Greening of Ethiopian Dairy Value Chains: Evaluation of environmental impacts and identification of interventions for sustainable intensification of dairy value chains

Report 948

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Greening of Ethiopian Dairy Value Chains: Evaluation of environmental impacts and identification of interventions for sustainable intensification of dairy value chains

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Commissioned by: Agricultural Transformation Agency (ATA), Ethiopia

Wageningen UR Livestock Research
Wageningen, April 2016

Livestock Research Report 948

Marion de Vries PhD (SNV); Sintayehu Yigrem PhD (SNV); Theun Vellinga PhD (DLO) 2016. *Greening of Ethiopian Dairy Value Chains: Evaluation of environmental impacts and identification of interventions for sustainable intensification of dairy value chains .* Wageningen UR (University & Research centre) Livestock Research, Livestock Research Report 948.

Livestock Research Report 948

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Key messages

This study showed that three categories of interventions contributed to reduction of environmental impacts of Ethiopian dairy value chains:

- Improving productivity of dairy herds in terms of milk and meat, both at animal and herd level. Interventions include improvements in feeding, breeding, herd composition, health and housing;
- Professionalization of the post farm-gate dairy value chain to reduce milk losses;
- Improving nutrient use efficiency for sustaining dairy production in the long term.

In parallel, these interventions contribute to the resilience of the agricultural and dairy value chains: feed is used more efficiently, nutrient losses and product losses will be reduced, while livelihoods are improved.

In general, improved resource use efficiency of dairy production, mitigation and adaptation will often go hand in hand, which implies that improving dairy production via the efficiency pathway will create multiple benefits.

Interventions in dairy value chains in this study resulted in:

- 2-29% reduction in greenhouse gas emissions per kg milk; this study showed that improvements in feed quality were most effective;
- 2-39% reduction in land use per kg milk;
- 0-72% reduction in energy use per kg milk.

Key recommendations for greening of Ethiopian dairy value chains are:

- Improve quality of feed rations, especially digestibility and nitrogen content, for specialized farms and urban SHF;
- Promote on-farm production of high quality forage and crop residues in rural SHF, as purchasing feed is too expensive for rural farmers;
- Replace oxen by mechanization and female stock in mixed systems;
- Reduce milk losses in post farm-gate stages of the commodity chain (transport, processing, and selling);
- Replace unproductive female animals with young productive females;
- Increase crossbreeding through improved AI services;
- Reduce the use of dung cake for fuel, and promote biogas as an alternative source of energy and animal manure / bio-slurry as a fertilizer;
- Promote manure management and selling of manure as a fertilizer in urban and peri-urban farms to prevent accumulation of manure;
- The implementation of the mitigation options requires a suite of actions:
- The mitigation options for better feeding and manure management are improvements within the current framework of dairy production. Their implementation can be fulfilled by extending existing activities as extension provision to farmers and the implementation of domestic biodigesters, combined with a proper manure handling strategy.
- The development of a dairy market and professionalising dairy processing, the mechanisation of field work and the specialisation in herd structure is closer to a transformation to specialisation of farms and requires a concerted action of a range of stakeholders. The enabling infrastructure in this case is wider than extension service, and development of a supply and commodity infrastructure is essential.

Executive Summary

Given the expected vast increases in Ethiopian cow milk consumption and production, the Ethiopian dairy value chains are facing tremendous challenges of limiting accompanied increases in greenhouse gas (GHG) emissions as well as enhancing resilience to climate change. Ethiopia has the ambition to foster economic development and growth, while limiting net GHG emissions and improving resilience to climate change towards 2030, i.e. transition to a green economy (CRGE, 2011). The objective of this study was to quantify baseline environmental impacts of the Ethiopian dairy value chain and identify entry points for reduction of environmental impacts so as to "green" the dairy sector in a cost-effective way in terms of ease and effect, production and income, and resilience.

Methods

To quantify environmental impacts of dairy value chain products (milk, beef and traction), a life cycle assessment (LCA) was used. LCA quantifies the use of natural resources and emissions of pollutants along the entire life cycle of a product. In this study LCA was based on the international LEAP guidelines, which are suitable to apply to smallholder farming (SHF) systems. To tailor the analyses to the Ethiopian SHF context, data was collected from 64 dairy farms near large towns in Amhara, Oromia, SNNP and Tigray. Three farm typologies were included in the field survey: 1) mixed semi-commercial SHF dairy farms in rural areas ('rural SHF'), 2) specialized commercial dairy farms in peri-urban areas ('specialized farms') and 3) specialized commercial SHF dairy farms in urban areas ('urban SHF').

First, baseline environmental impacts of rural SHF, specialized farms and urban SHF were quantified. Different types of interventions in the dairy value chain that could reduce environmental impacts were then identified and effects of these interventions were simulated, including cost-effectiveness. Promising interventions were discussed with stakeholders in in-depth interviews and with farmers in focus group discussions.

Results

Baseline Environmental Impacts. Per unit of product, GHG emissions, land use and energy use were highest among rural SHF, followed by urban SHF and specialized farms. In all farm typologies most GHG were emitted on-farm, mostly from enteric fermentation in animals (methane) and from feed production. Of all GHG, methane contributed most farm GHG. In rural SHF, 40% of total farm GHG was caused by male stock. This was caused by a relatively high number of oxen in rural SHF and a relatively high emission of methane per animal from oxen. Also, losses in post farm-gate stages contributed to higher environmental impacts per unit of product.
With regard to farm nutrient balances, land-based farms showed deficits of nitrogen and phosphorus, whereas landless farms showed surpluses of nitrogen. In specialized farms and urban SHF about half of the manure was burned for fuel. Surpluses in landless farms in urban and peri-urban were expected to strongly increase when manure would not be burned for fuel. In rural SHF, nutrient deficits could be solved when manure would not be burned for fuel.

Effects of Interventions on Environmental Impacts, Farm Income, and Resilience. Interventions investigated in this study reduced GHG emission intensities of dairy value chains by 2% to 29%. Most interventions were cost-effective, except for increasing the purchase of feed by rural SHF and not selling dung cakes by specialized farms and urban SHF.

- For all three farm typologies, improving digestibility of forage had the largest effect on reduction of environmental impacts, reducing GHG by 24% to 29% per kg milk. This was caused by a higher digestibility leading to less enteric fermentation in cows (which implies a reduction of methane emissions) and a higher milk production at the farm level. Improved feeding (increased use of concentrate feed and improved digestibility of forage) was cost-effective in specialized farms and urban SHF, but not in rural SHF. Costs of increased inputs such as feed and fodders were also considered a major constraint by stakeholders and farmers. Improvement of quality of on-farm produced feed was prioritized by stakeholders and farmers, but competition with crop agriculture was indicated as a constraint.

