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Milk production Life Cycle Assessment: A comparison between estimated and measured emission inventory for manure handling

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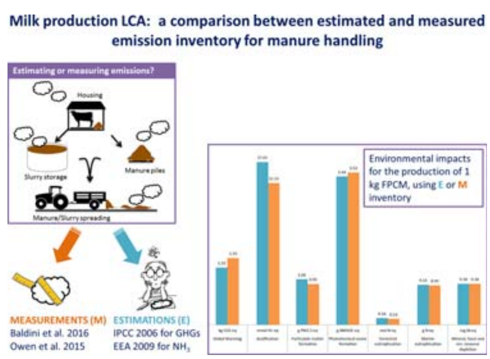
HIGHLIGHTS

- Housing emissions were measured from different manure removal systems.
- Measured or estimated emissions were used to compile life cycle inventory.
- Alternative data sources lead to different results.
- GWP impact seems to be underestimated by the IPCC equations.
- More flexible emission factors are needed to improve the accuracy of estimations.

GRAPHICAL ABSTRACT



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ABSTRACT

Measuring emissions from manure management operations (from the barns to the land) is a challenging task, subject to different uncertainties related to the spatial-temporal variability in the process leading to gaseous release. At the same time, emissions inventory is a prerequisite of Life Cycle Assessment (LCA) studies. Manure management emissions are usually estimated using equations developed by Intergovernmental Panel on Climate Change (IPCC, in the case of greenhouse gases emissions) and European Environmental Agency (EEA) for Nitrogen-related emissions. In the present study, the environmental impacts associated to three Italian dairy farms were calculated through a comparative LCA using two different approaches for complying the emission inventory. In the "estimated" approach (E) the commonly adopted IPCC and EEA equations were used, while in the "measured" approach (M) emissions actually measured were taken as input data to quantify the emissions associated to manure management. The results showed that the IPCC equation underestimates the manure management emissions, leading to a 10–42% lower global warming potential comparing E to M approach. On the other hand, ammonia related impact categories showed higher values if they were calculated using the estimated approach, underling that a safer level of estimation is maintained.

1. Introduction

The concept of *sustainability* has become a key driver in the last few years, steering the more recent political and socio economical choices. With the publication of "The livestock long shadow" in 2006, livestock's production in general, and in particular cattle, has been included among

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major responsible of environmental pollution and climate change. Since then, the awareness about emission reduction from livestock activities (GHG and other pollutants) has increased, resulting in a large number of researches focused on quantifying the environmental burden of milk production (O'Brien et al., 2012; van der Werf et al., 2014).

The environmental impact of livestock farming is strictly related to the emissions of methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3), arising from the manure management continuum (i.e. the animal housing, yards, manure storage and treatment, and land spreading (Chadwick et al., 2011)), and responsible for climate change, acidification and eutrophication effects, among other impacts. Gaseous losses from ruminant livestock in the form of manure management are responsible for 15.2% of agricultural emissions (Holly et al., 2017). Emissions of CH_4, N_2O and NH_3 may occur simultaneously from different sources: enteric fermentations and manure storages are the most important source of CH_4; while animal excreta in housing, manure storage systems and land application constitute the main source of N_2O and NH_3 (Hou et al., 2015).

Life Cycle Assessment (LCA) is a structured, comprehensive, international standardized and widely adopted method to assess the environmental impacts of a product or a process (Battini et al., 2014; O'Brien et al., 2014). LCA studies have four main pillars: the goal and scope definition; the inventory analysis; the impact assessment and the interpretation of results (ISO, 2006a). During the inventory phase, LCA practitioners refer to internationally recognized models to account for GHG and nitrogen emissions. The method proposed by Intergovernmental Panel on Climate Change (IPCC, 2006a, 2006b) is the most used (and recommended) for GHG estimation, while for NH_3 emissions, the most commonly selected reference are the equations developed by the European Environmental Agency (EEA, 2013) for the European area (Notarnicola et al., 2015). These models are based on emission factors (EFs) that were developed for the use in national GHG inventories, designed for the accounting at national scale (Nemecek and Ledgard, 2016). Their use for specific farming systems might be inappropriate, since the suggested EFs often do not take into account specific conditions of the investigated systems (Owen and Silver, 2015; Peter et al., 2016). Furthermore, recent researches indicate that the IPCC methodology may significantly underestimate CH_4 contributions from liquid dairy manure storage production, with discrepancies between inventory estimates and actual on-farm emissions (Baldé et al., 2016; Leytem et al., 2017; Lory et al., 2010).

