Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Environmental Sustainability

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

Viola Weiler[1], Henk MJ Udo[1], Theo Viets[1], Todd A Crane[2,3] and Imke JM De Boer[1]

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.

Addresses
[1] Animal Production Systems Group, Wageningen University, P.O. Box 338, 6700AH Wageningen, The Netherlands
[2] International Livestock Research Institute, P.O. Box 30709, Nairobi 00100, Kenya
[3] Knowledge, Technology and Innovation Group, Wageningen University, P.O. Box 8130, 6700EW Wageningen, The Netherlands

Corresponding author: Udo, Henk MJ (henk.udo@wur.nl, udo.henk@gmail.com)

Current Opinion in Environmental Sustainability 2014, **8**:29–38

This review comes from a themed issue on **Sustainability governance and transformation**

Edited by **Paul C Struik** and **Thom W Kuyper**

Received 24 January 2014; Accepted 14 July 2014

http://dx.doi.org/10.1016/j.cosust.2014.07.009

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

allocation focusses on the farmers' perspective and definitions of cattle functions, and is independent of economic values ('livelihood allocation').

Economic allocation to milk and meat ('food allocation')

In this allocation procedure, emissions of GHG were allocated to milk and meat based on their economic value. The economic value of milk was calculated based on producer prices [14]:

$$\text{MILK} = \text{milk output} \times \text{milk price}$$

where MILK is total economic value of milk of one year (in Ksh; 1€ = 113.4 Ksh in December 2012). Milk output was estimated as kg of milk produced on a farm per year, based on farmers' estimates on milk consumed at home and milk sold. Milk price was based on the average producer price of milk as paid by the local EADD hub Kapcheno Dairies, which is the main milk collection centre in Kaptumo. The economic value of meat was calculated as a function of the animal category and the price per head (in Ksh):

$$\text{MEAT} = \text{head} \times \text{meat price}$$

where MEAT is the total economic value of the meat utilized from cattle during one year (Ksh); head is the number and type of cattle used for meat; meat price is the producer price for the animal as paid by a local butcher.

Economic allocation to milk, meat, manure as fertiliser, cattle as a mean of finance and insurance ('economic function allocation')

In this allocation procedure, emissions of GHG were allocated to all functions that could be economically quantified, that is, milk, meat, manure as fertiliser, cattle as a means of finance and insurance values. The economic value of manure as fertiliser was valued based on synthetic N fertiliser equivalents, similar to Alary *et al.* [24]. The economic value of N was calculated based on the local price of N in DAP (Diammonium Phosphate; based on average price of a 50 kg bag) which was the most common fertiliser farmers used:

$$\text{MANURE} = \text{fertiliser price} \times \text{N}_{\text{manure}}$$

where MANURE is the total economic value of manure used as fertiliser during one year (Ksh), fertiliser price is the economic value of N in DAP (Ksh/kg); N_{manure} is kg N in manure used as fertiliser. N of manure used for fertilising was computed by multiplying the amounts of manure applied to crops based on farmers' estimates and an N content in cattle manure of 1.4% based on Lekasi *et al.* [25]. We assumed that 50% of N was lost during storage [26].

Manure production in kg DM per day was calculated by multiplying the live weights of the average herd of a farm by 0.8% [25]. The fraction of this total manure used as fertiliser was computed based on farmers' estimates of manure used on each crop during one year, assuming a moisture content of 50%.

In line with Moll [27], Moll *et al.* [6•] and Behnke and Muthami [28], the benefit of cattle for financing is related to the avoidance of paying an interest rate when borrowing money at a bank or from an informal money lender:

$$\text{FINANCE} = \text{head}_{\text{price}} \times b_f$$

where FINANCE is the economic value of cattle as finance during one year (Ksh); $\text{head}_{\text{price}}$ is the economic value of cattle sold due to reasons of finance; b_f is the interest rate. For all farms, an interest rate of 19% (December 2012) was applied which was the rate at Equity Bank, a popular bank in Kaptumo.

In line with Bosman *et al.* [28], Bebe *et al.* [14], Moll *et al.* [6•], and Behnke and Muthami [28], the benefit of cattle as insurance was understood as the absence to pay a premium in case of an insurance:

$$\text{INSUR} = \text{stock}_{\text{value}} \times b_i$$

where INSUR is the economic value of the cattle stock as an insurance for the household (Ksh); $\text{stock}_{\text{value}}$ is the economic value of the average cattle stock during one year (computed by the number of animals during the time of visit and one year before that); b_i is the insurance premium, that is, the cost that cattle owners would need to pay to purchase insurance coverage equal to the capital value of their herd. An insurance premium of 6% was applied for all farms as in Bebe *et al.* [14] and Moll *et al.* [6•].