- For rural SHF, replacing oxen with mechanization and female stock was the second-most effective intervention for lowering GHG per kg milk after improved digestibility of forage, and was cost-effective, but also resulted in a higher energy use per kg milk. The reduction in GHG was mainly due to a higher output (i.e. milk and meat) at the herd level. This intervention may also contribute to climate resilience of dairy value chains because it reduces the number of cattle at the national level and therefore pressure on limited (feed and water) resources. However, stakeholders and farmers were concerned about costs and long-term availability of mechanization, which will require investments and good organization at macro- and micro-level. Besides this, insufficient off-take of milk and meat was considered a threat in rural areas, which could lead to insufficient returns from investments.
- For specialized herds and urban SHF, improvement of the post farm-gate chain was the second-most effective intervention for lowering GHG, and the most effective for lowering energy use per kg milk. For this intervention, home processing of milk products and selling fresh milk on local markets was shifted towards selling milk to industrial processors, reducing post farm-gate milk losses from about 10-14% to 4–6% and reducing GHG emissions with about 0.45 kg CO_2-e per kg of sold milk. This implies dairy coops should invest in the development of local milk collection centres and frequent chilled transport to processing factories in the case of emerging urban markets. In rural areas, where development of markets will be limited and local markets remain important, a small scale 'cold chain' might reduce post farm-gate losses in direct sales and in home processing. (Bio) gas driven refrigerators or power supply by solar or wind power might solve problems of energy supply, although investments in equipment can be a barrier.
- Slightly smaller reductions in GHG, land use and energy use were found for increasing concentrates, increased crossbreeding, replacing unproductive females, and for improved utilization of manure.
- Although manure was not a very large contributor to GHG emissions, the lack of proper manure management led to depletion of nutrients in land-based systems. We estimated that approximately 40% of cattle manure was used as dung cake for fuel across farm typologies. This implies a large amount of valuable nutrients is lost from farm and regional nutrient cycles, thus reducing the potential fodder and animal productivity if not substituted by chemical fertilizer, besides negative human health effects of burning dung cakes. Reducing the use of animal manure for fuel requires that alternatives are promoted, such as (bio) gas or electricity, in combination with training on good manure management. Biogas production also contributes to reduced GHG emissions due to reduced use of firewood and deforestation while at the same time slurry from the digester can be utilized as organic fertilizer, replacing more expensive chemical fertilizer. While rural systems are threatened by depletion of nutrients, nutrients might quickly accumulate in urban and peri-urban dairy farms when animal manure is not burned for fuel, leading to pollution of ground water and public health risks in these areas. Given the lack of land in (peri-) urban dairy farms, solutions are needed to utilize manure from these systems as a fertilizer in crop production.
- General improvement of crop and livestock production practices can also contribute to climate adaptation due to improved resilience of animals and increased farm productivity and income. Reducing risks of limited resource availability, i.e. feed and water, can be realized through both on-

farm and off-farm solutions for appropriate storage to avoid feed losses, conservation of feed (e.g. drying or making silage), and resilient crop production techniques (e.g. diversity of crops and forages, climate resilient crop varieties).

Conclusions

This study showed that three categories of interventions contributed to reduction of environmental impacts of Ethiopian dairy value chains:

1) improved productivity of dairy herds in terms of milk and meat, both at animal and herd level. Interventions include improvements in feeding, breeding, herd composition, health and housing, and are mainly focussed at increased specialization of the dairy value chain;

2) professionalization of the post farm-gate dairy value chain to reduce milk losses;

3) improved nutrient use efficiency for sustaining dairy production in the long term.

Recommendations in this report show links with many of the existing plans for agricultural transformation, such as Ethiopia's Green Economy Strategy (CRGE), Livestock Master Plan (LMP), and Dairy Investment Plan (FDRE, 2015). These include a large number of planned activities that can be expected to contribute to mitigation of GHG emission intensities, such as improvement of animal health (e.g. improving veterinary services, disease control programs, and field animal health services), livestock genetic improvement and improved AI services, and actions for sustainable supply of quality feeds and fodders. It can be expected that realization of activities in existing national agendas on livestock transformation will contribute to mitigation of environmental impacts of Ethiopian dairy value chains.

1 Introduction

Ethiopia has a cattle population of around 55 million heads, of which about a quarter are considered milking or dairy cows (CSA, 2015). From the overall Ethiopian milk production, the rural system, including pastoral, agro-pastoral and mixed crop-livestock systems contribute about 98% to the total milk production of the country (CSA, 2009). The remaining 2% is produced by peri-urban and urban farms, and commercial dairy farms. Dairy farms show low milk production, on average about 1.7 litres per cow/day (FAO, 2011a), and poor reproductive performance. Although most of the milk (about 85%; CSA, 2010) is used for home consumption, domestic demand is projected to grow by 47% towards 2020 (GTPII, 2015). This can offer chances for the dairy farmers to increase their income from selling dairy products and enhance their livelihoods. The Ethiopian Livestock Master Plan (LMP; ILRI, 2015) envisions a 93% increase in national cow milk production over the period 2015-2020 as a result of interventions on better genetics, feed and health services, and policy support.

Given the expected vast increases in Ethiopian cow milk consumption and production, dairy value chains are facing tremendous challenges of mitigating accompanied increases in greenhouse gas (GHG) emissions as well as enhancing resilience to climate change. Ethiopia has the ambition to foster economic development and growth, while limiting net GHG emissions and improving resilience to climate change towards 2030, i.e. transition to a green economy (CRGE, 2011).

There is good general knowledge of practices that tend to reduce emissions per unit of product, i.e. lead to greater or equal product output with similar or less emissions. Emission reductions via this route, so called reductions in emission intensity, have strong alignment with the Ethiopian economic development strategy 'Climate-Resilient Green Economy' (CRGE, 2011) while improving smallholder farmers' livelihoods, increased food security and GDP. The present study has built on the large body of scientific research on environmental impacts of dairy production and mitigation options to realize practice change. Main entry points identified in these studies are:

- Improving feeding practices, e.g., use of improved fodder varieties, fodder conservation, and formulation of balanced diets, can help to improve animal productivity and reduce GHG emissions at the same time (Gerber, 2013).
- Improving general dairy management, e.g. breeding, feeding and animal health, will lead to increased efficiency of dairy production and a decrease in GHG emissions (Gerber, 2013). Improving productivity and feed conversion efficiency can also reduce the water scarcity footprint (e.g. Zonderland-Thomassen et al., 2014). In Ethiopia's Livestock Master Plan, crossbreeding with exotic dairy breeds, and AI and synchronization, combined with better feed and health services is already in the development roadmap for dairy farming (ILRI, 2015). In this roadmap, improved milk production and productivity is envisioned through more crossbred cattle and improved forage feed production and marketing in commercial dairy systems, while improvement of natural grazing land and health interventions are envisioned for farms with local cattle breeds.
- Improved manure management is an important factor in improving resource use efficiency at farm level. Sufficient and good quality fodder production is often not achieved in dairy farming systems because soils are depleted of phosphorus and organic matter as a result of poor nutrient cycling at farm level (Smaling, 1993). Manure is not a very large contributor to GHG emissions in extensive smallholder systems, but has a high potential to increase fodder and animal productivity.
- Reduction of dairy chain losses will lead to increased efficiency and a decrease in GHG emissions of products from dairy value chains. FAO (2011b) estimated food loss in the dairy chain in Sub-Saharan

Africa is about 20% (post-harvest and distribution losses). Post-harvest and distribution losses in well-developed commodity chains as in Europe and North America are on average 1%. Non-renewable energy use in post-farm dairy chains also contributes to global warming, although this contribution is relatively small (max. 8%, global average; Gerber, 2013).

