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Potential of life cycle assessment to support environmental decision making at commercial dairy farms

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ABSTRACT

In this paper, we evaluate the potential of life cycle assessment (LCA) to support environmental decision making at commercial dairy farms. To achieve this, we follow a four-step method that allows converting environmental assessment results using LCA into case-specific advice for farmers. This is illustrated in a case-study involving 20 specialized Flemish dairy farms. Calculated LCA indicators are normalized into scores between 0 and 100, whereby a score of 100 is assumed optimal, to allow for a mutual comparison of indicators for different environmental impact categories. Next, major farm and management characteristics affecting environmental performance are identified using multiple regression and correlation analyses. Finally, comparing specific farm and management characteristics with those of best performing farms identifies farm-specific optimization strategies. We conclude that this approach complies with most of the identified critical success factors for the successful implementation of LCA as a decision support system for farmers. Key aspects herein are (i) the flexibility and accessibility of the model, (ii) the use of readily available farm data, (iii) farm advisors being intended model users, (iv) the identification of key farm and management characteristics affecting environmental performance and (v) the organization of discussion sessions involving farmers and farm advisors. However, attention should be paid (i) to provide sufficient training and guidance for farm advisors on the use of the applied LCA model and the interpretation of results, (ii) to evaluate the correctness of the used data and (iii) to keep the model up-to-date according to new scientific insights and knowledge concerning LCA methodology.

1. Introduction

Life cycle assessment (LCA) is an approved method to evaluate the environmental impact of livestock production (e.g. Williams et al., 2006; de Vries and de Boer, 2010; Weiss and Leip, 2012). LCA is also frequently applied to compare the environmental impact of contrasting livestock systems, for example, conventional versus organic dairy production systems (Haas et al., 2001; de Boer, 2003; Thomassen et al., 2008; Cederberg and Mattsson, 2000), or grazing versus zero-grazing systems (Arsenault et al., 2009; O'Brien et al., 2012). Besides, LCA is used to assess environmental consequences of potential measures to reduce the environmental impact of livestock production, such as a change in diet composition for dairy cows (Van Middelaar et al., in press), or an increase in annual milk production per cow or cow longevity (Van Middelaar et al., in preparation). Most of these studies consider 'typical' production systems, they compare systems using average farm data or explore environmental reduction strategies for a typical farm. However, it has been shown that the variability in environmental impact between farms within a specific production system can be large (van der Werf et al., 2009; Dolman et al., 2012; Meul et al., 2012b) and that farmers can impact most environmental aspects through their management strategy (Van Vuuren and Van Den Pol-Van Dasselaar, 2006; Hernandez-Mendo et al., 2007). Moreover, the effect of introducing an environmental reduction measure often depends on specific farm characteristics. Changing the diet composition, for example, can affect farm plan and hence emissions related to the production of forage crops (grass and maize silage) and concentrates. The effect of such an optimization measure, therefore, depends on the initial diet and farm plan. In addition, animal production characteristics and feed use efficiency also largely determine the environmental reduction potential of a strategy. Increasing milk production per cow for

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example, can be an effective measure for farms where current production levels are low; whereas for farms where animal productivity is already high, trying to further increase annual milk production per cow might negatively affect animal health or fertility (de Vries et al., 2011; Oltenacu and Broom, 2010).

In order to optimize the environmental performance of livestock farms, therefore, it is important to provide farmers with farm-specific advice, i.e. identify the best farm-specific strategies to reduce environmental impacts. Few studies exist in which LCA is applied to analyze and to explain differences in environmental performance between farms. Dolman et al. (2012) used LCA to explore variation in environmental impact among a number of pig finishing farms in The Netherlands and identified general structural and management characteristics of a group of best performing farms. Using a combined LCA and data envelopment analysis (DEA) approach, Iribarren et al. (2011) were able to identify efficient farms from a group of 72 dairy farms in Spain and set target input consumption levels, and corresponding environmental impacts, for each inefficient farm. To our knowledge, however, no studies exist in which the potential of LCA as a decision support tool for farmers is explored, i.e. the usefulness of LCA to identify farm-specific strategies to reach defined target levels and reduce environmental impacts of individual farms. Yet, LCA possesses important characteristics of a potentially successful decision support system (DSS), such as the high environmental policy relevance, analytical soundness and transferability, and the ability to summarize and simplify complex systems, promoting the function of communication (Lebacq et al., 2013). On the other hand, the complexity of the model, the use of terminology and logic unfamiliar to farmers and the extensive data requirements can counteract this potential and additionally hamper the implementation of LCA as a DSS in practice (Van Meensel et al., 2012; Lebacq et al., 2013).