Allocation based on farmer's assessment and valuation of the role of cattle in their livelihoods ('livelihood allocation')

Farmers were interviewed in order to further identify non-tangible functions of cattle and to gain insight into farmers' motives for keeping cattle. Free listing [29] was first used to elicit the various functions that cattle play in farmers' livelihoods. Five functions were identified, namely 'milk for home consumption', 'milk for sale', 'cattle sales when cash is needed', 'dowry', and 'wealth'. This listing was later used as farmers were then asked to rank according to how important those are to them as reasons why they keep cattle. For the ranking exercise, each function was written on one paper which farmers used to put them into a rank order. Forty-five per cent of farmers completed the exercise and ranked 'milk for home consumption' the highest and 'milk for sale' as second, followed by 'cattle sales when cash is needed', 'dowry' and 'wealth'. It is worth noting that farmers struggled with the ranking exercise, finding it difficult to assign relative importance to each aspect of cattle keeping in their livelihoods. In the end, nine out of twenty informants completed the ranking exercise, with the remainder simply saying that all functions were important. For the purposes of preliminary integrating the outcome of the ranking into the LCA model, ranks were assumed to be ordinal and with an equidistant relationship between them. GHG emissions were allocated to those five functions depending in the relative importance of each, that is, 33%, 27%, 20%, 13% and 7% of emissions for the functions of rank 1 to rank 5.

Computation of greenhouse gas emissions

The major GHGs related to agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Emission of CO_2 results from the combustion of fossil energy to power machinery for, for example, land cultivation, and from land use change. CH_4 is emitted mainly during enteric fermentation in ruminants and manure management, whereas N_2O is released during manure management and from managed soils [30••]. Emissions of GHG were calculated based on IPCC guidelines [31] (details on emission calculations are available in the Supplementary material). The time period considered was January up to December 2012.

To quantify GHG emissions, cattle stocks were divided into the categories lactating dairy cows, non-lactating dairy cows, heifers and young stock of Friesian or Ayrshire crossbreds with local cattle (details on cattle weights, herd compositions, milk production, and sales are available from the Supplementary material). GHG emissions related to feed production were computed based on interview information on feed inputs for cattle, crop land sizes and GHG emissions were accounted for based on mass relationship, that is, the fraction of mass of feed out of the annually produced biomass of each crop.

Off-farm processes are those related to external inputs, that is, in this study, off-farm emissions included emissions due to the production of synthetic fertilisers, molasses, grinding of maize for feed, and other processes related to the production of concentrates. Changes in carbon stocks and carbon losses due to deforestation were excluded. Emissions of CO_2, CH_4 and N_2O were summed based on their equivalence factor in terms of CO_2-equivalents (CO_2-e; 100-year time horizon): 1 for CO_2, 25 for CH_4 and 298 for N_2O [31].

Results

The production system

Table 1 presents household and farm characteristics of the case study farms. The mean age of the respondents was about 50 years, whereas the average household was composed of about 5 members. The two most important income sources originated from tea and dairy production. Ninety per cent of the households had no formal insurances. The average farm size was 2.4 ha, mostly own land; on average 1.1 ha was used for cattle, including pasture and fodder crops. Crops were grown for home consumption and sale. Ninety per cent of the farms kept other livestock than cattle, that is, sheep, goats, chickens or donkeys.

The majority of cattle were either a cross of Friesian or Ayrshire with local breeds. The average herd size was 2.9 cows, 1.1 heifers and 1.3 other young stock (Table 1). The share of lactating animals was 49% (range: 27–82%). Farmers have life-long experience with cattle keeping as this is an integral part in the Kalenjin culture. Cattle were grazing most times and fed only limited additional feed, mainly napier grass or crop residues. Concentrates were given mainly to lactating cows. Table 2 shows main characteristics of dairy cattle herds and management practices. During one year, a farm produced, on average, about 4.5 tons of DM cattle manure. Ninety per cent of the farmers used manure as a fertiliser on their land. Around one third of the manure was used as fertiliser. Manure was collected and stored for differing periods of time in bags or open heaps before applying it on crops. Most manure was applied to napier grass, bananas and vegetables. Details on land, feed and manure use are available from the Supplementary material.

Table 1

Household and farm characteristics of 20 smallholder farms in Kaptumo.