- Besides evaluation of entry points known from previous studies, the present study explored mitigation options specific to the Ethiopian SHF context. For example, Ethiopia's cattle herd structure features relatively high male representation (44.5% of the population; CSA, 2015). Oxen are used for traction, requiring feed during the whole year, providing draught power for a limited period of time. Mechanization could contribute to reduction of emission intensity, even though fossil fuel use increases.

In this study, entry points for reduction of emission intensities were evaluated for three types of dairy value chains: 1) smallholder semi-commercial family dairy farms managed as rural integrated/mixed system, 2) specialized medium-scale commercial dairy farms of peri-urban areas and 3) specialized smallholder and landless commercial urban dairy farms. The study was focussed on farms with at least a regular selling of dairy products to markets, since these are the farms that are expected to increase their production as a response to increases in domestic demand. Because of this selection, results of this study apply to these dairy value chains only, and should not be extrapolated to the general Ethiopian dairy farming population.

There was no need to analyse the beef sector separately because beef production from the dairy chain is high. Statistics show that the total number of dairy cows in Ethiopia is 10.9 million heads. Based on the herd dynamics at the mixed farms, this means that a dairy-related herd of 31 million heads is present. This herd is already capable of producing all the registered beef production in Ethiopia. This indicates that the largest part of the marketed beef in Ethiopia comes from dairy cattle and related animals.

1.1 Goal and Purpose of this Study

Goals of this study were twofold:

1. To evaluate baseline environmental impacts of the Ethiopian dairy value chain products in a life cycle assessment (LCA), including (a) cost of abatement along the value chain in terms of ease, effect, and production, and (b) suggested adjustments to international assessment protocols to tailor them to the Ethiopian smallholder farmer (SHF) context.
2. To identify and prioritize interventions in the SHF dairy value chain which (a) 'green' the value chain in a cost effective manner, (b) increase SHF production and income, or enhance stability of SHF to maintain current production levels in the face of environmental changes threatening their production, and (c) extrapolate findings and implications to the Ethiopian Livestock Sector Master Plan, including beef production from dairy systems.

Part 1 of this report presents a technical report assessing baseline environmental impacts of Ethiopian dairy value chain products. **Part 2** presents the identification and prioritization of interventions in Ethiopian dairy value chains.

PART 1: TECHNICAL REPORT ASSESSING BASELINE ENVIRONMENTAL IMPACTS OF ETHIOPIAN DAIRY VALUE CHAIN PRODUCTS

2 Material and Methods

This section describes the scope, and material and methods used for the environmental impact assessment of Ethiopian dairy value chains. Besides this, it describes methods used for evaluation of climate mitigation options, identification of climate adaptation options and resilience indicators, and feedback of stakeholders on mitigation and adaptation options proposed in this study.

2.1 Scope of the Study

This study focussed on Ethiopian dairy value chains, which implies that dairy farms with no regular selling of dairy products to markets were not included in this study. Characteristics of dairy value chains vary largely across Ethiopia. To ensure that mitigation options resulting from the LCA are suitable and effective for the majority of dairy value chains, analyses were carried out separately for farms that were more homogeneous with respect to farming characteristics (indirectly) having a major influence on environmental impacts; land base, herd size, and access to markets (influencing farm inputs and outputs). Three typologies of dairy value chains were defined:

1. Smallholder semi-commercial family dairy farms managed as rural integrated/mixed system (hereafter called 'rural SHF'), including both cereal-based and perennial crop based farms.
2. Specialized medium-scale commercial dairy farms in peri-urban areas (hereafter called 'specialized farms'), including both landless and land-based farms from Mixed Rainfall Sufficient (MRS) and Mixed Rainfall Deficient (MRD) areas.
3. Specialized smallholder and landless commercial urban dairy farms (hereafter called 'urban SHF').

A smallholder farm was defined as a farm keeping < 5 milking cows, and a medium-scale farm was defined as a farm with ≥ 5 milking cows (adapted from ILRI (1996)). A landless farm was defined as a farm with a farm area ≤ 0.10 ha. With regard to the level of commercialisation, semi-commercial was defined as the generation of income from a surplus of dairy products (Pingali, 2001) with regular selling of dairy products to markets at least during wet seasons. Despite our selection criteria, however, it appeared that not all selected farms sold dairy products. Commercial was defined as the maximization of profit from dairy products (Pingali, 2001).

System boundaries and LCA approach

System boundaries of the dairy production system evaluated in this study are shown in Figure 1. All processes were assessed up to the retail stage (i.e. cradle to retail; including production of farm inputs, on-farm production activities, transport of animals and products to market or processing plants, processing, refrigeration, packaging, and transport to retail distributor). Impacts at retail and consumer level were not included. LCA can be performed in two ways: consequential or attributional. Consequential LCA aims at quantifying environmental consequences of a change in a production system or a change in product demand (Thomassen et al., 2008). In this study, we used attributional LCA, which aims at quantifying the environmental impact of the main product of a system in a status quo situation.

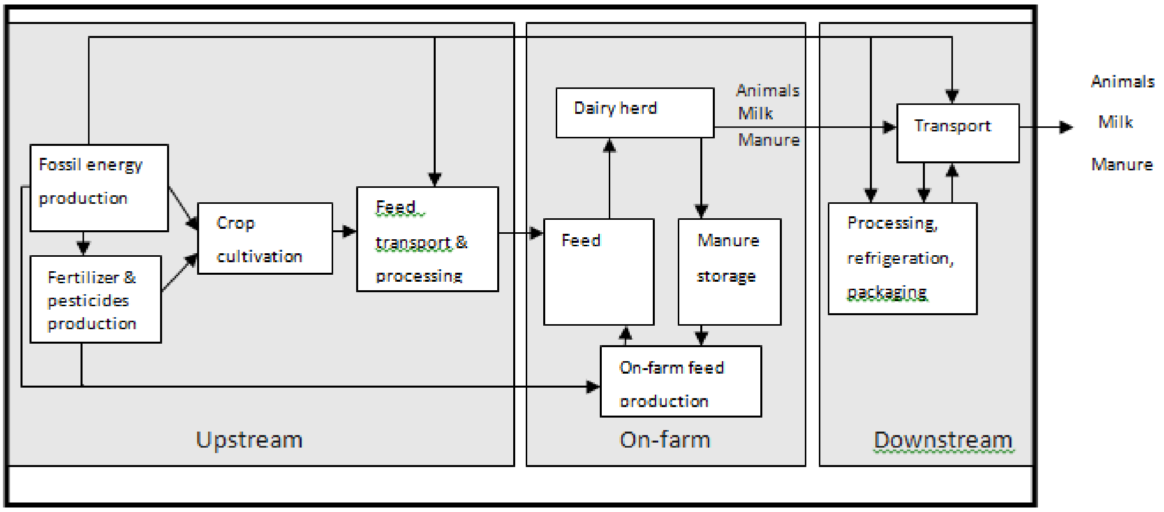

Figure 1*: System boundaries for the LCA of Ethiopian dairy value chains.*

2.2 LCA modelling

Global warming potential, land use and non-renewable energy use of Ethiopian dairy value chain products were quantified following a LCA approach. LCA is a scientifically accepted and internationally standardized method to evaluate use of resources and emission of pollutants along an entire production chain (ISO 14040 and ISO 14044; ISO, 2006). In this study, the LCA approach was based on international LEAP Animal Feed, Large Ruminants, and Small Ruminants Guidelines (FAO, 2015a; b; c). These guidelines developed by the Livestock Environmental Assessment and Performance (LEAP) partnership reflect a common vision among different partners, including farmer organizations representing smallholders. Therefore, LEAP guidelines could be suitably applied to SHF systems, while enabling consistent and science-based environmental assessments with a view to reduce the environmental footprint of animal products.

