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Handling multi-functionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya

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Life cycle assessment (LCA) is an acknowledged method to assess the contribution of livestock production to greenhouse gas (GHG) emissions. Most LCA studies so far allocate GHG emissions of livestock to marketable outputs. Smallholder systems, however, provide several products and services besides the production of marketable products. We explored how to account for multi-functionality within the LCA method in a case of smallholder milk production in the Kaptumo area in Kenya. Expressed per kg of milk, GHG emissions were 2.0 (0.9–4.3) kg CO_2-e, respectively in case of food allocation, 1.6 (0.8–2.9) kg CO_2-e in case of economic function allocation and 1.1 (0.5–1.7) kg CO_2-e in case of livelihood allocation. The two Carbon Footprint (CF) estimates of milk production considering multi-functionality were comparable to CF estimates of milk in intensive milk production systems. Future LCA's of smallholder systems should account for multi-functionality, because CF results and consequently mitigation options change depending on the functions included.

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Introduction

Livestock production is responsible for about 15% of the global anthropogenic emissions of greenhouse gases (GHGs; [1••]). The sector, therefore, is widely challenged to reduce its impact on climate change [1••,2]. Studies on global emissions are based on life cycle assessment (LCA), which is a method that is increasingly used to assess the environmental impact along the entire life cycle of an animal product. In LCA, the environmental impact is related to a functional unit, that is, the main function of a production system expressed in quantitative terms. For example, in a recent landmark report entitled 'Greenhouse Gas Emissions from the Dairy Sector', the FAO used LCA to calculate the emissions of GHGs per kg of fat-and-protein corrected milk (FPCM) of milk production globally [3••]. It showed that emissions of GHGs per kg FPCM declined exponentially as annual milk production per cow increased [3••]. Based on this report, Gerber *et al.* [4] concluded that increasing annual milk production per cow could lower emissions of GHGs in systems with a low milk yield per cow, such as small-scale mixed crop-livestock systems, also known as smallholder systems.

However, in smallholder systems, livestock are often kept not only to produce milk or meat, but also to produce fertiliser, provide draught power and act as capital asset [5,6•]. In many smallholder systems, livestock also have other less tangible values, such as use for dowry, as signs of prestige and wealth and as a part of ethnic identity construction [7,8]. Despite the prevalent multi-functionality of cattle in smallholder systems, in the few studies that apply LCA to smallholder systems in which livestock have multiple functions, those are not all acknowledged. And despite the fact that they ignore many aspects of livestock multi-functionality in smallholder systems, such analyses guide policy making regarding them [1••,3••].

Several LCA studies have addressed handling the interaction between milk and meat production in cattle systems [9,10,11•]. Only Ripoll-Bosch *et al.* [12] explore the interaction between meat production and ecosystem services of sheep production systems, such as nature conservation. These studies demonstrate that the calculation and comparison of GHG emissions among livestock production systems is highly affected by whether or not multi-functionality is included. To the best of our knowledge, no LCA study has focused on handling multi-functionality of livestock in smallholder mixed systems, despite the fact that these systems produce the majority of the cereal and livestock products for households in developing countries [2,13]. This paper, therefore, explores methods to handle multi-functionality of livestock in an LCA of smallholders systems. We illustrate our approaches using the case study of smallholder Kenyan milk production in Kaptumo, Rift Valley. In the Kenyan highlands, dairying is an integral part of smallholder systems and important for livelihoods of about two million households [6•,14,15].

Material and methods

System description

The case study involves 20 mixed crop-livestock farms in Kaptumo Division, Rift Valley Province, Kenya. These farms were a random sample of the mixed farms in this area. The research was facilitated through the Mitigation of Climate Change in Agriculture (MICCA) programme of the Food and Agriculture Organisation of the UN (FAO) in collaboration with the East African Dairy Development Project (EADD). Data were collected between September 2012 and January 2013. Kaptumo is in Nandi South District, and lies in altitudes from 1800 to 2100 m above sea level with rainfalls ranging from 1500 to 2100 mm/year [16]. All households belong to the Kalenjin tribe, with 80% to the sub-tribe Nandi. The farms under study are small-scale mixed crop-livestock systems. These smallholder systems grow cash crops, mostly tea, and crops for home consumption; and keep some dairy cattle and other livestock.

Data collection

The field research was divided into on-farm and off-farm assessments. A step-wise approach was used for the data collection on-farm. First, open ended interviews with free listing of cattle functions was done with ten farmers. The identified functions were used for a ranking exercise in a second set of interviews which was done with a different group of 20 farmers. With this group of farmers first open and semi-structured interviews were done. The open interviews aimed at understanding cattle functions and their meanings to the farmers. During the semi-structured interviews detailed information about the household, farming, and cattle feeding and management was collected.

Milk production was assessed through interviews. Farmers were asked how many liters of milk per day (over the year) the family used for home consumption and how many liters were sold. Feed ingredients for cattle were grass from grazing, crops produced on farms (Napier grass, Boma Rhodes grass, maize), crop-residues produced on farms (bean straw, maize stalks, sweet potato residues, sugarcane cuttings, sorghum stalks) and purchased feeds (concentrates, molasses). Feed inputs other than from grazing were computed based on farmers' estimates of feed inputs during one year. To estimate the feed inputs, feeding calendars were made to discuss with farmers the use of specific feeds over the year. This formed the basis for estimates of the use of specific feeds during one year. These estimates were later translated into kg DM for each feed by applying weight factors ([17] and own measurements) and literature based DM conversion factors. Concentrate composition was based on the composition of a concentrate mixture of a local provider in Eldoret. Detailed information on concentrate composition, and on-farm and off-farm feed use is available in the Supplementary material.

The amounts of manure utilized for fertilizing were computed based on farmers' information of manure use on different crops during one year. Off-farm field research involved collecting information of local interest rates (from a local bank), cattle prices (cattle markets, traders, local butcher), milk prices (from the local milk collection centre) and fertilizer prices (from local shops).

System boundaries, functional unit, emissions

LCA is an acknowledged method to assess the environmental impact along the life cycle of animal-source food [18,19]. A carbon footprint (CF) is a single-issue LCA, focussing only on emission of GHGs. We assessed GHG emissions for all processes involved up to the farm-gate, including the animals, feeding, feed production and manure management. Our CF assessment of milk is attributional, implying that we considered emissions under current production and marketing conditions [20].

Allocation procedures

An LCA has a product-focus and the guidelines of LCA [21,22] provide rules on how to allocate the environmental impact of a process in case of multiple outputs. In our CF assessment, multiple functions of livestock are handled as multiple products of the production system. Economic allocation is commonly used in LCAs of dairy systems [20,23], and implies allocation of emission of GHGs to the various outputs based on their economic values. This allocation method, however, requires economic values of functions of livestock. Milk and meat have a direct market value, whereas the economic value of manure as fertiliser and of cattle as a mean of finance and insurance can only be assessed indirectly. Other functions of livestock, such as the use for dowry and a sign of identity and wealth, cannot be appropriately and meaningfully quantified in economic terms. We explored three methods of allocation, reflecting the different perspectives on smallholder dairying:

(1) Economic allocation to the conventional animal products, that is, milk and meat ('food allocation').
(2) Economic allocation to all products (market and non-market products) that could be economically quantified, that is, milk, meat, manure as fertiliser, cattle as a means of finance and insurance ('economic function allocation').
(3) Allocation based on farmer's assessment and valuation of the role of cattle in their livelihoods, including milk for home consumption, milk for sale, animal sales when cash is needed, dowry and wealth: This

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