The aim of the present study was to explore the potential of LCA as a DSS to support environmental decision making at dairy farms. To achieve this, we developed a method that allows to convert environmental assessment results using LCA into case-specific advice for farmers, based on the four-step process used in MOTIFS (Monitoring Tool for Integrated Farm Sustainability; Meul et al., 2008). MOTIFS is a sustainability monitoring tool for dairy farms, used as a DSS to guide farmers towards higher farm sustainability (described by Meul et al., 2009, 2012b; de Mey et al., 2011). Application of this method is illustrated in a case-study involving 20 specialized Flemish dairy farms. Strengths and critical success factors for the implementation of LCA as a DSS are discussed.

2. Materials and methods

2.1. The LCA model

The LCA model is conceptualized as a spreadsheet package using Microsoft Excel, and allows to estimate the environmental impact of milk production at farm level on a yearly basis, considering a cradle-to-farm gate approach, i.e. including all processes of the milk production cycle up to the moment that raw milk leaves the farm (Fig. 1). Production of applied medicine, minerals fed to dairy cows and machinery are not included in the LCA because of their small effect on the environmental impact of milk production (O'Brien et al., 2012). A detailed description of considered processes and applied methods is provided below.

The functional unit is 1 kg fat-and-protein-corrected milk (FPCM). Attributional LCA is applied using economic allocation whenever a multifunctional process occurs; i.e. environmental impact of a process is partitioned to multiple outputs based on their relative economic value. In case of the production of feed ingredients and their co-products, allocation values are used from FeedPrint (Vellinga et al., 2013), whereas allocation between produced milk and meat at the dairy farm is based on the farm-specific revenues from milk and meat. No environmental impact is allocated to exported manure and environmental impact associated with the application of exported manure is completely allocated to the receiving crop. In our model exported manure is used on own arable land or arable land of a neighboring farmer. The LCA model uses detailed farm data, that can generally be retrieved from farm accountancies of Flemish farms, including the area of on-farm produced forage crops, the amount and composition of purchased feeds, average number and weight of dairy cows and heifers, amount and weight of purchased animals, productivity and fertility parameters, total milk production, average milk production per cow and milk composition (% fat and protein), the amount of used inputs (mineral fertilizers, lime, pesticides, diesel and electricity) and detailed farm-level nutrient balances. The farmer provides additional information concerning grazing management, the time per year spent on pasture by calves, heifers and dairy cows.

2.1.1. Life cycle inventory

Methane emission from feed digestion is estimated from the gross energy intake by the animals according to IPCC (2006) Tier 2, using the following formula for the methane emission factor (Ym): $Ym = 9.75 - 0.05 * \text{Digestibility rate (DE\%)}$, as reported by FAO (2010) to incorporate variability in feed digestibility between farms. Feed digestibility (DE%) is estimated from the amount of produced forages and purchased concentrates and their digestibility values as reported by NIR Belgium (2010), FAO (2010) and Smink et al. (2004). Note that we take different animal categories (calves, heifers, cattle) into account to tackle uncertainty (Henriksson et al., 2011).

Methane emission from manure storage and manure deposited on pasture is estimated using IPCC (2006) Tier 2, combining grazing management information to calculate the fraction of manure in each manure management system (i.e. on pasture, on straw bedding and pit storage below animal confinements), with methane conversion factors for cool temperatures (i.e. 1% for manure deposited on pasture, 2% for solid manure and 19% for manure in pit storage). Direct nitrous oxide emissions from manure storage and deposition are estimated using IPCC (2006) Tier 2: Nitrogen (N) excreted by animals is estimated as the difference between total N intake – calculated from the dietary dry matter intake and the N content of the diet – and the amount of N retained by the animals in milk production and weight gain. Nutrient contents of feed ingredients are retrieved from the environmental accounting manual for Flemish farms (AMS, 2005). Emission factors for nitrous oxide in kg N_2O-N per kg N excreted are 0.02 for manure excreted on pasture; 0.005 for solid manure and 0.002 for manure excreted in pit storage. Ammonia emissions from manure in stables and during grazing are calculated based on the total ammoniacal nitrogen (TAN) content of the manure. Emissions are 7.6% of TAN in manure from calves on straw, 31.5% of TAN in slurry from cattle and 6.0% of TAN in manure excreted during grazing (Misselbrook et al., 2010). For cattle, TAN equals 60% of N excreted. Ammonia emissions from storage of solid manure (i.e. from calves housed on straw bedding) equals 35% of TAN in manure storage (Misselbrook et al., 2010). The latter is calculated by subtracting the amount of ammonia emitted during housing of the calves from the total initial TAN pool, according to the mass flow model of Webb and Misselbrook (2004). Direct NO_x emissions from manure storage and grazing are estimated as 21% of direct N_2O emissions according to Nemecek and Kägi (2007). Leaching and run-off of N from storage of solid manure is estimated at 5% of N in solid manure storage, according to IPCC (2006) guidelines. All calculated emissions of N from manure deposition and storage are subtracted