2.2.1

The GLEAM modelling framework (Global Livestock Environmental Assessment Model; Opio et al., 2013) was used for calculation of environmental impacts. The LCA approach in this model, which is defined in ISO standards 14040 and 14044 (ISO, 2006), simulates the interaction of activities and processes involved in livestock production and the environment. GHG emissions were assessed based on current IPCC Guidelines (2006, updated 2014) mainly working at Tier 2 level. IPCC Tier 2 method (IPCC, 2014) was used for estimating enteric methane emissions and nitrogen and phosphorus excretions in the model.

The GLEAM modelling framework consisted of 5 modules (Table 1). Three of these modules represented off-farm and on-farm activities and processes in the dairy value chain, e.g. animal production, feed production, and manure management, and were fed with primary data collected in a field survey among Ethiopian dairy farms and secondary data collected from existing databases. The other 2 modules linked the data in the first 3 modules to calculate amounts of output from the dairy value chain (e.g. milk and animals) and environmental impacts, and to allocate impacts to the different outputs of the dairy value chain.

Table 1
Modules in the GLEAM modelling framework.

Module	Description
Herd module	Defined the average dairy herd composition (i.e. male and female adult, replacement, and surplus stock), live and slaughter weights, death rates, percentage of cows lactating, age at first calving, fertility rates, replacement rates, animal activity (i.e. grazing and stall time), labor, and milk production and composition.
Feed basket module	Defined the average share of each feed material in the feed basket for cattle present on-farm, and, for each feed material, inputs for field work (e.g. fertilizer; fuel use), feed processing and transport, feed characteristics (e.g. digestibility, and dry matter, nitrogen, phosphorus, and gross energy content), and yield and economic information for allocation of emissions.
Manure module	Defined the average share of each type of manure management storage on-farm, and the share of nutrients in animal manure applied to land.
System module	Calculated average energy requirements and feed intake per animal type, total herd production, and environmental impacts.
Allocation module	Calculated environmental impacts and allocation per unit of product.

Customizing the GLEAM model to the Ethiopian context

The original version of the GLEAM model (Opio et al., 2013) was customized to the Ethiopian dairy farming context in 4 ways:

- First, whereas input for the original GLEAM model (Opio et al., 2013) was based on secondary data only, inputs for the customized GLEAM model were largely based on primary data from Ethiopian dairy farms, leading to more accurate estimates of environmental impacts of Ethiopian dairy value chains.
- Second, to enable a simulation of replacing draught power for ploughing and seed bed preparation by mechanization as a mitigation strategy, mechanization level was added to the feed basket module in the GLEAM model for both on-farm and off-farm field work. To this end, field work was divided in four stages of feed production: a) ploughing, harrowing, seed bed preparation and sowing, b) application of fertilizer and pesticides, c) application of animal manure, and d) harvesting. For the first stage, GHG emissions related to mechanized and animal activity were included, enabling a calculation of emissions per feed ingredient for different levels of mechanization. For the other three stages of feed production, mechanization was assumed to be in exchange for manpower.
- Third, to enable to a simulation of improving reproductive performance of cows and reducing the number of unproductive animals as a mitigation strategy, environmental impacts were calculated separately for lactating and dry cows in the system module.
- Fourth, we modified the methane conversion factor for the lower digestibility levels of the animals' rations in Ethiopia the methane conversion factors in relationship to feed digestibility. There are indications that methane emissions are similar for different breeds and depend on the digestibility of the feed. The same bacteria and methanogens (microbes producing methane) appear to dominate in nearly all rumens across the world, for a wide variety of ruminant species and ruminant diets (Global Rumen Microbial Network). This means that new technologies that seek to reduce methane emission by influencing rumen microbes can have global application.

2.3 Functional Units and Allocation

An LCA relates the environmental impact to the main function of a production system. Because of the multi-functionality of cattle on Ethiopian dairy farms, we used three functional units in this study: one kg of milk, one kg of carcass weight, and one hour of traction. Because farming systems can yield multiple outputs, the environmental impact of the production system or process within the system has to be divided between the various outputs by means of allocation. Important outputs from Ethiopian dairy value chains are animals, milk, manure, and traction in the process of animal production, and grain and crop residues in the process of feed production. Methods of allocation are in Table 2. As shown in Table 2, resource use and emissions were analysed separately from male animals used for traction, reproduction, and beef production. For traction animals, all energy requirements for maintenance and traction in the adult phase are allocated to crop production. Resource use and emissions based on growth and maintenance requirements in the youth phase of oxen were attributed to beef (live weight of the animals).

Table 2

Allocation and sub-division approach used in the LCA of Ethiopian dairy value chains.

Product	Allocation
<u>Animals</u>	
Edible animal products (meat and milk)	Allocation based on energy requirements (Thoma et al., 2013; FAO, 2015a).
Manure	Allocation based on sub-division of production process. - manure storage: emissions from manure management systems (MMS) allocated to livestock sector, irrespective of subsequent use or application; - manure applied to fodder production and crop residues: emissions allocated to livestock sector based on mass harvested and relative economic value; - manure applied to non-feed: emissions allocated to crop products based on mass harvested and relative economic value; and - manure used for fuel: emissions from burning allocated to households.
Animal traction[1]	Extra life time energy requirements for maintenance and labour and related emissions deducted from the overall livestock emissions, and added to the feed module as input to crop production.
Capital function	No allocation performed in this assessment.
<u>Feed</u>	
Crop residues	Allocation based on digestibility of crop and crop residues as a proxy for price
Industrial by-products	Economic allocation based on prices of crop and crop by-products

2.4 Data Inventory

Primary data collection

Sixty-four farms were selected covering the three types of dairy value chains in the proximity of capitals of SNNPR, Tigray, Amhara, and Oromia region: 32 rural SHF, 21 specialized farms, and 11 urban SHF (Table 3). A relatively large sample was selected from the rural SHF, because these systems contribute about 98% to the overall Ethiopian milk production, versus 2% produced by the (peri-) urban and commercial dairy farms (Brandsma et al., 2013).

Table 3

Number of farms surveyed per Woreda, region, and dairy value chain typology.

