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Life Cycle Assessment of broiler chicken production: a Portuguese case study

Sara González-García [a,b,*], Zaira Gomez-Fernández [a], Ana Cláudia Dias [b], Gumersindo Feijoo [a], Mª Teresa Moreira [a], Luis Arroja [b]

[a] Department of Chemical Engineering, Institute of Technology, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain
[b] CESAM, Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal

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ABSTRACT

An environmental assessment of the life cycle of broiler chicken production from a cradle-to-slaughterhouse gate perspective was carried out with the aim of identifying the environmental *hot-spots* of the system. To do so, broiler chicken production in Portugal was investigated in detail. Inventory data for the different production stages (chicken farm- and slaughterhouse-related activities) was gathered in collaboration with an integrated Portuguese chicken company.

Results showed that the chicken farm is the main factor responsible for the environmental impacts analysed. Specifically, both feed production and on-farm emissions were the main environmental *hot-spots*. Concerning the slaughterhouse-related activities, the production of electricity and packaging materials presented a significant contribution at this stage.

The environmental results were compared with other published Life Cycle Assessment studies of chicken production in other countries, with special attention paid to the quantification of greenhouse gas emissions. A number of improvement actions are proposed to reduce the environmental impacts of poultry litter management and feed production.

Moreover, studies of pork, beef and fish (sardines) were also included for comparison using a functional unit based on an identical protein content. The results (excluding subsequent packaging) showed that the production of broiler chicken could be preferable in comparison to other types of meat due to its lower global warming potential. On the contrary, sardines presented a reduction of 88% in comparison with the chicken profile; however, the availability of sardines for consumption may be limited throughout the year due to EU fishing protocols concerning sea stocks protection.

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1. Introduction

The food sector is one of the most important manufacturing and economic sectors in Europe, contributing 14.5% of the total manufacturing turnover (European Comission, 2013). Additionally, to satisfy societal demand, an increasing demand for food has been observed. In parallel, the environmental impact associated with this sector has also experienced an increasing interest (González-Garacía et al., 2013a; Iribarren et al., 2011). The life cycle stages of food products (such as production, preservation and distribution) require large amounts of energy, which could be translated into negative environmental impacts such as greenhouse gas (GHG) and acidifying emissions (Roy et al., 2008). In contrast, consumers in developed countries have started to demand high-quality food produced under more environmentally friendly conditions (Boer, 2002). In this context, there is an increased recognition and acceptance of the need to develop more sustainable systems within the food sector (Notarnicola et al., 2012).

One of the most widely accepted international methods of quantifying the environmental impacts of food products is Life Cycle Assessment (LCA) (Roy et al., 2008). This is a standardized and holistic methodology that allows for the identification of the environmental consequences of the life cycle of a product by evaluating potential environmental impacts over its entire life cycle production chain (ISO 14040, 2006). LCA method has been chosen by numerous authors to conduct environmental assessment of a wide range of food products such as bread (Andersson et al., 1994),

* Corresponding author. CESAM, Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal. Tel.: +351 234370387.
E-mail addresses: sara.gez.garcia@gmail.com, saraggarcia@ua.pt, sara.gonzalez@usc.es (S. González-García).

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tomato ketchup (Andersson et al., 1998), beer (Takamoto et al., 2004), dairy products (González-García et al., 2013a, 2013b; Hospido et al., 2003) and fish products (Hospido et al., 2006; Vázquez-Rowe et al., 2010).

Meat consumption is growing consistently worldwide as a result of its increasing demand by emerging countries (Cioloş, 2012). In Europe, the main types of meat – beef, veal, pork, chicken, goat and sheep – account for one quarter of the total value of agricultural production (European Commission, 2004). Previous LCA studies performed for beef (Cedeberg and Stadig, 2003; Beauchemin et al., 2010), pork (Reckmann et al., 2012) and poultry (Baumgartner et al., 2008; Bastianoni et al., 2010; Bengtsson and Seddon, 2013; Boggia et al., 2010; da Silva et al., 2012; Katajajuuri, 2007; Pelletier, 2008; Wiedema et al., 2008; Williams et al., 2006) are mainly related to the farm stages, while only a few include the slaughtering stage and/or packaging, distribution and preparation (Beauchemin et al., 2010; Bengtsson and Seddon, 2013; da Silva et al., 2012; Katajajuuri, 2007; Reckmann et al., 2012). In addition, different rearing scenarios (organic and conventional) have been compared from an environmental perspective in an attempt to define the best option (Boggia et al., 2010). Analysis from a cradle-to-grave perspective to obtain comprehensive information for the whole process (including the logistics, cooking and consumption stages) has been rarely considered (Roy et al., 2012; Wiedema et al., 2008).