	Mean	Range
Household characteristics		
Age of respondents (y)	49.9	31–75
Gender of respondents (males %)	75	–
Number of children per household	4.8	1–11
Farm size (ha)	2.4	0.6–7.2
Land used for cattle (ha)	1.1	0.1–4.8
Households with insurances (%)	10	–
Cropping area (ha[a]); (farms growing the crop)		
Tea	1 (17)	0.1–2.8
Maize	0.3 (20)	0.04–1.2
Beans	0.2 (18)	0.04–0.6
Bananas	0.1 (18)	0.02–0.2
Potatoes	0.1 (6)	0.04–0.08
Vegetables	>0.1 (18)	0.02–0.08
Other crops	0.2 (12)	0.04–0.6
Livestock (n[b])		
Cows	2.9	1–8
Heifers	1.1	0–4
Young stock	1.3	0–4.5
Sheep	0.9	0–8
Goats	0.2	0–2
Chickens	12.7	0–40
Donkeys	0.2	0–1

[a] Average area for the number of farms growing this crop and where crop land size could be estimated.
[b] Number of animals on the 20 farms.

Farmers' valuation of cattle in their livelihoods

The interviews showed that farmers' motives for cattle keeping are manifold, thus the total value of cattle is comprised of a complex combination of functions rather than a single function. For all farmers, milk for home consumption and milk for sale play important roles. All farmers are using milk for home consumption, sharing it among the whole family. Milk is an important component of tea drinking, which is very typical in the area. Because of the Kalenjin history as herders, there is a cultural value

Table 2

Feeding and manure management of 20 smallholder farms in Kaptumo.

	Mean	Range
Feed components other than grazing (kg DM/y); (farms feeding it)		
Napier grass	3823 (19)	123–31,009
Banana stalks	506 (7)	29–1685
Bean straw	704 (10)	53–3071
Maize stalks	2343 (17)	106–5400
Boma Rhodes	1211 (3)	93–2281
Sweet potato plant	31 (2)	22–40
Sugarcane cuttings	32 (1)	–
Sorghum stalks	122 (12)	118–126
Maize silage	65 (1)	–
Concentrates	891 (17)	56–4502
Maize meal	239 (5)	7–700
Molasses	101 (2)	29–172
Manure management		
Manure production (kg/y)	4502	1168–11,605
Manure used as fertilizer (%)	31	0–100

attached to milk consumption, including the preparation of *murzik*, traditional sour milk. There is a strong appreciation for self-produced milk, which is perceived as being superior to purchased milk. On average, 58% of the milk off-take was sold.

Ninety-five per cent of the farmers talked about the role of cattle as a security for them or had sold cattle in the past 12 months. Cattle can act as a security for future major expenses, furthermore owning cattle increases the chance to get loans from banks. For 85% of the farmers, dairy cattle are a means of financing urgent cash requirements. A review of cattle sales during the past year illustrated the important role of cattle as a means for finance for a household. It is noteworthy that 93% of cattle sales were due to financial pressure and not directly related to production or reproduction performances of the animal sold. To be able to invest in the farm or consumer goods, money is needed and this is a major reason to sell cattle. A prominent example of the role of cattle for financing is school fees. When the time for paying school fees comes, cash is needed and cattle are used to liquidate that money within a short period of time. Other examples are paying for urgent expenses or investments like buying some land.

Beyond the direct nutritional and financial benefits of cattle ownership, 90% of the farmers cited cattle as having important, though less tangible, social cultural roles. Keeping cattle is part of farmers' identity and cattle can be a source of social prestige. As a man, it seems to be essential to have at least one cow to be regarded as part of the community. The own cultural identity, belonging to a community, and the interpretation of cattle as a sign of wealth lie close to each other. Dowry was a prominent topic, it is an important practice in Nandi culture even to this day.

GHG emissions of dairy production

Total greenhouse gas emissions and emission hotspots are shown in Table 3. Total GHG emissions per farm averaged 6526 kg CO_2-e (range: 1261–20,720 kg CO_2-e), from which about 68% was methane emission from enteric fermentation. GHGs due to feed production were on average 16% of total emissions, of which almost all emissions occurred off-farm with concentrates being the most important emission source due to the fact that there were no other emission hot spots (there is no mechanical field work and respective fossil energy use) and due to a relatively high CF per kg concentrates (1.36 kg CO_2-e/kg concentrates; largely due to the rice bran component of the concentrates). GHGs due to manure deposit on pasture were on average 15% of total emissions. Details on the GHG's emissions per farm are available in the Supplementary material.

The economic values of milk, meat, manure as fertiliser, financing and insurance were quantified for the time period of one year (Table 4). Milk contributed on average 82% to the economic value of a farm, with a range of 59–95%. On average, 42% of the economic value of milk originated from milk consumed at home by humans (10–82%). Milk suckled directly by the calf was not accounted for. Meat played a role on two farms only, where slaughtering occurred because of visitors or a broken leg of the cow. The economic value of manure averaged 4% of the total economic value of a farm. The value of cattle as insurance contributed on average 7% to the economic value of a farm (4–12%). The benefit of cattle for financing contributed 5.5% (0–22%). Half of the farms had sold cattle in the past year due to financial pressures.