Region	Rural SHF– cereal-based (n farms)	Rural SHF– perennial-based (n farms)	Specialized – land-based (n farms)	Specialized – landless (n farms)	Urban SHF – landless (n farms)
Oromia	Chancho (4)	Woliso (4)	Addis outskirt (4)	Addis (3)	Addis (1)
SNNPR	Hawassa Zuria (4)	Yirgalem (4)	Hawassa (1)	Hawassa Zuria (3)	Hawassa (4)
Amhara	Bahar Dar Zuria (8)	-	Bahar Dar Zuria (1)	Bahar Dar (4)	Bahar Dar (3)
Tigray	Mekelle Zuria (8)	-	Mekelle Zuria (2)	Mekelle Zuria (3)	Mekelle (3)
Total	24	8	8	13	11

A questionnaire (Annex 1) was designed to collect primary data on Ethiopian dairy farms, to be used as input for the GLEAM model. Four experienced local extension officers (MSc level) were trained in a two-day course on collection of primary data from farms using the questionnaire. After data collection, it appeared that part of the data was missing or incorrect. Missing and incorrect values were imputed using the average value of other farms in the same typology or using expert opinion. After data validation and imputation, raw data were recalculated to data suitable as input to the GLEAM modelling framework.

Secondary data collection
Secondary data was collected from IPCC guidelines (2006; default values, coefficients, and emission factors for calculation of emissions from animals, feed, and manure), GLEAM databases (Opio et al., 2013), EcoInvent (using Simapro; energy use of road transport, modelling field work emissions), FeedPrint (e.g. data for field work emissions; Vellinga et al., 2012), Feedipedia (www.feedipedia.org; nutritional characteristics of feed materials), ILRI/CGIAR DAGRIS database (live weights of local breeds), FAOSTAT, Ethiopian Central Statistical Agency (crop yields and market prices), and various scientific publications (e.g. crop yields, nutritional characteristics of feed materials, and energy use and allocation of processing crops (e.g. Zeist et al., 2012)). Regarding nutrient balances, nitrogen and phosphorus contents of animals entering or leaving the farm were based on those in Dutch cattle (CBS, 2009). When data was not available from the farm survey or in existing databases, assumptions were made for input data in the GLEAM model based on expert opinion (Annex 2).

2.5 Environmental Impact Categories

In this study we considered the environmental impact categories fossil energy use, land use and global warming potential (GWP). Units, contributing elements and characterization factors of these impact categories are in Table 4.

Table 4
Selected environmental impact categories with related units, contributing elements and characterization factors.

Impact category	Unit	Contributing elements	Characterization factors	Source
Land use	ha	land occupation	1	Guinée et al. (2002)
Fossil energy use	MJ	energy consumption	1	Recipe (2012)
GWP	kg CO_2-equivalents	CO2	1	IPCC (2014)
		CH4	28	
		N2O	265	

2.6 Assumptions and Modelling of Post Farm-Gate Stages

Food losses and waste
FAO (2011b) define food losses or waste are the masses of food lost or wasted in the part of food chains leading to "edible products going to human consumption". This definition also implies that food loss ending as animal feed is considered as a loss. In the animal commodities and products chain FAO (2011b) consider four categories of loss:

- **Agricultural production:** for meat, losses refer to animal death during breeding; for milk, losses refer to decreased milk production due to dairy cow sickness (e.g. mastitis).
- **Postharvest handling and storage:** for meat, losses refer to death during transport to slaughter and condemnation at slaughterhouse. For milk, losses refer to spillage and degradation during transportation between farm and distribution.

- **Processing:** for meat, losses refer to trimming spillage during slaughtering and additional industrial processing, e.g. sausage production. For milk, losses refer to spillage during industrial milk treatment (e.g. pasteurization) and milk processing to, e.g., cheese and yoghurt.
- **Distribution:** includes losses and waste in the market system, at e.g. wholesale markets, supermarkets, retailers and wet markets.

In this report we only considered post-harvest handling and storage, and processing. Little is known about losses at home processing of milk. Actually, home processing is the main reason to prevent loss by product degradation. One might expect that losses at home processing will be higher than at industrial processing.

FAO (2011b) estimated food loss in the dairy chain in Sub-Saharan Africa at about 20% for post-harvest handling and storage, processing and distribution losses. Waste of milk during post-harvest handling and storage is the largest of the three. On average, losses during post-harvest handling and storage, processing and distribution in well-developed commodity chains as in Europe and North America are 1% each.

In the case of the surveyed Ethiopian farmers, transport distances between the location of production and sale of milk and related products were on average 4 kilometres, with a maximum of 30. There was no chilled transport at all, but at the same moment, farmers report only very limited post-harvest losses. Probably post-harvest losses were low due to the short distance of transport and the limited time between production and consumption. On the other hand, the contrast between the assessed loss of FAO (2011b) and the reported information by the farmers is large. It gives the impression that farmers underestimate the loss or it could be that we have not asked the right questions. Also the comparison with well-developed dairy chains give the impression that there is room for improvement.

It is known that chilling of milk is a prerequisite to reduce loss in every step of the production chain (Postharvest Education Foundation, 2013). The use of chilling equipment at farm level is limited by the lack of a power grid in rural areas. In urban and peri-urban areas, power might be available. Given the lack of exact figures, a number of post-farm situations were assumed for the Ethiopian situation to calculate environmental of post farm gate stages.

Model Assumptions for Post Farm Milk Processing
We analysed environmental impacts for three situations of post farm milk processing:

- local market: fresh milk sold at home,
- local market: milk products sold
- formal, urban market: milk sold to industrial processors.

Home consumption was considered as part of the local market. The three situations are not mutually exclusive, they can exist next to each other in a village, but also at one farm.

A number of assumptions was made for the calculation of post farm losses and related GHG emissions: local markets hardly use mechanised transport and this was set to zero km. Transport on foot or by bike was set to 4 km, the average distance of the inventory. Post-harvest handling, storage and distribution losses in case of fresh milk were assumed to be 20%. In case of home processing of milk, losses were set at 10%. Losses in a chilled industrial commodity chain were set at 1 % for both, as was the case in well-developed post farm chains. Based on the assumptions, 80 to 90% of the produced milk was left for consumption, whereas this was 98% in the case of industrial processing (Table 5).

Table 5
Assumptions on transport, energy use, post farm and processing losses in three possible commodity chains.

	Transport foot/bike (km)	transport car/lorry (km)	proc energy (MJ)	loss post farm	loss processing	fraction milk left
Processed at home local market	4	0	8	0	10	0.90
Fresh milk, local market	4	0	0	20	0	0.80
All products, urban market	0	150	9	1	1	0.98

Slightly more than half of the surveyed farmers processed the milk themselves (Figure 2). In the rural farmers group, this is about two third, in the specialised about half, and in the urban group it is about one third. Types of processed products were more diverse in the rural group (e.g. fresh milk, butter, cheese).

