Greenhouse Gas Emissions from the Global Livestock Sector – Methodology for a Life Cycle Assessment

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ABSTRACT

This paper presents a methodology developed for the estimation of greenhouse gas (GHG) emissions from the livestock sector. The methodology is based on the Life Cycle Assessment (LCA) approach and is illustrated for dairy cattle production, assessing the sector's emissions profile from cradle to retail. Three main methodological innovations have been made: the development of a herd model, a feed basket computation module linking locally available feed with animal numbers and productivity; and third, the use of geographic information system (GIS) to store data and compute emissions. These innovations permitted the computation of information required for the analysis, unavailable from statistical databases or literature as well as ensure spatial coherence. This paper also presents results on the dairy sector's contribution to GHG emissions and on the evaluation of the model. This new method is an important step towards a standardised approach to coherently assess the environmental implications of food systems.

Keywords: life cycle assessment, dairy cattle systems, climate change, greenhouse gas emissions

1. Introduction

This paper introduces a methodology developed for the assessment of greenhouse gas (GHG) emissions from the global livestock sector. This work seeks to refine and elaborate the initial estimates carried in FAO's 'Livestock's Long Shadow' by estimating GHG emissions for major dairy-related products and services--disaggregated by farming system and geographical region. The specific objective of the study was two-fold: to develop a methodology based on the Life Cycle Assessment (LCA) approach applicable to the global dairy sub-sector; and to apply this methodology to assess greenhouse gas emissions from the dairy cow sector and provide insight on the sector's contribution to GHG emissions.

2. Methodology

The methodology is based on standard guidelines regarding the use of Life Cycle Assessment such as ISO 14044 (ISO, 2006), PAS2050 (BSI, 2008) and IPCC Guidelines (IPCC, 2006). The functional unit in the animal production sector is a kg of animal protein, from milk and meat. This unconventional unit is used because the method reflects the primary function of the dairy sector, which is to provide humans with edible protein. The system boundary is defined by GHG emissions associated with milk production from 'cradle to retail' and encompasses the entire production chain of dairy cow milk production, from feed production through the final processing of milk and meat, including transport to the retailer.

Emissions of production are commonly allocated to meat and milk on an economic basis (Casey and Holden 2005; Thomassen *et al.*, 2008a), although physical allocation approaches have also been applied (Cederberg & Stadig, 2003). In this study, the protein production in the form of meat and milk is used for allocation. Cattle are not only important for milk and meat, but in certain regions also provide manure and draught. A detailed description of the allocation rules is provided in FAO (2010). The assessment introduces three methodological innovations: a herd model, a feed balance module and the use of Geographic Information System.

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The herd demography

Data on cattle herd structure are generally not available at national level. A specific "herd demography" module was thus developed to partition the total number of cattle into complete dairy and beef herds and to partition the animal numbers over adult, replacement and fattening animal categories. The module has a number of state variables and a number of rates. Rates used in the model include: the fertility rate, death rate of calves, replacement rate, growth rate of animal, and the bull to cow ratio. The six animal categories shown in Figure 1 are state variables. Calves are not counted *per se*, since they are immediately transferred to one of the replacement or meat categories. A detailed explanation is provided in FAO (2010).

