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Mitigating the environmental impacts of milk production via anaerobic digestion of manure: Case study of a dairy farm in the Po Valley

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HIGHLIGHTS

- Biogas from manure is a valid option for GHG emission mitigation.
- GHG emissions of an intensive dairy farm in Northern Italy amount to 1.21 kg CO_2 eq. kg^{-1} FPCM.
- If manure is digested in a biogas plant, GHG emissions decrease by 23.7 % if the digestate is stored in an open tank.
- If manure is digested in a biogas plant, GHG emissions decrease by 36.5 % if the digestate is stored in a gas tight tank.
- Manure digestion in a biogas plant significantly influences other local environmental impacts.

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ABSTRACT

This work analyzes the environmental impacts of milk production in an intensive dairy farm situated in the Northern Italy region of the Po Valley. Three manure management scenarios are compared: in Scenario 1 the animal slurry is stored in an open tank and then used as fertilizer. In scenario 2 the manure is processed in an anaerobic digestion plant and the biogas produced is combusted in an internal combustion engine to produce heat (required by the digester) and electricity (exported). Scenario 3 is similar to scenario 2 but the digestate is stored in a gas-tight tank. In scenario 1 the GHG emissions are estimated to be equal to 1.21 kg CO_2 eq. kg^{-1} Fat and Protein Corrected Milk (FPCM) without allocation of the environmental burden to the by-product meat. With mass allocation, the GHG emissions associated to the milk are reduced to 1.18 kg CO_2 eq. kg^{-1} FPCM. Using an economic allocation approach the GHG emissions allocated to the milk are 1.13 kg CO_2 eq. kg^{-1} FPCM. In scenarios 2 and 3, without allocation, the GHG emissions are reduced respectively to 0.92 (−23.7%) and 0.77 (−36.5%) kg CO_2 eq. kg^{-1} FPCM. If land use change due to soybean production is accounted for, an additional emission of 0.53 kg CO_2 eq. should be added, raising the GHG emissions to 1.74, 1.45 and 1.30 kg CO_2 eq kg^{-1} FPCM in scenarios 1, 2 and 3, respectively. Primary energy from non-renewable resources decreases by 36.2% and 40.6% in scenarios 2 and 3, respectively, with the valorization of the manure in the biogas plant.
The other environmental impact mitigated is marine eutrophication that decreases by 8.1% in both scenarios 2 and 3, mostly because of the lower field emissions.
There is, however, a trade-off between non-renewable energy and GHG savings and other environmental impacts: acidification (+6.1% and +5.5% in scenarios 2 and 3, respectively), particulate matter emissions (+1.4% and +0.7%) and photochemical ozone formation potential (+41.6% and +42.3%) increase with the adoption of a biogas plant. The cause of the increase is mostly emissions from the CHP engine. These impacts can be tackled by improving biogas combustion technologies to reduce methane and NO_x emissions. Freshwater eutrophication slightly increases (+0.8% in both scenarios 2 and 3) because of the additional infrastructures needed.
In conclusion, on-farm manure anaerobic digestion with the production of electricity is an effective technology to significantly reduce global environmental impacts of dairy farms (GHG emissions and non-renewable energy consumption), however local impacts may increase as a consequence (especially photochemical ozone formation).

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1. Introduction

Livestock activities have significant impacts on all aspects of the environment. Such impacts are increasing and changing rapidly. The Food and Agriculture Organization (FAO) has developed and applied a methodology based on the life cycle assessment (LCA) approach applicable to the global dairy sector (FAO, 2010). According to their results, the global dairy sector contributes 4.0% to the total global anthropogenic GHG emissions. This figure decreases to 2.7% if meat production is excluded (FAO, 2010). Concerning other environmental impacts, Tukker et al. (2006) have found that dairy products are responsible for about 10% of the total anthropogenic eutrophication potential, 6% of the acidification potential and 4% of the photochemical oxidant formation potential due to all products consumed in EU.

Hagemann et al. (2011) have reviewed the GHG emissions of bovine milk production systems in 38 countries and reported that GHG emissions range between 0.8 and 3.07 kg CO_2 eq. kg^{-1} milk. They concluded also that enteric and manure related emissions accounted for 70–95% of the total dairy farm GHG emissions. Nguyen et al. (2013) have assessed several combinations of dairy cattle breeds and feed types in terms of environmental performances and found that enteric fermentation emissions provided the highest contribution to the climate change impact category (45–50%). Their results range between 0.85 and 1.62 kg CO_2-eq. kg^{-1}.

Fantin et al. (2012) have reported GHG emissions ranging between 0.8 and 1.5 kg CO_2 eq. kg^{-1} milk for a collection of European LCA studies. The variations within the range are due not only to the different environmental conditions and farming systems, but also to the assumptions and models used in each study.

