of Norwegian seafood products (Ziegler et al., 2003; Ziegler and Valentinsson, 2008), and energy use in global salmon farming (Ayer and Tyedmers (2009); Nijdam et al. (2012)). Likewise LCAs comparing different farming methods have also been published (e.g. Aubin et al., 2009; d'Orbcastel et al., 2009a,b; Jerbi et al., 2012). Aquaculture, as a food production system, involves: diverse and multidisciplinary aspects, interlinkages amongst them, and highly variable production processes (e.g. different species and farming requirements, diverse production systems, and locations). This, coupled with the lack of transparency of the industry (Badiola et al., 2012), which makes difficult obtaining reliable data to represent all year around conditions, ends with an exhaustive data inventory and hinders a realistic comparison between studies. This complexity has limited the usability of traditional LCA methodologies (e.g.Wegener et al., 1996; Ellingsen and Aanondsen, 2006; Finnveden et al., 2009; Samuel-Fitwi et al., 2012). In this context, the authors reviewed the most significant publications in food production to assess the usefulness of LCA for aquaculture. As a result, a SWOT analysis was undertaken (conclusions shown in the supplementary material). One of the threats, presented as an outcome in the analysis and already mentioned before, was the complexity of aquaculture, limiting results comparison among studies; and this being directly linked with the lack of transparency for data collection in the industry. Consequently, LCAs are often based on generic and average data given by a database (i.e. no system-specific data), which leads considering diverse assumptions and obtaining so, wrong conclusions. In contrast, the multi-criteria approach of the LCA and the possibility of identifying critical points of processes can provide the framework to support the weaknesses mentioned. Some of the specific limitations detected in the aforementioned literature review have been solved in the past by combining different methods, such as LCA with Ecological Footprint (Samuel-Fitwi et al., 2012), energy analysis with greenhouse gas emissions (Colt et al., 2008a,b), LCA with Emergy Accounting (Wilfart et al., 2013), and the combination of LCA with Data Development Analysis (Ramos et al., 2014). Even so, the need for a broader range of science-based decision-making tools for aquaculture has been highlighted (e.g. Samuel-Fitwi et al., 2012).

In aquaculture, and particularly in RAS, energy consumption is dependent on several factors such as species, rearing water temperature, climate and system configuration/design or layout and management. Furthermore, onsite energy consumption follows a time-based pattern (Ioakeimidis et al., 2013). Cumulative Energy Demand has been commonly used in environmental assessment method, such as Life Cycle Assessments (LCAs), as a single indicator of energy consumption (Frischknecht et al., 2015) when calculating different energy demands of the studied systems. Hence, limiting energy to a single value (e.g. an average value for a product or process) as resulted in the Cumulative Energy Demand indicator, may not reflect the reality of the farm, and energy saving measures cannot be accurately proposed. Energy audits provide an adequate proceeding/scheme through a detailed recording of energy flows. They provide real data (i.e. system-specific data) and estimate the energy consumption of a given system or process throughout a given period defining time-based energy-saving measures from both economic (€) and environmental terms (for example, with respect to CO_2 eq. emission). Consequently, an energy audit can proffer the energy model of a production cycle, by showing the energy consumption pattern of each of the devices forming the system. Thus, they may procure the best framework to quantify on-farm time-based energy consumption and in this manner provide more reliable and real data to be included in the LCA's data collection procedure. LCA in the seafood sector is fairly new compared to the development of this method in other sectors, such as petrochemical industry (e.g. Neelis et al., 2008), food and beverages (e.g. Ogunjuyigbe et al., 2015), and industrial in general (Boharba et al., 2016). Energy audits have also aided to reduce fuel and electricity costs and to increase predictable earnings in the fishing sector (Basurko et al., 2013),, especially in times of high energy price volatility; but it is not widespread activity. However, their inclusion as part of the life cycle inventory within the LCA has not been widely used but yet recommended (Nisbet et al., 2002). In contrast, in aquaculture and, particularly in RAS, among more than 20 LCA and system energy consumption related works published (Colt et al., 2008a,b; d'Orbcastel et al., 2009a,b; Eding et al., 2009; Buck, 2012) only one regards to energy efficiency (Ioakeimidis et al., 2013).

The contribution presented herein proposes a combined methodology (LCA with energy audits), which objective is to increase the precision of LCA results. The audits permit more accurate and system-specific data to be included in the Life Cycle Inventory (LCI) of the LCA by using detailed system's energy consumption quantification, temporally and spatially representative, that the data provided by the standard Cumulative Energy Demand indicator. Thus, this will help making a more precise diagnosis of the studied systems (i.e. already existing as well as new systems) and a possible energy consuming map. LCA studies reveal emission hotspots along the whole product value chain allowing to identify opportunities for improvements. Its combination with energy audits may offer an opportunity to substantially improve the assessment and the efficiency of the systems, by giving additional to use in the assessment. This will ultimately enable the proposal of time-based eco-design measures, which will depend on seasonality and particular conditions of the sea.

The methodology is implemented to assess the sustainability of a marketable size cod (*Gadus morhua*) production pilot-scale RAS facility located in the Basque Country. This species is one of the most important in the Basque households; the current consumption being 3500 T/year while salmon consumption (the fastest growing species among the most popular species for the Basque consumers) is 2800 T/year (MAGRAMA, 2014). Nowadays, the principal on-growing method for the codfish aquaculture is through marine net pens (Bjornsson and Olafsdottir, 2006) - only Fülberth et al., 2009 reported an attempt of on-growing codfish to marketable size utilizing RAS. This particular situation makes also difficult to obtain reliable data for the study. Species such as salmon which is currently reared in RAS (e.g. Summerfelt et al., 2013), presents a wider optimal rearing temperature range, which facilitates the rearing conditions by making the water temperature a