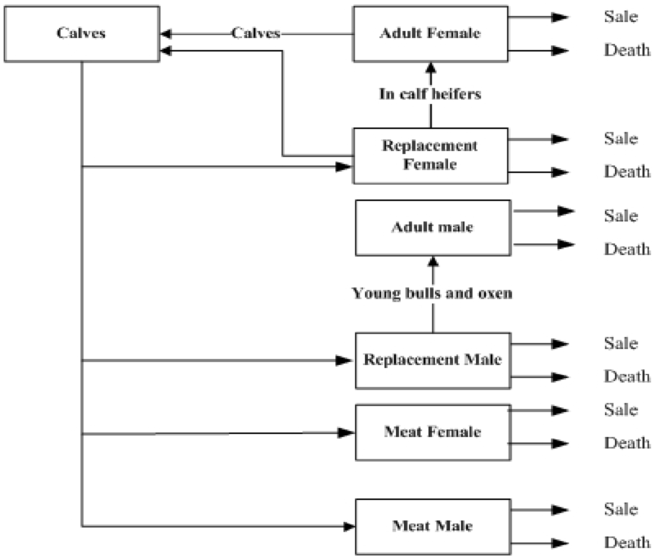

Figure 1: Structure of herd demography

To partition the total cattle numbers into complete dairy and beef herds, we perform two strings of calculations. The first sequence starts from the number of adult cows (input) and allows us to compute the numbers in the other five categories of the dairy herd. The total number of cattle in the dairy herd, deducted from the total number of cattle in the country, gives the number of animals in the pure beef herd. The number of animals in the six beef categories can then be computed.

Feed module

Feed plays a key role in any animal production system. High quality feed is necessary for optimal productivity and growth levels. In many livestock production systems, feed quality and quantity is a major limiting factor. In this assessment, all feed ingredients are identified by three key parameters: dry-matter yield per hectare, the digestible energy and the nitrogen content. Animal rations are generally a combination of different feed ingredients. Major feed ingredients include grass from natural pastures and roadsides to improved grasslands and leys; feed crops such as maize silage and grains; tree leaves, crop residues like straw and stover; agro-industrial by-products from the processing of non-feed crops such as oilseeds, cereals, sugarcane, and fruit and; concentrates.

The average digestibility and nitrogen content of the ration are based on the relative proportion of each ingredient. Emissions related to the production of feed are calculated according to the methods of Thomassen *et al*. (2008a, 2008b) and Cederberg *et al*. (2009).

Geographic Information System

The use of Geographic Information System (GIS) has proven to be essential in the calculations for two reasons. First, it has permitted the utilization of available geo-referenced data on animal densities (FAO, 2007), grassland area and production (GLC 2000 database, 2003) and area and yield of major arable crops (IFPRI, 2009) to calculate the feed balance which requires information on animal densities and feed availability on a local scale. Second, data on herd demography, feed availability, and land use are related to climatic and socio-economic conditions and are not bound to national boundaries. These data have to be combined with statistical data that are collected on a national scale.

To preserve and manage spatial heterogeneity, both at the level of data management and at the level of calculation, we relied on GIS to create the database and develop the calculation model. In this way, emissions are estimated at any location of the globe, using the most accurate information available, and then aggregated along the desired category, e.g. by farming systems, country grouping, commodity, or animal species.

3. Results

The amount of milk produced globally in 2007 was about 553 million tons (FAOSTAT, 2009). The total meat production related to the global dairy herd is calculated at 34 million tonnes (10 and 24 million tonnes from culled dairy cows and reproduction bulls and surplus calves fattened for beef production, respectively), contributing 57 percent of the global cattle meat production (60 million tons in 2007) (FAOSTAT, 2009).

The GHG emissions from the dairy herd, including emissions from deforestation and milk processing were estimated at 1,969 million tonnes CO_2-eq., of which 1,328 million tonnes are attributed to milk, 151 million tonnes to meat production from slaughtered animal and 490 million tonnes to meat production from fattened animals. The total emissions account for 4.0% of the total GHG anthropogenic emissions, of which milk production itself contributes 2.7%.