The CF of milk based on food allocation (economic allocation to milk and meat) averaged 2.0 kg CO_2-e per kg milk (0.9–4.3 kg CO_2-e per kg milk), whereas the CF of milk with economic function allocation (economic allocation to milk, meat, manure as fertiliser, cattle as a mean of financing and insurance was on average 1.6 kg CO_2-e/kg milk (0.8–2.9 kg CO_2-e per kg milk, Table 5)). Farmers ranked milk for home use and milk

Table 3

Greenhouse gas emissions of cattle keeping in 20 smallholders farms in Kaptumo (kg CO_2-e/farm).

Emission source	Mean	Range	Per cent
On-farm			
Enteric fermentation (CH_4)	4422	1102–11,346	67.8
Manure management (CH_4)	55	0–169	0.8
Manure on pasture (N_2O)	985	0–3030	15.1
Feed production (N_2O)	14	0–53	0.2
Off-farm			
Feed production[a] (CO_2,CH_4,N_2O)	1050	10–6141	16.1
Total	6526	1261–20,720	100

[a] From fertilizer use, grinding maize, molasses, concentrates.

Table 4

Economic values of the five quantified cattle functions (€/y) and allocation factors (%) using food allocation (A1), economic function allocation (A2) and livelihood allocation (A3).

Cattle function	Econ. value[a] (*n*)		A1[b] (*n* = 20)		A2 (*n* = 20)		A3[c] (*n* = 9)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Milk	809.2 (20)	233–2033	97.9	67–100	81.7	59–95	–	
Home use	341.8	146–1411	–		–		31.7	27–33
Sale	467.4	0–1777	–		–		22.2	7–33
Meat	16.3 (2)	0–221	2.1	0–33	1.8	0–29	–	
Manure	28.2 (18)	0–124	–		3.6	0–13	–	
Insurance	70.7 (20)	16–186	–		7.4	4–12	18.6[c]	7–27
Financing	45.5 (10)	0–161	–		5.5	0–22		
Dowry			–		–		14.9	7–27
Wealth			–		–		12.7	7–20

[a] Economic values are average values in € (1€ = 113.4 Ksh in December 2012) of the 20 farms. *n* is the number of farms the function was present.
[b] Meat was a function on only two farms; on those two farms the economic allocation to meat was on average 20.5%.
[c] Insurance and financing are one function, namely financial security.

for sale as the most important reasons why they keep dairy cattle, thus between 40 and 60% of emissions were allocated to milk in the livelihood allocation (allocation based on farmers' assessment and valuation of the role of cattle in their livelihoods). Applying the livelihood allocation, the average CF of milk was 1.1 kg CO_2-e/kg milk (0.5–1.7 kg CO_2-e/kg milk, Table 5).

Discussion

Methodology: farming system and multi-functionality

The great majority of smallholder dairy farms in the Kaptumo area represent free-grazing smallholder dairy systems. The farm sizes, number of cattle, cattle management practices, milk production performances, economic results, and motives for keeping cattle in the present study were comparable to free-grazing smallholder dairy farms from a large cross-sectional study in the Kenya Highlands [14]. In such farms cattle are kept for a variety of reasons [6•,14]. We argue that all functions of cattle can be understood as products they provide to their owner, and they all have to be considered when allocating GHG emissions.

An economic quantification of market and non-market functions is widely applied and helps to understand the decision making of farmers with regard to the allocation of their resources and the management of their herds [5,6•,14,32]. The economic function allocation method included the functions that could be quantified in money terms. However, whether this covers all contributions of cattle to livelihoods is debatable. For example, we computed the economic value of milk by applying the producer price, though this economic value does not say anything about the important nutritional benefits, especially for children whose diets are mostly plant-based [28]. Furthermore, our value of manure based on the synthetic fertiliser N-equivalent misses the P and K values of manure, and the positive effects manure has on soil organic matter and water-holding capacity.

Table 5

Carbon Footprint of milk production using food allocation (A1), economic function allocation (A2) and livelihood allocation (A3) in 20 smallholders farms in Kaptumo.

Allocation	kg CO_2-e/kg milk	
	Mean	Range
A1	2.0	0.9–4.3
A2	1.6	0.8–2.9
A3	1.1	0.5–1.7

In the case of intangible functions, economic quantification is unlikely to meaningfully cover all benefits of cattle. We argue that other socio-cultural values as cattle as part of identity or the use of cattle for dowry are beyond economic values. Thus, the development of an alternative method of allocating GHG emissions to cattle functions based on a perspective that is more close to the reality of the farmers and independent of economic quantification was explored. The categories of functions were based on farmers' perceptions on the uses they make from their cattle. Ranking was used to give a quantitative weighting factor to the functions. However, the ranking exercise was successful with only nine out of 20 farmers because the nature of the exercise lay outside the scope of many farmers and all functions were seen as important. Our chosen method, and thus the precise numerical outcome, is not meant to be conclusive. Instead, this is intended to provide a proof of concept that indicates the importance of smallholders' valuation of cattle in their livelihood practices in the context of LCA. Further development of this novel LCA approach to multi-functionality will need to attend to more precise and appropriate weighting of livelihood allocation values, keeping in mind that (a) smallholders do not necessarily recognize the validity of rank ordering the various functions that cattle serve in their livelihoods, and (b) values will vary across different socio-ecological systems.

