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Life cycle assessment of swine production in Brazil: a comparison of four manure management systems

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ABSTRACT

Population growth and the consequent increase in food demand will certainly intensify the threat to the environment. Brazil, the fourth largest producer and exporter of swine meat, has an important role to ensure the fulfillment of the goals of food security and climate change mitigation. Therefore, the aim of this study was to evaluate the environmental impact of swine production in Brazil based on life cycle assessment, comparing four manure management systems: liquid manure storage in slurry tanks; the biodigestor by flare; the biodigestor for energy purposes; and composting. Additionally, we performed a Monte Carlo simulation to evaluate the uncertainty due to different emissions factors to estimate nitrogen-related emissions from the manure-handling stage. The functional unit considered was 1000 kg of swine carcass in the equalization chamber for cutting or further distribution. The results indicated an environmental profile of swine production in Brazil of 3503.29 kg of CO_2 eq. for climate change, 76.13 kg of SO_2 eq. for terrestrial acidification, 2.15 kg of P eq. for freshwater eutrophication, 12.33 kg of N eq. for marine eutrophication, 21,521.12 MJ for cumulative energy demand, 1.63 kg of 1.4-DB eq. for terrestrial ecotoxicity, 1706.26 BDP for biodiversity damage potential and 14.99 m^2 for natural land transformation. Feed production had a significant contribution with a range of 17.6–99.5% for all environmental impact categories. Deforestation represented 9.5 and 31.3% of the total impacts for cumulative energy demand and climate change, respectively. Therefore, avoiding the use of grain from deforested areas can significantly decrease the impacts for these impact categories. Regarding the uncertainty analysis, we observed greater variations for terrestrial acidification in slurry tanks, biodigestor by flare and for energy purposes, while for the case of composting, major uncertainties were observed for climate change. For manure management systems, efforts should be made to reduce the emissions of methane in the storage and ammonia in the field application. In this sense, the comparative life cycle assessment indicated that the biodigestor for energy purposes had the best environmental performance for almost all the environmental impacts, mainly due to the biogas capture and the potential of energy saves. Nevertheless, if the goal is to decrease the impacts for terrestrial acidification and marine eutrophication, the slurry tanks is the most preferable scenario compared to all alternative options.

1. Introduction

The agricultural sector, especially livestock production, has a significant impact on the environment, being responsible for 18% of worldwide carbon dioxide (CO_2) equivalent emissions (de Vries and de Boer, 2010; Steinfeld et al., 2006). In the European Union (EU-27), the consumption of meat and dairy products contributes on average to 24% of the environmental impacts, of which swine meat represents 19–44% (Weidema et al., 2008). Swine production is a recognized pollution source due to the

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large generation of manure and the large consumption of grain for animal feed.

In 2013, the average herd for Brazilian swine production was 38.578 million animals, making Brazil the fourth largest producer and exporter of swine meat in the world (USDA, 2013). In the last decade, production has expanded into the central west region, becoming a potential stage for further environmental impacts (Kunz et al., 2009); however, the state of Santa Catarina (in southern Brazil) is still the major producer in the country, with 19.3% of the national herd (IBGE, 2012). The Environmental Agency of Santa Catarina State (FATMA), through the Normative Instruction no.11/2004, establishes 50 m^3 ha^{-1} $year^{-1}$ as the maximum amount of manure for use in arable land, but depending on the soil requirements for nutrient fertilization, the application rate of manure can be lower (FATMA, 2004).

The most common manure management system (MMS), which is used in 80% of integrated farms, is the storage of manure in open slurry tanks without a natural crust cover, while the biodigestor with flare is used in nearly all of the remaining 20% of farms (Higarashi et al., 2013; Kunz et al., 2005). In both of the MMS, the manure is then applied on land as organic fertilizer. The use of biodigestor has grown in Brazil mainly due to the potential reduction of greenhouse gas (GHG) emissions by the conversion of methane (CH_4) emissions into carbon dioxide in the burning processes (i.e., flares) or into heat or electrical energy (Amon et al., 2006; Cantrell et al., 2008; Massé et al., 2011; Murphy et al., 2004; Oliveira, 2004). Some studies (Amon et al., 2006; Chantigny et al., 2007; Vallejo et al., 2006) have demonstrated that the use of an anaerobic digestion system, such as biodigestor, also reduces nitrous oxide (N_2O) emissions during the manure application compared to the application of raw manure. However, biodigestor does not offer solutions to other manure disposal problems, such as removing N and P or reducing the quantity of manure (Chantigny et al., 2007; Kunz et al., 2009). In this sense, an alternative to open slurry tanks and biodigestor is to handle manure in the solid form by composting.