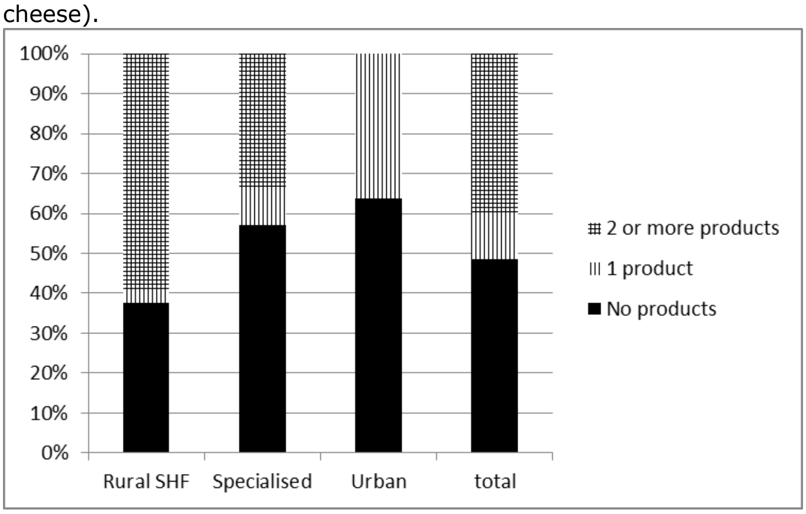

***Figure 2**: Proportions of farms processing milk and number of milk products per farm typology.*

The energy requirements for processing at home were assumed to be 50% higher compared to the industrial energy requirements. The energy source for home processing was assumed to be fire wood, where GHG emissions are formally neutral (it belongs to the short carbon cycle). But carbon sequestration by soil organic matter and forestation was considered as an addition to fossil stocks and calculated as a compensation for GHG emissions. Hence, the use of firewood should be considered as a net GHG emission to the atmosphere. We used the GHG emissions of coal to represent firewood emissions. The energy source for industrial processing was electricity, produced with very low emissions in Ethiopia (7.5 grams CO_2-eq per MJ).

For rural SHF, 70% of the milk was assumed to be processed at home, 20% was sold via local markets and 10% was sold to dairy coops. For specialised farms and urban SHF, we assumed 20, 70 and 10%, respectively.

3 Results and Discussion

This section describes and discusses the results of the environmental impact assessment of Ethiopian dairy value chains. Besides this, this section shows the results of the simulation of mitigation scenarios, as well as feedback from stakeholders on mitigation and adaptation options. It should be noted that baseline environmental impacts are shown separately for cradle to farm-gate and post farm-gate stages of the dairy value chain (excluding retail and consumer), whereas all stages were considered jointly for the evaluation of interventions.

3.1 Characteristics of Farms in the Field Survey

The field survey yielded primary data of 64 Ethiopian dairy farms. One rural SHF herd was not included in the data analyses because there were no adult cows in this herd. In the following paragraphs, general characteristics and environmental impacts of the remaining 63 farms are shown for each of the 3 farm typologies: rural SHF (31 farms), specialized farms (21), and urban SHF (11). Characteristics and environmental impacts of sub-typologies (rural SHF cereal (23 farms), rural SHF perennial (8), specialized land-based (8), and specialized landless farms (13)) are shown in Annex 3 and 4. It should be emphasized that characteristics and environmental impacts of rural SHF are not representative of the average Ethiopian rural SHF, because rural SHF were selected in proximity to towns and only if they had regular selling of dairy products to markets (see Materials and Methods section). During analyses, however, it appeared that 26% of rural SHF did not sell dairy products (Table 7).

With regard to characteristics of herds in Table 7, there are two methodological aspects that should be taken into account. Firstly, as mentioned previously, herd characteristics and performance of rural SHF in this study were not representative of the average Ethiopian rural SHF. Because rural SHF in this study were selected based on regular selling to markets, productivity of herds was better in our study herds compared to performance of average Ethiopian SHF. According to FAO (2011) and the DAGRIS database (results from a selection of four common cattle breeds in our study regions: Boran, Arsi, Horro, and Fogera cattle), for example, average daily milk production in Ethiopian dairy herds was 1.7 and 2.2 litres per cow, respectively, compared to 6.0 litres in our rural SHF study herds. Average lactation length of breeds selected in the DAGRIS database was 6.1 months, compared to 9.7 months in our study herds. With regard to reproductive performance, average age at first calving and average calving interval of breeds selected in the DAGRIS database were 44 and 17 months, respectively, versus 35 and 16 months in rural SHF in our study.

Secondly, two reproduction parameters in Table 7, age at first calving (AFC) and calving interval (CI), refer to average reproductive performance of lactating cows rather than reproductive performance of the total herd. In the field survey, questions about these parameters were asked for cows lactating at the moment of farm visit only, because respondents were expected to not know herd averages. It was expected that CI is better for cows lactating than for other cows in the herd. Non-lactating cows are often older or infertile cows. Therefore, it was expected that CI was longer for the total herd.

Dairy Farm Characteristics
Selling of livestock products was the main source of income for most specialized farms and urban SHF, whereas in rural SHF it was the main source income in only 16% of farms (Table 7). Cattle functions were more diverse in rural SHF than in specialized farms and urban SHF. When cattle functions were ranked, draft power was most important in most rural SHF (52% of farms), and selling milk was most important in most specialized herds and urban SHF (81% and 82%).

Most cattle in rural SHF were local breeds, whereas cows in urban SHF and specialized herds were mainly exotic breeds or crossbreds. Herd size was largest among specialized farms, with few males kept in specialized farms and urban SHF. In rural SHF and specialized farms most male adults were used for traction. Milk production per lactation per cow was higher in urban SHF and specialized herds compared to rural SHF. Fertility rate was about 0.4 calves per cow per year in farms of all typologies, but reproductive performance was slightly lower in rural SHF, especially showing a higher age at first calving.

A large variation was observed in the performance of herds within the different typologies (Table 7). Average age at first calving (**AFC**) of cows lactating at the moment of farm visit, for example, ranged from 18 months to 57 months in rural SHF. For maximum profit, an optimum AFC is recommended (23 to 24 months of age; Heinrichs, 1993). Too low AFC can increase health problems like dystocia (i.e. calving difficulties) and reduce milk yields, whereas too high AFC results in reduced lifetime production (Erb et al., 1985; Lin et al., 1988; Ettema and Santos, 2004). Although the average AFC's of dairy value chain typologies were close to the optimum AFC for maximum profit, individual farms showed too low and too high AFC's. Because this leads to poorer herd production and reproduction, it also negatively affects farm production, farmer income, and environmental impacts.

Land size was largest among rural SHF. In total, 29 out of the 63 farmers used artificial fertilizer, 16 used pesticides, 3 used lime, and 16 used irrigation.

Composition of Animal Diets
In all typologies, most of the diet of cattle consisted of grass products and wheat straw, with a relatively larger share of grass products being fed in rural SHF (Table 8). Average proportion of feed in the diet produced off-farm was large among urban SHF and specialized herds (89% and 77%) and small among rural SHF (7%). This implies there was a high input of nutrients from off-farm feed on urban SHF and specialized farms, that can lead to surpluses of N and P on those farms (Table 9).

Table 6

General characteristics of dairy farms in three typologies.