Emissions and emission sources

The farms in the Kaptumo area, just as all smallholder dairy type farms in the Kenya Highlands are characterized by a capital-extensive way of farming; there is no mechanization, little use of concentrates or synthetic fertilisers and thus, no burning of fossil fuels which are associated with high emission intensities. These cattle farming practices resulted in a total emission of, on average, 6526 kg CO_2-e. The majority of these emissions occurred on-farm (84%). The largest share of emissions was associated with methane emission from enteric fermentation. This again is related to the capital-extensive nature of the farming system, that is, absence of emissions through burning of fossil energy and also due to the limited use of concentrates.

In general, the number of non-lactating animals (about half of the total number of cattle in the study farms) has a strong effect on the CF of milk production, as the total emissions are later divided by the kg of milk produced. However, this is where the importance of valuing multi-functionality begins to have great effect. From a single commodity production point of view, it is inefficient to keep animals that do not produce milk. Acknowledging multi-functionality of cattle allows us to see those animals as still being productive, though serving other functions than producing milk.

Emissions due to feed production were the second most important emission source, with an average of 16% of the emissions. More than 95% of the feed production emissions were due to the use of concentrates. The CF of concentrates was calculated as 1.36 kg CO_2-e/kg concentrates. These emissions were much influenced by the large percentage of rice bran in the concentrates. Rice production is associated with relatively large methane emissions [33]. Manure and DAP fertilisers were applied during on-farm feed production, which are associated with nitrous oxide emissions in crop production. Due to the limited amounts of these inputs, as well as the limited amounts of given feeds to cattle in general, direct and indirect N_2O emissions in feed production had a small share in total GHG emissions. GHG emissions due to manure storage were removed from the livestock emissions as they are to be accounted for in the crops to which the manure is applied as fertilisers. Most manure was left on pasture which was associated with N_2O emissions, amounting to, on average, 15% of total GHG emissions.

Impact of different allocation methods on CF results for milk

Different allocation methods resulted in different CFs of milk: food allocation resulted in a CF of 2.0 kg CO_2-e/kg milk; economic function allocation in 1.6 kg CO_2-e/kg milk and the livelihood allocation based on farmer's assessment and valuation of the role of cattle in their livelihoods resulted in 1.1 kg CO_2-e/kg milk. So, as could be expected, disregarding the multiple functions of cattle results in higher CFs of milk production. In the livelihood allocation, on average, 54% of the emissions were allocated to milk. There are few studies that can be used for comparisons of results as there has been limited research of CF of milk on smallholder dairy systems. Bartl *et al.* [34] compared typical Peruvian dairy systems using allocation to kg ECM (Energy Corrected Milk). High emissions per kg ECM (13.8 kg CO_2-e) were found in the Andean highlands, roughage-only and low productive system compared to the coastal, high productive system (3.2 kg CO_2-e), whereas emissions per ha or per animal were lower in the highlands system. The results of the CF of milk of the present study using the economic function and the livelihood allocation are close to or in the range of results of high producing dairy systems in OECD countries (0.84 to 1.3 kg CO_2-e/kg milk; [19]). Thus, from an emission intensity point of view related to kg CO_2-e per kg of milk, the systems in the Kaptumo case are not performing worse than high producing, specialized farms. The milk yields per cow in Kaptumo (on average 1456 kg/cow*year) are much lower than in OECD countries (e.g. 7537 kg/cow*year in The Netherlands in 2011 [35]), but also much less inputs are used.

Our results contradict global studies which showed emissions of dairy systems of 2.4 and 7.5 kg CO_2-e/kg milk for the global average and for Sub Saharan Africa, respectively [3••,4]. However, these studies do not consider multi-functionality in dairy systems as in the present study. Another explanation for the difference of our results with the global studies is that home consumed milk is not included in cow milk yield estimates in global studies. In Kaptumo, on average, 42% of the milk output was consumed at home. Thus, the milk outputs per cow are higher in this study compared to the study done by FAO which estimated for Sub Saharan Africa an overall average of about 350 kg milk/cow and year [3••]. Milk production levels in the global studies use FAO statistical data, which are based on all cattle and official market channels for milk in specific countries. So, a third reason is that smallholder dairy farmers in areas such as Kaptumo keep dairy type cows that produce more milk than an average production level per country.

