Journal of Cleaner Production 57 (2013) 280–292

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

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

Accounting for farm diversity in Life Cycle Assessment studies – the case of poultry production in a tropical island

Alexandre Thévenot [a,b,c,*], Joël Aubin [d,e], Emmanuel Tillard [a], Jonathan Vayssières [a]

[a] CIRAD, UMR SELMET Livestock systems in Mediterranean and Tropical areas, F-97410 Saint-Pierre, La Réunion, France
[b] CEMOI, Université de la Réunion, F-97715 Saint Denis, La Réunion, France
[c] Crête d'Or Entreprise, F-97427 Etang Salé, La Réunion, France
[d] INRA, UMR1069, Sol Agro et hydrosystème Spatialisation, F-35000 Rennes, France
[e] Agrocampus Ouest, UMR1069, Sol Agro et hydrosystème Spatialisation, F-35000 Rennes, France

ARTICLE INFO

Article history:
Received 16 November 2012
Received in revised form
14 May 2013
Accepted 17 May 2013
Available online 1 June 2013

Keywords:
Life Cycle Assessment
Cluster analysis
Mitigation scenarios
Uncertainty
Broiler supply chain
Reunion island

ABSTRACT

The farm is the most influential stage of agricultural production because farming practices affect both pre-farm and on-farm environmental impacts. Since farm diversity is not usually taken into consideration, it is legitimate to question the interest of including it in Life Cycle Assessment (LCA) studies. This work explores several approaches to modelling the farm stage when assessing the environmental impact of an agricultural supply chain in a context with variable farm performances. A LCA of a poultry supply chain was applied from cradle-to-slaughterhouse gate. The first approach is a classical one in which farm diversity is not taken into account and an average farm is constructed on the basis of weighted average farm characteristics. The second approach distinguishes four farm types identified by cluster analysis, and four LCA were performed according to these farm types. Farm types were distinguished based on their consumption of inputs and the type of ventilation of the farm buildings. Results indicate that the classical approach is sufficient to highlight problem hotspots and to identify promising mitigation measures. Reducing the transport distance of imported maize, improving feed conversion efficiency and anaerobic digestion of slaughterhouse animal wastes were identified as appropriate mitigation measures. As feed production and poultry rearing are the stages with the most impact, distinguishing farm types provides i) insight into farm functioning to better explain the variability of environmental impacts and understand how to reduce them, ii) reduce the uncertainty of results, and iii) provide appropriate recommendations for mitigation measures. Coupling a farm typology with the LCA is particularly useful when farming systems are very diverse like in Reunion Island where the climate varies considerably across the island.

1. Introduction

It was demonstrated many years ago that livestock industries have a major impact on the environment from local to global scale (FAO, 2010). Life Cycle Assessment (LCA) is a useful tool to assess impacts at different scales and to highlight problem hotspots throughout the life cycle of a product (Haas et al., 2000). In agricultural systems, most resources are consumed and most emissions into the environment occur during the on-farm stage (Ellingsen and Aanondsen, 2006; Eriksson et al., 2005). For industrial monogastric livestock system, poultry for instance, the pre-farm stage is also important because the feed is usually produced off-farm (De Haan et al., 1997). In both cases, the farm is the most influential stage because it affects both pre-farm and on-farm environmental impacts. Unlike other industries, agricultural systems are subject to variability which is inherent to both the system and its environment. Due to the resulting uncertainty, the answers provided by LCA may be incomplete or erroneous (Huijbregts et al., 2001). Even if industrial monogastric livestock systems are generally standardised (De Haan et al., 1997), all agricultural systems have to deal with biotic and abiotic stresses which affect their production, resource consumption, and emissions from a flock, or from one harvest to the next (Basset-Mens et al., 2006). The rearing method (e.g. conventional versus organic farming) also has major consequences for the final results (Boggia et al., 2010). Variability increases even more when considering systems functioning under

---

[*] Corresponding author. CIRAD, UMR SELMET Livestock systems in Mediterranean and Tropical areas, F-97410 Saint-Pierre, La Réunion, France.
E-mail addresses: alexandre.thevenot@cirad.fr, alexandre.thevenot@outlook.fr (A. Thévenot).

0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.05.027

difficult climate conditions (e.g. tropical arid) or contrasted relief (e.g. high altitude, narrow territory) or when the level of technology varies considerably between the different types of farms (e.g. between smallholder low-input crop-livestock integrated systems and intensive production systems) (Al-Aqil et al., 2009; Herrero et al., 2010). Like other methods of assessment, LCA requires the widest possible data inventory to obtain the most realistic results possible. For the assessment of agricultural products, data is usually collected through farm surveys, which are expensive and time consuming. Assessing an agricultural product could mean basing the assessment on only a small sample of highly variable farms, hence the risk of incorrect results.