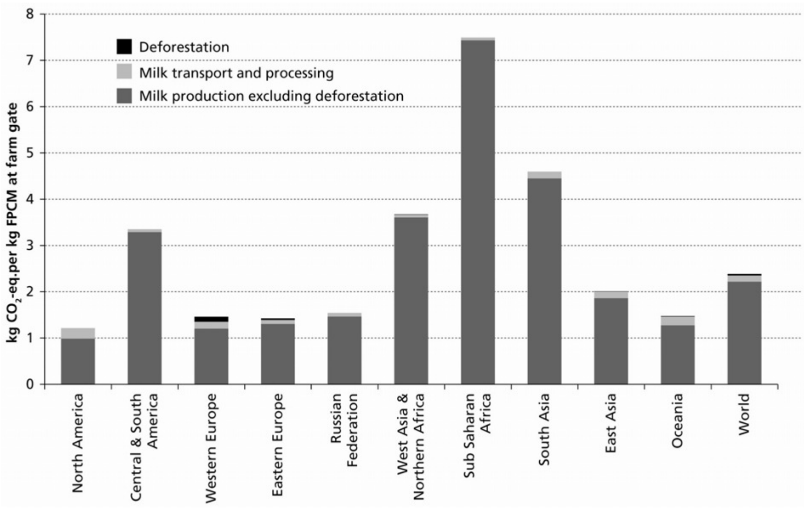

Figure 2: Average estimated GHG emissions per kg of FPCM at farm gate

The average global emissions per kg of milk and kg of meat (from the culled dairy cows and bulls and surplus calves) are 2.4 kg of CO_2-eq. and 15.6 kg CO_2-eq., respectively. The regional variation of emissions per kg of fat and protein corrected milk (FPCM) is shown in Figure 2. The highest emissions are calculated for sub-Saharan Africa with an average of about 7.5 kg CO_2-eq. per kg FPCM. The lowest values are calculated for the industrialized regions of the world: 1 to 2 kg CO_2-eq. per kg FPCM. South Asia, West Asia & Northern Africa and Central & South America have intermediate levels of emissions (3 to 5 kg CO_2-eq. per kg FPCM). The highest proportion of emissions takes place at farm level. In North America, Western Europe and Oceania, 78 to 83 percent of emissions are generated by on-farm activities and in other parts of the world, these emissions contribute 90 to 99 percent to the total emissions. Regional variations in emissions per kg of milk are thus predominantly driven by differences in farming systems.

Sensitivity analysis

The effect of herd parameters (fertility, replacement rate, death rates, age at first calving and milk yield per cow) and feed characteristics (digestibility and nitrogen content) was tested for extensive and intensive systems. The effect of these parameters on greenhouse gas emissions and milk and meat production are tested by changing one parameter by 10 percent at a time, holding others constant at the average level (Figure 3).

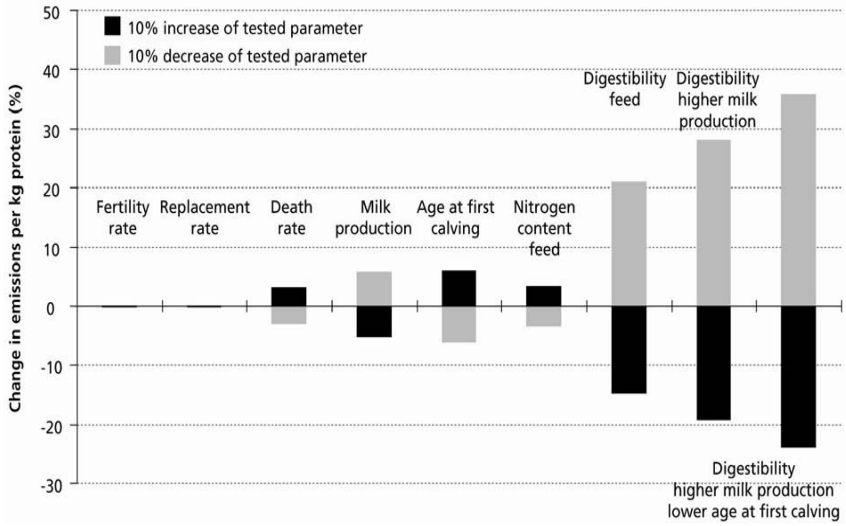

Figure 3: Sensitivity analysis: effect of a 10% change in key parameters on GHG emissions per kg of animal protein from a dairy system

The change in the herd reproduction parameters such as fertility, death and replacement rates affect the meat production proportionally, but the emissions per kg of animal protein (the sum of milk and meat protein) only change marginally. The changes in the milk production per cow and the age at first calving (in fact the growth rate) clearly have some effects on the emissions per kg of animal protein, but the effect is not as strong as the change in milk production or growth rate.