Mitigation options and policy implications

The results of this study show that the CF of milk changes depending on the methodological choice of allocation within an LCA. This does not change the total emissions, but recommendations about mitigation options might differ depending on which aspects of a system are included in the assessment. Common mitigation options based on LCA studies focus on increased animal productivity in terms of edible products, better feeding and manure management [2,4]. Nevertheless, when focussing on GHG emissions of the dairy production considering the products milk and meat only, the mitigation options may also lie in the animal component, that is, number of animals, feeding management and manure management. Keeping a smaller number of more productive animals and utilizing more manure could result in higher milk production and a lower CF per kg of milk. Feeding has been challenging due to dry seasons, feed shortages at times and limited feed conservation on farms. The use of leguminous fodder shrubs could be an opportunity [36]. However, a livelihoods lens is more enlightening than a commodity lens when considering mitigation options. Thus, when widening the perspective to all functions, milk, meat, manure as fertiliser, cattle as a mean of finance and insurance, and social values, reducing the number of animals does not make sense because all animals play important roles for the livelihoods of households.

To identify the most effective mitigation options in mixed farming systems like in the Kaptumo case it even makes more sense to assess the whole farm, as the most effective GHG mitigation options may lie outside the dairying activities on a farm [37]. In the Kaptumo case study, one example could be the cooking devices, as women usually cook with wood, which are associated with wood use and smoke. Another example is fertilisation in tea production. Farmers usually do not use manure or compost on tea, but rely only on synthetic fertilisers. A central issue in the Kenya highlands is extension service, as farmers were interested in more on-farm training opportunities. For example, if farmers have the opportunity to receive training, they are enabled to make better management decisions for their individual situations [38]. An assured market for milk with stable producer prices will also trigger the motivation to change management practices, especially as farmers said they intend to increase their milk production in the future.

It should be realized that Carbon Footprinting is a single-issue LCA, that is, only assesses GHG emissions which are of global environmental impact. In a sustainability assessment attention needs to be paid also to other environmental impacts that can be of local or global relevance, among social and economic issues [30••].

LCA and multi-functionality

The principle of relating the GHG emissions to the products based on farmer's assessment and valuation of the role of cattle in their livelihoods provides an important new angle on how CFs for smallholder systems are calculated. In multi-functional smallholder systems, defining 'productivity' more from farmers' points of view better enables the identification of problems and solutions that are more relevant to farmers' livelihood practices. For an intensive dairy farmer in an OECD country, the production of milk is by far the most important reason to keep dairy cattle and the motivation behind dairy production. Due to the different nature of those systems they cannot be analysed in the same way; applying the production units of LCA of specialized farms does not work for smallholder, mixed systems. LCA is a tool that originates from industry. Our study shows that when it is applied to complex mixed smallholder dairy systems with multi-functional aspects related to cattle keeping, traditional LCA is poorly suited to grasp the system for what it is. It follows that policy recommendations stemming from such a fundamental misapprehension of smallholder agricultural practice will be misguided, at best.

This leads to the question of comparability between systems that are characterised by different degrees of specialisation. According to the ISO guidelines for LCAs, 'the deletion of life cycle stages, processes, inputs or outputs *is only permitted if it does not significantly change the overall conclusions of the study*' ([22]: 4.2.3.3.1, emphasis added). Furthermore, 'comparisons between systems shall be made on the basis of the same function(s), quantified by the same FU in the form of their reference flows' ([22]: 4.2.3.2). Thus, a direct comparison of CF results of milk of dairy systems characterized by different degrees of specialization is not appropriate if the systems outputs differ. Results indicate that the CF of milk decreases when additional system outputs are included in the study. It is important, therefore, that the aspect of multi-functionality is given serious consideration in any future LCAs on smallholder cattle systems. It can be argued that European farms would also need to be evaluated considering multi-functionality principles. For example some small-scale dairying in Europe is supported by policy measures in order to retain rural infrastructure and amenities. Also the value of manure and slurry for soil fertility could be considered. Organic dairy farms might also have different objectives compared to conventional dairy farms.