In the literature, one farm is usually modelled to represent the production step. Several ways of modelling this step can be found: random or oriented selection of an actual farm (Cederberg and Mattsson, 2000; Knudsen et al., 2010), construction of a theoretical farm using a range of data sources (Beauchemin et al., 2010; Castanheira et al., 2010; Halberg et al., 2010; Ogino et al., 2007; Pelletier, 2008), or construction of an average farm based on observed data collected from a sample of farms (Basset-Mens et al., 2009; Haas et al., 2001; Pelletier et al., 2010). The first option, i.e. random selection is generally not recommended because of the high risk of obtaining a non-representative sample. In the case of oriented selection, the main criticism is subjectivity. The second option, i.e. the construction of a theoretical farm, is widely used for assessment at regional or national scale. In the third option, i.e. the construction of an average farm, the quality of the average farm is strongly influenced by the size of the sample. In all three cases, the studies generally fail to take farm diversity and variability into account. Another option is to distinguish farm types using cluster analysis, and then to define an average farm for each type. This method has been used for several other purposes including farm simulations (Kobrich et al., 2003; Righi et al., 2011) but only rarely in LCA (Dalgaard et al., 2006).

The present study examines the chicken industry in Reunion Island (a French tropical island in the Indian Ocean, 700 km east of Madagascar). In Reunion, eating chicken meat has no religious or cultural connotations, and is the most widely consumed meat (AGRESTE, 2008). One cooperative and two industrial firms comprise main poultry supply chain, which supplies about 27% of the local demand for chicken meat for a population of around 850,000 (IEDOM, 2008). Future population growth will require these firms to double their production over the next ten years while facing several constraints. First, supply chain decision-makers have to deal with the narrowness of the territory and the risk of extreme climatic events (hurricanes) which limit cereal production. Geographic isolation also complicates access to inputs (e.g. spare parts for machinery, ingredients, choice of packaging) and waste treatment (Christofakis et al., 2009). Consequently, most raw materials and equipment used in the supply chain are imported over long distances hence increasing both operating costs and environmental impacts.

Secondly, the poultry farms are located in contrasted relief (elevation ranges from 0 m to 2540 m on an island that covers only 2512 km^2) which complicates logistics and is a major obstacle to the creation of large farms, making economies of scale difficult to achieve. Moreover, temperature and humidity varies a great deal depending on the time of day, the season, the altitude and the location of the farm, which increases the difficulty of maintaining optimum conditions for poultry. In addition, not all farmers can afford the additional costs of equipment (e.g. dynamic ventilation systems). These constraints incur unequally to farmers and consequently result in variability in performance. At the end of the chain, the consumer obtains a local product on the same market but with variable economic and environmental performances depending on the location of the farm.

The objective of this study was to examine the interest of including a farm typology in the LCA to improve the reliability of results of LCA studies. We chose to use the poultry supply chain in Reunion Island as a source of data. First, we applied LCA using a standard farm modelling method to identify a first set of promising mitigation measures. Second we tested the use of representative farm types for environmental diagnosis and to evaluate the relevance of the previously identified mitigation measures, this time taking farm diversity into account. In the final section of the paper, we discuss several methodological issues we encountered.

2. Material and methods

2.1. Farm typology and modelling methods

Two methods for farm modelling are described in this paper. The first is a standard method based on a single farm using average data from the whole sample which is assumed to be representative of the actual farm population. The second method distinguishes different farm types and is based on many average farms that are representative of each farm type, i.e. one farm is modelled per farm type. Farm models and LCA results (obtained using the two farm modelling methods) are based on the same inventory dataset taken from a single questionnaire used to survey 42 farms. The 42 farms represented 55.3% of the farms that belong to the poultry supply chain and supply 56.3% of the total weight of poultry slaughtered each year. The 42-farms sample was based on criteria chosen in collaboration with experts, with the objective of covering the geographical and technical diversity. The criteria for sampling were the altitude of the farm (low, medium, high), its location (north, south, west, east), and its level of mechanisation (natural or dynamic ventilation of the building in which the poultry are raised).

During the farm survey, a set of 25 parameters was collected to build the typology and the farm models, and to feed the LCA inventory. These parameters were grouped in three categories: parameters that affect the atmosphere in the poultry buildings (e.g. quality of the building, natural or dynamic ventilation, density of birds), technical performance parameters including farm production (e.g. average daily weight gain, average live weight on arrival at the slaughterhouse, average age on arrival at the slaughterhouse, mortality rate) and data on the consumption of inputs on the farm (e.g. chicken feed, electricity, gas). The complete dataset is described in Table 3. The 25 parameters were extracted from farm revenue and expenditure accounts and cooperative databases, and validated with the farmers concerned during the farm survey.

In a first modelling approach, the input and output parameters of the farm model were calculated as the mean of the characteristics of the 42 farms (including consumption of inputs and production of outputs) weighted by their relative contribution to total chicken production in tonnes. The second farm modelling method distinguished a specific farm model for each farm type determined by cluster analysis. To determine the types, the analysis included the following steps: i) a principal component analysis was performed on the standardised set of variables, ii) a hierarchical cluster analysis of the scores of the first principal component was conducted using Ward's method (Saporta, 1978). To select the appropriate number of clusters, we used the Silhouette clustering quality index described by Rousseeuw (1987). The principal component analysis procedure (step i) sought uncorrelated linear combinations (components) of the original variables such that the maximum variance was extracted from the variables (Sabatier et al., 1989). Then, meaningful variables were identified from the loadings which measured the contribution of each original variable in the variance of the principal component. Variables with a loading (for a given component) that fell outside the 95% confidence interval of