Variable	Typology (% of farms, or mean ± s.d.)					
	Rural SHF		Specialized		Urban SHF	
Household						
Family size (persons)	7.4	±3.8	5.7	±3.2	9.1	±5.1
Main source of income (%)						
Crops	83.9		0.0		0.0	
Livestock products	16.1		76.2		72.7	
Off-farm labour	0.0		14.3		9.1	
Other	0.0		9.5		18.2	
Gender stockperson (% male)	64.5		57.1		72.7	
Age stockperson (%)						
<20	19.4		0.0		0.0	
20-60	67.7		95.2		90.9	
>60	12.9		4.8		9.1	
Education stockperson (%)						
Illiterate	32.3		19.0		27.3	
basic education	19.4		9.5		0.0	
Primary (1-6)	22.6		9.5		18.2	
Junior (7-8)	9.7		14.3		0.0	
Secondary or higher	16.1		38.1		54.5	
Dairy herd						
Cattle functions (% of farms)						
milk for home consumption	93.5		66.7		54.5	
milk for sales	51.6		95.2		100.0	
meat	12.9		4.8		0.0	
draft power	74.2		0.0		0.0	
manure	51.6		52.4		54.5	
other functions (e.g. capital, insurance)	77.4		76.2		63.6	
Selling dairy products (%)	74.2		100.0		100.0	
Herd size (head)	9.7	±4.9	19.4	±11.5	7.0	±2.9
Adult females	3.5	±2.6	10.3	±6.7	3.5	±1.4
Adult males	2.7	±1.8	0.6	±1.4	0.2	±0.6
- used for traction	2.2	±1.7	0.4	±1.4	0.0	±0.0
Young stock	3.5	±2.2	8.5	±5.5	3.3	±2.0
Breed adult cows (% of cows)						
Local	57.1	±42.6	0.6	±2.7	4.5	±15.1
Exotic	11.2	±30.0	92.6	±23.3	63.6	±50.5
Crossbred	31.7	±39.2	6.8	±23.3	31.8	±46.2
Milk production (L/lactation)	1533.7	±1003	2514.8	±975.2	2663.6	±1005.7
Fertility (calving) rate cows	0.43	±0.24	0.37	±0.17	0.40	±0.20
Cows lactating at moment of farm visit (%)	70.8	±29.1	79.1	±19.9	69.7	±22.5
- age at first calving (months)[1]	35.3	±10.4	26.1	±5.8	28.1	±3.3
- calving interval (months)[1]	16.3	±4.6	15.2	±6.3	14.9	±2.0
Using artificial insemination (%)	48.4		85.7		63.6	
Land						
Total land size (ha)	3.2	±1.7	0.4	±0.6	0.1	±0.2
Cropland (ha)	2.6	±1.6	0.2	±0.6	0.0	±0.0
Grassland/forage (ha)	0.4	±0.7	0.2	±0.4	0.1	±0.2
Other (ha)	0.1	±1.2	0.0	±0.1	0.0	±0.0
Purchased artificial fertilizer (kg/ha cropland)	133.9	±165.7	10.0	±36.1	0.0	±0.0
Purchased pesticides (kg active matter/ha cropland)	0.5	±1.4	3.6	±16.4	0.2	±0.8
Purchased lime (%)	3.2		0.0		0.0	
Use of irrigation (%)	48.4		4.8		0.0	

[1] Data based on four cows (two lowest and two highest producing cows) lactating at the moment of the farm visit.

Table 7
Diet composition per typology.

Ingredient (%)	Rural SHF	Specialized	Urban SHF
Produced on-farm			
Grazed grass	22.9	5.1	7.4
Hay	15.6	3.6	0.0
Fresh cut grass	15.6	5.1	2.7
Wheat straw	15.0	6.3	0.0
Teff straw	5.9	0.6	0.0
Enset leaves	9.7	0.0	0.0
Barley straw	7.3	0.7	0.0
Produced off-farm			
Hay	4.5	37.8	36.1
Fresh cut grass	0.0	5.5	8.5
Wheat straw	1.4	19.4	21.7
Wheat bran	1.4	6.0	6.4
Maize stover	0.0	2.6	7.4
Bean straw	0.0	3.3	6.2
Noug cake	0.4	1.9	1.1
Brewery by-products	0.1	1.7	2.0
Compound feed	0.0	0.4	0.4

3.2 Nutrient Balance

Table 9 shows the farm gate nutrient balance, in which the quantities of nitrogen (N) and phosphate (P) coming onto the farm (imported) are balanced against N and P leaving the farm (exported) during one year. The difference between the input and output indicates a surplus or deficit in the farm nutrient balance. The farm has a surplus of nutrients if more nutrients are imported than exported, and a deficit if more nutrients are exported than imported. A distinction was made between land-based and landless farms because these types of farms differ fundamentally in their inputs and outputs: land-based farms can grow their own feed and apply the manure on their own land while landless farms have to purchase feed and export manure.

Table 9 shows that land-based farms were nutrient deficit for both N and P, whereas landless farms showed a N surplus and a P deficit. Contrary to rural SHF, specialized farms and urban SHF imported large amounts of nutrients via feed. A P deficit exists because the N to P ratio in the imported feed is about 4:1, while the N:P ratio in the exported products (milk, livestock and dung) is about 3:1. A large part of the imported nutrients were exported via dung burned for fuel.

When manure would not be burned for fuel, this could solve nutrient deficits in land-based systems (Table 9). Not burning dung for fuel in landless systems would strongly increase accumulation of nutrients on the farm.

Nutrient balances are often expressed per hectare. Given the small land sizes in landless systems, these would be hotspots for nutrient surpluses in case dung would not be burned. In that situation, nutrient surpluses would be 41241 and 1444 kg N/ha/y, and 6545 and 292 kg P/ha/y in landless specialized farms and urban SHF, respectively. For rural SHF, surpluses would be 12 kg N/ha/y and 5 kg P/ha/y.

Table 8

Mean nitrogen (N) and phosphate (P) surplus1 in kg/farm per year (farm balance).

	Land-based				Landless			
	Rural SHF		Specialized		Specialized		Urban SHF	
	Kg N/y	Kg P/y	Kg N/y	Kg P/y	Kg N/y	Kg P/y	Kg N/y	Kg P/y
Input								
Purchased animals	4.2	1.3	15.9	5.2	21.3	6.9	5.3	1.7
Concentrate	22.6	6.9	232.0	62.2	286.1	74.7	79.4	21.2
Roughage	12.4	2.5	198.8	33.1	539.4	130.8	147.6	35.5
Artificial fertilizer	71.0	22.4	16.0	5.0	0.0	0.0	0.0	0.0
Total	110.2	33.0	462.6	105.	846.8	212.4	232.3	58.4
Output								
Sold animals	7.8	2.4	11.4	3.6	25.0	7.7	6.0	1.9
Milk	21.4	8.2	82.7	31.8	140.8	54.2	37.6	14.5
Dung (sold)	0.0	0.0	0.0	0.0	300.2	90.1	40.4	12.1
Dung (burned for fuel[2])	90.2	27.0	415.2	124.	331.8	99.5	111.1	33.3
Crops	43.0	7.9	12.6	2.3	0.0	0.0	0.0	0.0
Total	162.4	45.6	521.9	162.	797.9	251.5	195.2	61.8
Surplus	**-52.2**	**-12.6**	**-59.3**	**-56.9**	**48.9**	**-39.1**	**37.2**	**-3.4**
Surplus (no dung burned)	**38.0**	**14.5**	**355.9**	**67.7**	**380.7**	**60.4**	**148.3**	**29.9**