Conclusions

The CF assessment of mixed smallholder dairying in the Kaptumo area in Kenya shows that the inclusion or exclusion of multiple functions of cattle in smallholder systems has strong impacts on the outcomes of CF estimates of milk production, and consequently on conclusions about mitigation. Our results show that it is feasible to account for multiple functions of dairy systems using the LCA methodology, but there are limitations. Economic allocation and economic quantification of cattle functions showed that including multiple products is one methodological option. However, relying on economic valuation still leads to some important products being left out, such as socio-cultural values and functions related to cattle keeping that cannot be adequately captured in economic terms. When applying farmers' perspectives on cattle and their functions, the picture changes further. The process of applying such different perspectives revealed that there is a limit in understanding systems for what they are when applying a common LCA frame. The challenges we encountered in the design and implementation of our methodology indicate a need for further refinement. The present estimate of CF of milk production in the Kaptumo area, in particular when applying the livelihood allocation, was comparable to CF results of milk in intensive milk production systems and lower than results of other studies dealing with dairy production in Sub Sahara Africa. This was not only due to inclusion of multi-functionality, but also to the milk production estimates in this case-study. On average 42% of the milk output was consumed at home. In global studies home consumed milk is not included in estimates of cow milk yields. Consequently, GHG mitigation options must be discussed in face of farmers' complex and diverse economic opportunities, objectives and constraints. This might require assessing the whole farm, as the most effective GHG mitigation options may lie outside the dairy component or even beyond the farmgate. Furthermore, the common commodity focus in CF research is not equipped for multi-functional production systems; using it to analyse those systems creates a real danger of developing misguided and misinformed mitigation options that do not fit their complex realities. An LCA methodology that incorporates multiple products and farmers' valuations of multiple cattle functions is more capable of accurately characterizing the system, and thus more likely to lead to mitigation options and policy recommendations that are grounded in and effective for the realities of smallholder livelihoods.

Acknowledgements

The authors gratefully acknowledge the farmers in Kaptumo who participated in this research and shared their time, experiences and views. Thank you also to Moses Ndathe (MICCA), Josephine Kirui (ICRAF) and Patrick Mudavadi (ICRAF) for the support during the field research in Kenya. The authors gratefully acknowledge the support from Carolyn Opio (FAO), Pierre Gerber (FAO), Christina Seeberg-Elverfeldt (FAO-MICCA), Marja-Liisa Tapio-Biström (FAO-MICCA), and Simon Oosting (Wageningen University). We thank two anonymous reviewers for their constructive comments.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cosust.2014.07.009.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. •• Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G: *Tackling Climate Change Through Livestock –— A Global Assessment of Emissions and Mitigation Opportunities*. Rome, Italy: Food and Agriculture Organization of the United Nations; 2013.

The most recent assessment of the global impact of keeping livestock on the environment.

2. Herrero M, Thornton PK, Notenbaert AM, Wood S, Masangi S, Freeman HA, Bossio D, Dixon J, Peters M, van de Steeg J *et al.*: **Smart investments in sustainable food production: revisiting mixed crop-livestock systems**. *Science* 2010, **327**: 822-825.

3. •• FAO: *Greenhouse Gas Emissions from the Dairy Sector. A Life Cycle Assessment*. Rome. Italy: Food and Agriculture Organization of the United Nations; 2010.

A comprehensive study on GHG emissions from the global dairy sector.

4. Gerber P, Vellinga T, Opio C, Steinfeld H: **Productivity gains and greenhouse gas emissions intensity in dairy systems**. *Livest Sci* 2011, **139**:100-108.

5. Udo HMJ, Cornelissen T: **Livestock in resource-poor farming systems**. *Outlook Agric* 1998, **27**:237-242.

6. • Moll HAJ, Staal SJ, Ibrahim MNM: **Smallholder dairy production and markets: a comparison of production systems in Zambia, Kenya and Sri Lanka**. *Agric Syst* 2007, **94**:593-603.

A paper showing the contribution of non-market functions of dairy type cattle to livelihoods.

7. Crane TA: **Of models and meanings: cultural resilience in social–ecological systems**. *Ecol Soc* 2010, **15**:19.

8. Pica-Ciamarra U, Nouala S, Kim S: **Livestock and livelihoods in the IGAD region: a policy and institutional analysis**. *IGAD LPI Working Paper No* 2011. No. 01-11.

9. Cederberg C, Stadig M: **System expansion and allocation in life cycle assessment of milk and beef production**. *Int J Life Cycle Assess* 2003, **8**:350-356.

10. Flysjö A, Cederberg C, Henriksson M, Ledgard S: **How does co-product handling affect the carbon footprint of milk? Case study of milk production in New Zealand and Sweden**. *Int J Life Cyc Assessm* 2011, **16**:420-430.

11. • Zehetmeier M, Baudracco J, Hoffmann H, Heißenhuber A: **Does increasing milk yield per cow reduce greenhouse gas emissions? A system approach**. *Animal* 2012, **6**: 154-166.

A thorough study showing that also in European dairy systems the co-products of dairy cattle keeping need to be considered in discussing GHG mitigation strategies.

12. Ripoll-Bosch A, De Boer IJM, Bernues A, Vellinga TV: **Accounting for multifunctionality of sheep farming in the carbon footprint of lamb: a comparison of three contrasting Mediterranean systems**. *Agric Syst* 2013, **116**:60-68.