Agricultural emissions are from nonpoint sources, characterized by high degree of variability due to climatic conditions, soil type, and agricultural practices (Goglio et al., 2017). For this reason, measuring emissions from manure management operations (from the barns to the land) is a challenging task, subject to different uncertainties related to the spatial-temporal variability in the process leading to gaseous release, which is strongly and complexly influenced by environmental conditions (Calvet et al., 2013; Owen and Silver, 2015). Despite the considerable efforts extended to measure gaseous emissions from natural ventilated buildings, measurement accuracy and standardization of methodology still are goals to be achieved (Takai et al., 2013).

Dairy system plays an outstanding role in the Italian context, but the high animal density characterizing the Northern regions pose a risk to the environment. The accurate estimation of the potential burdens associated to dairy farms is the first step for the identification of the best mitigation options that should be recommended to producers. In this context, manure handling systems play an important role, because different treatments and management strategies can alter manure composition, affecting GHG and NH_3 emissions from all the manure continuum (Holly et al., 2017).

The IPCC and EMEP/EEA equation are widely used for the estimation of emissions from the manure management. The aim of this work was to use two different data sources, field measurements or estimated emissions, to calculate the environmental impact associated to milk production in Italian dairy farms. In particular, results of LCA analysis conducted using the IPCC and EMEP/EEA equations for manure management were compared to the environmental impacts calculated using measured gaseous emissions. The use of these two different approaches for LCA calculation would allow to verify the degree of convergence of the methodologies applied for LCA and to underline their strengths and weakness. A Monte Carlo Simulation was also performed, in order to evaluate whether the two different approaches used for the LCA calculation could lead to different results even considering the high variability associated to measurements. Moreover, the impact caused by different animal categories (lactating or dry cows, heifers and calves) was investigated, to understand the contribution of the different physiological phases of animal growth to environmental burdens associated to milk production.

Results of the considered impact categories were separately discussed, highlighting differences achieved using the two calculation approaches (measured-M or estimated-E). The differences among impact associated to animal categories were underlined in a dedicated paragraph.

2. Materials and methods

2.1. Farms

For the present study three farms located in the North of Italy were monitored over one year (2015). The farms bred Holstein Friesians cows in permanent confinement. The main characteristics of the selected farms were resumed in Table 1. Farm 1 and Farm 2 can be considered of medium size for Italian conditions, as number of lactating cows and as arable land. Land was destined largely to cereal and annual forages. Farm 3, although smaller than the others, achieved a high production for cow.

In the three farms, the barns hosting cows had more consistent construction features, reflecting some farmer's management choices for manure handling, while higher variability was observed in barns where replacement herd lives. In particular, barns destined to cows were equipped with different flooring type and different manure removal systems, representative of the most common option spread in the Po Valley, as better described below.

Farm 1 was equipped with perforated concrete floor (holes diameter of 3.5 cm). The manure accumulated in the pit below the slatted surface and was periodically removed (approximately every 14 days). The cubicles were covered with rubber mats and were cleaned manually.

Farm 2 was equipped with flushing system. The feeding and the resting alley had a convex (1.5% slope) and inclined (3% slope) concrete surface, in order to increase the cleaning efficiency. The flushing was carried out twice a day with a flowrate of 0.15 $m^3\ s^{-1}$ for about ten minutes. The flush system utilized mainly recycled effluent from a screw press solid-liquid separator or occasionally water from the municipal water supply network. The cubicles were equipped with rubber mats and covered with the solid fraction derived from the manure separation system.

Farm 3 had solid floor covered with a rubber mat pavement. Manure was removed with delta scrapers running twice a day. The cubicles were equipped with straw and cleaned weekly.

2.2. Life Cycle Assessment

An attributional LCA was performed according to the ISO 14040 and 14044 standards (ISO, 2006a, 2006b), using the software Simapro PhD 8.4.0.0 (PRé Consultants, 2016).

2.2.1. Goal and scope definition

The aim of this study was to compare the environmental impact of three dairy farms with different manure handling options, using two different data set of emissions (measured or estimated emissions factors form manure management). The final scope was to verify the soundness