Chicken meat has become one of the most extensively consumed food products in the world (Magdelaine et al., 2008). The highest consumption rates have been registered in the most industrialized countries, with Europe placed third in 2011 behind USA and China (Ministry of Agriculture Food and Environment of Spain, 2012). Apart from its low price, chicken is popular as it is an important source of proteins, vitamin B and minerals, and is low in saturated fats (Windhorst, 2006; FAO, 2012a). European chicken meat production represented 11% of total world production in 2011 (Ministry of Agriculture Food and Environment of Spain, 2012). In general, chicken production systems can be classified into two groups according to the farming scheme (Bengtsson and Seddon, 2013): free-range chicken, which is reared outdoors with a purely vegetable diet, and broiler (or conventional) chicken, which is reared on farms with industrial feed as the base diet (Castellini et al., 2006).

This study focuses on environmental evaluation of broiler chicken production, from a cradle-to-slaughterhouse gate perspective, in Portugal, which ranks ninth in chicken production among European Union countries (Ministry of Agriculture Food and Environment of Spain, 2012). In addition, broiler chicken represents 75% of the total meat consumption in Portugal (30 kg of meat$\cdot$cap$^{-1}\cdot$year^{-1}), according to national statistics (INE, 2010). The results from this study are of potential interest for LCA practitioners and stakeholders in the meat sector as chicken meat occupies the second position in the ranking of meat consumption in Europe (Magdelaine et al., 2008). Moreover, detailed inventory data has been reported which can help the LCA community focus on the quantification of environmental impacts derived from protein sources, which are basic ingredients in the human diet.

2. Materials and methods

2.1. Goal and scope definition

The main function of the system under study is to satisfy the food requirements for chicken in an average Portuguese family during one meal. To do that, this study aims to identify and evaluate the environmental impacts throughout the life cycle of broiler chicken through a cradle-to-gate perspective, from extraction of raw materials to the slaughterhouse gate. Moreover, the study proposes different improvement alternatives for the farm to reduce the environmental burdens associated with this activity.

The functional unit, 1.2 kg of broiler chicken meat ready to be distributed to the point of sale, was chosen because a) it is the amount of raw chicken that contains the recommended daily protein supply for an average family (four people) (CDC, 2012), and b) it is the average weight of a broiler chicken (excluding packaging) available for consumption in Portuguese markets.

2.2. Description of the system under study and system boundaries

The production system under study encompassed all activities related to the chicken farm and the slaughterhouse according to a cradle-to-gate analysis (Fig. 1). In this way, the product (broiler chicken) could be monitored until it was packaged and ready for distribution to wholesales.

Thus, the production system in this study was divided in two main subsystems: the chicken farm and the slaughterhouse.

Chicken farm: Activities carried out directly in this subsystem start with the reception of chicks at the farm gate. Chicks are transferred to a production pen for a fattening period of 34 days. Chickens are housed in poultry beds, which are commonly composed of a mixture of materials such as sawdust, bark, wood shavings and/or chips. Production of these bedding materials as well as their distribution to the chicken farm was considered within the subsystem boundaries.

As mentioned, chickens are fed for 34 days with a ratio of 85 g of feed$\cdot$day$^{-1}\cdot$chicken^{-1}. The production of chicken feed was included within the subsystem boundaries (Fig. 1). The feed is mainly composed of maize, wheat, soybean cake, soybean oil, monocalcium phosphate, protein concentrate and fats.

Throughout the growth period, vaccines and antibiotics are administered. The production and use of these pharmaceuticals were excluded from the assessment due to the lack of information.

Cleaning activities at the chicken farm involve not only water but also chemicals. The production and use of cleaning agents (detergents and disinfectants) were not considered within the system boundaries in agreement with other studies (Castanheira et al., 2010; Hospido et al., 2003), which state that the environmental burdens derived from the production of these substances do not represent a significant percentage of the global environmental profile of the entire system. Wastewater generated from cleaning activities and farm-related uses is treated in a small wastewater treatment plant (WWTP), which is located on the chicken farm.

Manure produced in the farm is an important source of nutrients. The wasted poultry beds and manure (poultry litter) are spread over agricultural land. This organic waste management (including handling, storage and application) cause emissions such as NH_3, N_2O, CH_4, NO_3^- and PO_4^{-3}. Its application as an organic fertilizer avoids the production of an equivalent amount of mineral fertilizers (N, P and K), which has also been considered within this subsystem boundaries.

According to several studies in which the environmental impacts of farm-related activities were identified (e.g., Castanheira et al., 2010; Hospido et al., 2003), feed production is one of the main factors responsible for environmental damage. Thus, special attention was paid to feed production-related activities. Feed production (Fig. 1) involves the production of different raw materials (primarily cereals), which are stored separately in silos. First, the raw materials are ground to reduce their size, before being measured, weighed and mixed. Thereafter, the product is granulated using steam produced in boilers and stored in bulk bags or silos to be delivered to the farm gate. Fungicides are also required to

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