Del Prado et al. (2013) have modeled a dairy farm in Northern Spain and found GHG emissions of 0.84–2.07 kg CO_2 eq. kg^{-1} milk. They also provided evidence that the methodology choice used for the assessment had a large effect on the results. Moreover, they concluded that methane from the rumen and manures, and N_2O emissions from soils, were responsible for most of the GHG emissions for milk production. Kristensen et al. (2011) have analyzed 35 conventional farms and 32 organic farms and found global warming emissions, before allocation, of 1.2 and 1.27 kg CO_2 eq. kg^{-1} ECM (Energy Corrected Milk), respectively. They developed a new method for the allocation to milk and meat and compared it to 4 others already in use, finding that the share of emissions allocated to milk may vary from 74% to 87%. They identified farming strategies based on low stocking rate or with focus on high efficiency in the herd as the most promising for reducing GHG emissions.

Yan et al. (2011) analyzed thirteen LCA studies of European milk production and found that technical issues, arbitrary choices and assumptions make direct comparison between studies challenging.

According to Weiske et al. (2006), mitigating the impacts derived from dairy farms is possible by means of the following techniques: (1) improved efficiency of dairy cows; (2) frequent removal of manure and use of scraping systems; (3) improved manure management; and (4) biogas production by anaerobic digestion (AD).

Gerber et al. (2011) have analyzed the relationship between productivity of dairy cows and GHG emissions per kg FPCM on global scale and found that GHG emissions decline substantially as animal productivity increases.

Anaerobic digestion of manure to biogas is an interesting option because it reduces firstly direct emissions from slurry storage, and, secondly, the emissions from the fossil system replaced (Maranon et al., 2011). Boulamanti et al. (2013) analyzed the environmental impact of several biogas to electricity scenarios, in order to evaluate the sustainability of this process. Their scenarios included maize, manure and co-digestion of the two. They found that when using manure, GHG savings higher than 100% were possible and showed that one of the most crucial factors is the management of the digestate.

In fact, while the storage of slurry in gas-tight tanks is not generally promoted by agricultural policies, energy and climate policies are starting to subsidize best practices for digestate storage (MSE, 2012). According to Holm-Nielsen et al. (2009), at least 25% of all bioenergy in the future can originate from biogas produced from wet organic materials which include animal manure. In the 27 European Union countries (EU-27) the amount of manure produced is about 1500 million tonnes per year. Manure storage is the second largest source of methane emissions (after enteric fermentation) from European farms (Sneath et al., 2006). Statistics are not easily available but a recent survey indicates that only about 50.7 million tonnes (equal to 8.5% of all slurry produced in EU-27) was treated via AD in EU in 2011 (Lyngsø Foged et al., 2011).

In Italy the production of biogas by AD is subsidized by the government (MSE, 2012) and a large increase in the number of farm biogas plants has been recorded in the last years (Fabbri et al., 2013). In most cases, these plants, especially the small ones, apply uncovered storage of digestate.

The aim of this study is to carry out an LCA on a representative dairy cattle farm in North Italy. The data were collected from a real farm in the Lodi district. The environmental impacts from the milk production processes are calculated and an assessment of the effects of introducing a biogas plant is carried out.

2. Materials and methods

Life cycle assessment (LCA) is a structured, comprehensive and internationally standardized method that aims at quantifying all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any product or service. LCA is widely acknowledged as the most suitable tool to assess the environmental impacts of a product or a process (ISO, 2006a; IES, 2010). However, LCA has some inherent sources of uncertainty linked to: the exogenous data used to model the background system (normally from commercial databases); the unavoidable assumptions and the approach used to model the system under analysis (Basset-Mens et al., 2009).

Uncertainty is particularly relevant in the case of agricultural systems because of the great variability in the farming practices and the local soil and climate conditions (Flysjö et al., 2011). Comparing results of different LCA studies may be misleading as estimates may vary significantly depending on the assumptions, models and data used (Flysjö et al., 2012). However, comparing systems within the same study (with the same assumptions, input data and models), may lead to reliable conclusions that can be used to provide scientifically sound support to policy makers.

This LCA is performed according to the ISO 14040 and 14044 standards (ISO, 2006a, 2006b), using the software GaBi 6 from PE International (PE International, 2013). In Section 2.1 the goal and the scope of the analysis are defined. In Section 2.2 the input data are presented (the life cycle inventory (LCI)). In Section 3 the emissions and resource consumption derived from the LCI are assigned to each impact category analyzed and aggregated into indicators using weighting factors. The results obtained are then interpreted and discussed. The conclusions from the study are reported in Section 4.

2.1. Goal and scope definition

The goal of this study is the analysis of the changes in the environmental impacts of a typical Northern Italian dairy farm due to the adoption of a biogas plant running on manure.

The following scenarios are compared:

Scenario 1: dairy farm without biogas plant

Scenario 2: dairy farm with biogas plant and AD of manure with open storage of digestate

Scenario 3: dairy farm with biogas plant and AD of manure with covered storage of digestate.