Increasing the nitrogen content of feed, without increasing milk production or growth rate causes a proportionally smaller increase in GHG emissions from both extensive and intensive systems. The digestibility of feed has a strong effect on the GHG emissions per kg of product; a 10 percent increase in feed digestibility (on an average digestibility of 56%) reduces GHG emissions by 14.8 percent and 10.1 percent in extensive and intensive systems, respectively. In practice, however, the quality of the feed is interrelated with milk production and growth, so looking at the combined effect of changes in feed quality, milk production and growth is more realistic. Assuming a 10% increase in milk production, parallel to the increased digestibility, GHG emissions are reduced by 19.2% and 15.4% in extensive and intensive systems, respectively. In a situation where the growth rate is also increased, GHG emissions are further reduced.

4. Discussion

Accuracy

The three main methodological innovations: the use of GIS, development of the herd model and feed basket described above has permitted the computation of information required for the assessment but not available in statistical databases and also ensured coherence between the production parameters (e.g. reproduction and herd size or feed intake and milk yields). Despite these methodological breakthroughs, the assessment relies on a substantial number of assumptions and simplifications, as well as on methodological choices that influence results. The sensitivity analysis has shown that the emissions per kg of milk and meat are mostly affected by digestibility, milk yield per cow and manure management.

Validation

The slaughtered animals and total meat production results calculated with the herd demography module were compared to FAO statistics (FAOSTAT, 2009) and found to be very similar for all countries, except for a few countries where live animals are traded in large numbers. Calculated GHG emissions were also compared to previous studies based on similar methodologies. Methane emissions per animal from this assessment are comparable to figures obtained by Schils *et al.* (2007), Cederberg *et al.* (2009) in OECD countries (ranging from 110 to 130 kg methane per cow per year) and by Herrero *et al.* (2008) in Africa, ranging between 21 and 40 kg methane per livestock unit per year. Emissions per kg of milk compare well with prior LCA studies for dairy production (Basset-Mens *et al.*, 2009; Block *et al.*, 2008; Capper *et al.*, 2008; Cederberg *et al.*, 2009; Foster *et al.*, 2007; Herrero *et al.*, 2008; Sevenster and DeJong, 2008; Thomassen *et al.*, 2008a; Vergé *et al.*, 2007).

Some of the results from prior analyses are lower than those presented in paper, which in part is caused by discrepancies in emission factors (e.g. Basset Mens *et al.*, 2009, Cederberg *et al.*, 2009) or allocation technique (Cederberg *et al.*, 2009). The choice to use the standard emissions factors of the IPCC at Tier 2 level may also result in discrepancies if compared to studies that utilise country-specific emissions factors.

5. Conclusions

The global average of emissions from milk production, processing and transport is estimated to be 2.4 CO_2eq. per kg of FPCM, which is 2.7 percent of the total anthropogenic emissions. The overall global emissions attributed to the dairy herd plus milk processing and transport activities are estimated to contribute between 4.0 percent of total anthropogenic emissions [±26 percent]. This includes the production of milk and milk products, the production of meat from dairy related animals (old stock and young fattened stock), as well as the provision of draught power. The method and database developed for this assessment effectively supported the calculation of GHG emissions related to dairy production on a global scale, and may be regarded as a step towards a harmonised methodology for the quantification of emission. In the same way, the global datasets collected for this assessment can serve as an initial data source, to be refined and updated by users over time.

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