13. Herrero M, Thornton PK, Gerber P, Reid RS: **Livestock, livelihoods and the environment: understanding the trade-offs**. *Curr Opin Environ Sustain* 2009, **1**:111-120.

14. Bebe BO, Udo HMJ, Thorpe W: **Development of smallholder dairy systems in the Kenya highlands**. *Outlook Agric* 2002, **31**:113-120.

15. Muriuki HG: *Dairy Development in Kenya*. Rome Italy: Food and Agriculture Organization of the United Nations; 2011.

16. Livestock Extension Department 2009 census, cited in Wambugu C, Franzel S: **Options for Climate Smart Agriculture at Kaptumo Site in Kenya**. Project report, 2012.

17. Lukuyu B, Gachuiri CK, Lukuyu MN, Lusweti C, Mwendia S: *Feeding Dairy Cattle in East Africa*. Nairobi, Kenya: East Africa Dairy Development Project; 2012.

18. Baumann H, Tillman A-M: **The Hitch Hiker's Guide to LCA. An orientation in life cycle assessment methodology and application**. *Studentlitteratur* 2004.

19. De Vries M, De Boer IJM: **Comparing environmental impacts for livestock products: a review of life cycle assessments**. *Livest Sci* 2010, **128**:1-11.

20. Thomassen MA, Dalgaard R, Heijungs R, De Boer IJM: **Attributional and consequential LCA of milk production**. *Int J Life Cycle Assess* 2008, **13**:339-349.

21. ISO 14040 2006: *Environmental Management — LCA Principles and Framework*. Geneva: International Organization for Standardization; 2006.

22. ISO 14044 2006: *Environmental Management — LCA — Requirements and Guidelines*. Geneva: International Organization for Standardization; 2006.

23. Alary V, Corniaux C, Gautier D: **Livestock's contribution to poverty alleviation: how to measure it?** *World Dev* 2011, **39**:1638-1648.

24. De Boer IJM: **Environmental impact assessment of conventional and organic milk production**. *Livest Prod Sci* 2003, **80**:69-77.

25. Lekasi JK, Tanner JC, Kimani SK, Harris PJC: *Manure Management in the Kenya Highlands: Practices and Potential*. Second edition. HDRA Publications; 2001.

26. Moore JA, Gamroth MJ: *Calculating the Fertilizer Value of Manure from Livestock Operations*. Oregon State University Extension Service; 1993.

27. Moll HAJ: **Costs and benefits of livestock systems and the role of market and nonmarket relationships**. *Agric Econ* 2005, **32**:181-193.

28. Behnke R, Muthami D: **The Contribution of Livestock to the Kenyan Economy**. *IGAD LPI Working Paper No. 03-11* 2011.

29. Antweiler C: **Kognitive Methoden**. In *Methoden ethnologischer Feldforschung,* Second edition. Edited by Beer B. Dietrich Reimer Verlag; 2008:233-254.

30. •• De Boer IJM, Cederberg C, Eady S, Gollnow S, Kristensen T, Macleod M, Meul M, Phong LT, Thoma G, Van der Werf H, Zonderland-Thomassen MA: **Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment**. *Curr Opin Environ Sustain* 2011, **3**:423-431.

A crucial review of GHG mitigation options in animal production and their relation with other aspects of sustainability.

31. IPCC: **Climate change 2007**. *IPCC Fourth Assessment Report*. UK: Cambridge University Press; 2007.

32. Bosman HG, Moll HAJ, Udo HMJ: **Measuring and interpreting the benefits of goat keeping in tropical farm systems**. *Agric Syst* 1997, **53**:349-372.

33. Phong LT, De Boer IJM, Udo HMJ: **Life cycle assessment of food production in integrated agriculture–aquaculture systems of the Mekong Delta**. *Livest Sci* 2011, **139**:80-90.

34. Bartl K, Gómez CA, Nemecek T: **Life Cycle Assessment of milk produced in two smallholder dairy systems in the highlands and the coast of Peru**. *J Cleaner Prod* 2011, **19**:1494-1505.

35. FAOSTAT: http://faostat.fao.org/.

36. Giller KE: *Nitrogen Fixation in Tropical Cropping Systems*. second edition. Wallingford: CAB International; 2001.

37. Havlik P, Valin H, Herrero M, Obersteiner M, Schmid E, Rufino MC, Mosnier A, Thornton PK, Böttcher H, Conant RT *et al.*: **Climate change mitigation through livestock system transitions**. *PNAS* 2014. doi: 10.1073/pnas.1113080441.

38. Kilelu CW, Klerkx L, Leeuwis C: **Unravelling the role of innovation platforms in supporting co-evolution of innovation: contributions and tensions in a smallholder dairy development programme**. *Agric Syst* 2013, **118**:65-77.