Life cycle assessment (LCA) is a methodology for the estimation of the potential environmental impacts of products and has been widely used in livestock systems (Reckmann et al., 2012; Thomassen and de Boer, 2005; van der Werf and Petit, 2002). Furthermore, LCA allows the environmental performance evaluation of established scenarios and the ability to compare the improvement options of a process/product throughout its life cycle, such as the manure management system options (Nguyen et al., 2011). Several LCA studies of swine production have been conducted worldwide (Basset-Mens and van der Werf, 2005; Baumgartner et al., 2008; Cederberg and Flysjö, 2004; Dalgaard et al., 2007; Halberg et al., 2007; Kingston et al., 2009; Nguyen et al., 2011; Reckmann et al., 2013; Schenck, 2006; Wiedemann et al., 2010; Williams et al., 2006). Regarding the Brazilian production systems, Spies (2003) conducted a streamlined LCA of swine and poultry production indicating the need for these activities to adjust their management practices to a more sustainable production. In addition, the author notes the need to create a complete LCA from the streamlined LCA to build a more consistent database, also considering the different manure management systems to better understand the environmental effects and the improvements offered by each alternative.

Ruviaro et al. (2012), in a scientific research on LCA application to products worldwide found that specific for Brazilian products, LCA was applied to ethanol, sugarcane, biofuels, agricultural machinery manufacture, coffee, soybeans, orange juice, poultry, aquiculture, and oysters. To date, there is no published paper addressing swine production with a complete LCA for Brazil or other tropical countries, nor is there one that performs a MMS scenario variation with composting and biodigestor by flare. Moreover, there is no uncertainty assessment that encompasses every aspect of these scenarios so that a seamless decision-making process is guaranteed.

Hence, the aim of this study was to evaluate the environmental impacts of swine production in Brazil through the use of a complete LCA, comparing four manure management systems (MMS): liquid manure storage in slurry tanks (Sce.Ref); the biodigestor by flare (Sce.Flare); the biodigestor for energy purposes (Sce.CHP); and composting (Sce.Comp). Additionally, the uncertainty due to different emissions factors was evaluated to estimate the nitrous oxide and ammonia emissions from the manure handling stage.

2. Materials and methods

The environmental impacts were evaluated following ISO standards 14,040 and 14,044 (ISO, 2006a, 2006b), with SimaPro® software. The comprehensive scope of LCA is useful in order to avoid problem-shifting from one phase of the life-cycle to another and it is recognized as a trustworthy, scientific and understandable approach to address the environmental sustainability of human activities (Baitz et al., 2013; Finnveden et al., 2009). On top of that, the use of several mathematical models to address all the environmental aspects to its respective environmental impacts reduces the uncertainty in decision making between different options.

2.1. Goal and scope

The system boundaries of this LCA begin with the crop production, grain drying and processing, piglet production (PP) and growing to finishing (GF) and end at the slaughterhouse with the cooled and eviscerated carcass, as displayed in Fig. 1. The animals are raised in housing with an uneven concrete floor for manure runoff to a downspout that transports the slurry to the manure management system (MMS).

The functional unit (FU) considered was 1000 kg of swine carcass (deadweight) in the equalization chamber for cutting or further distribution.

2.2. Life cycle inventory

The life cycle inventory (LCI) for the animal production and slaughterhouse stage was obtained from the integrated farms of Brazilian agroindustry and represents the southern Brazil. For the other stages, we used data based on the literature.

2.2.1. Crop production

Inputs and emissions data for Brazilian soybean and maize cultivation and processing were obtained from Prudêncio da Silva et al. (2010) and Alvarenga et al. (2012). The data for rice cultivation were obtained from the Ecoinvent® database (Nemecek and Kägi, 2007).

In Brazil, the origin of crop production has an important role in the environmental costs due to the impacts of land transformation (hereinafter: deforestation). Although recent data published by the National Institute for Space Research have indicated that since 2005, the annual rate of deforestation in the Amazon area has decreased (INPE, 2012), this is a major issue for the evaluation of the life cycle in animal production. We assumed impacts from deforestation only for the grains produced in the central west region because in southern Brazil the deforestation occurred many years ago.

To estimate the origin and transport distance of grains, we performed a weighted mean of the amount of grains from the central western and southern regions and the distance to the feed factory located in Santa Catarina, based on the year 2011. Soybean used in swine production in southern Brazil comes mainly from the central west (98%), with 1713 km of distance, while the soybean