[1] Assuming no fixation, no deposition and no sedimentation.
[2] Includes dung cake sold or given away

3.3 Baseline Environmental Impacts

Table 10 shows baseline cradle to farm-gate resource use and global warming potential (GWP) per farm typology. Compared to specialized farms and urban SHF, cradle to farm-gate resource use and GWP was highest among rural SHF for meat and milk. Environmental impacts per hour of animal traction were much higher for specialised farms, due to the 90% lower workload of the traction animals in that system. Environmental impacts of urban SHF could not be expressed per hour of traction because traction was not used in this system.

For all typologies, land use was higher, whereas energy use was lower than what was found in other studies in developed countries (De Vries and De Boer, 2010). The higher land use is due to lower yields per hectare and poorer quality of feed, causing that a larger area is needed to fulfil the animals' energy needs. Besides this, productivity of cattle is higher in developed countries, leading to a smaller area per unit of product. Fossil energy use included in our study was related to feed production only. As most field work, transport, and processing of feed is done manually or by animal traction in Ethiopia, energy use was relatively low compared energy use in developed countries, where most activities are performed by machines.

GWP per kg milk was higher than GWP in other studies from developed countries (De Vries and De Boer, 2010), but within the range of GWP found in other studies in developing countries (e.g. Bartl et al., 2011; Opio et al., 2013; Weiler et al., 2014). Differences in GWP between these studies may be caused by differences in production systems (e.g. productivity and feed quality), or by differences in methodological approach (e.g. allocation of emissions to milk and meat).

Table 9

Baseline cradle to farm-gate land use, energy use, and global warming potential (GWP) per dairy value chain typology.

Impact category	Unit	Rural SHF	Specialized	Urban SHF
Land use	m^2/kg milk	14.7	7.9	8.7
	m^2/kg live weight	95.4	42.6	40.9
	m^2/hour traction[1]	5.4	-	-
Energy use	MJ/kg milk	1.3	1.0	1.2
	MJ/kg live weight	8.4	5.5	5.9
	MJ/hour traction[1]	2.1	-	-
GWP	CO_2-e/kg milk	4.5	3.5	3.8
	CO_2-e/kg live weight	29.0	18.9	17.9
	CO_2-e/hour traction[1]	7.1	-	-

[1] Impacts for traction were not included for specialized farms because the use of traction was very low in these farms.

For specialized farms and urban SHF, most land was located off-farm as these typologies purchased a large part of their feed (Figure 3). In urban SHF, on-farm feed concerned grazed grass and fresh cut grass only, whereas specialized farms also produced some wheat straw, barley straw, teff straw and enset leaves on the farm. On the contrary, rural SHF used hardly any off-farm feed resources. Downstream (i.e. processes after the farm gate) land use refers to losses of milk, causing a higher land use per kg milk.

For energy use, 72-88% was in post-farm gate stages (Figure 3) and a smaller amount upstream in specialized farms and urban SHF as energy use is directly related to feed production.

Most GHG were emitted on-farm in all 3 typologies (Figure 3), which was due to the large contribution of the animal stage. During the animal stage, GHG emitted are methane from enteric fermentation, and methane and nitrous oxide from animal manure. Of all GHG, carbon dioxide contributed most to total dairy value chain GWP (about 50% for all typologies; Figure 4).

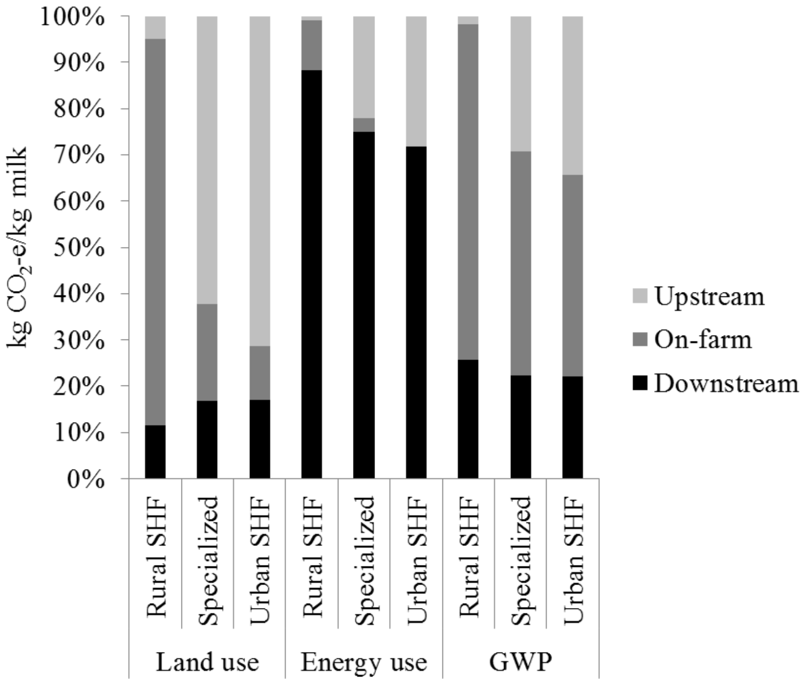

Figure 3*: Contribution of upstream, on-farm and downstream processes to dairy value chain environmental impacts per farm typology.*

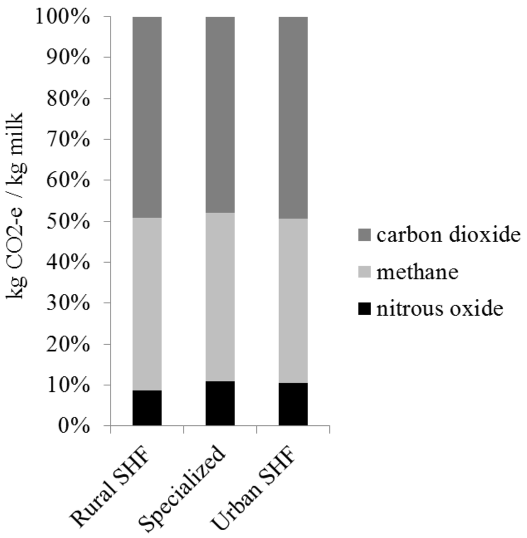

Figure 4*: Contribution of individual GWP elements to dairy value chain GWP per farm typology*

Of all processes in the dairy value chain, methane from enteric fermentation contributed most to chain GWP, and feed production second-most (Figure 5). For rural SHF, GHG from feed production were mainly emitted on the farm, whereas feed related GHG were mainly emitted off-farm in specialized farms and urban SHF. Part of the feed related GHG consisted of methane, due to enteric fermentation in traction animals.

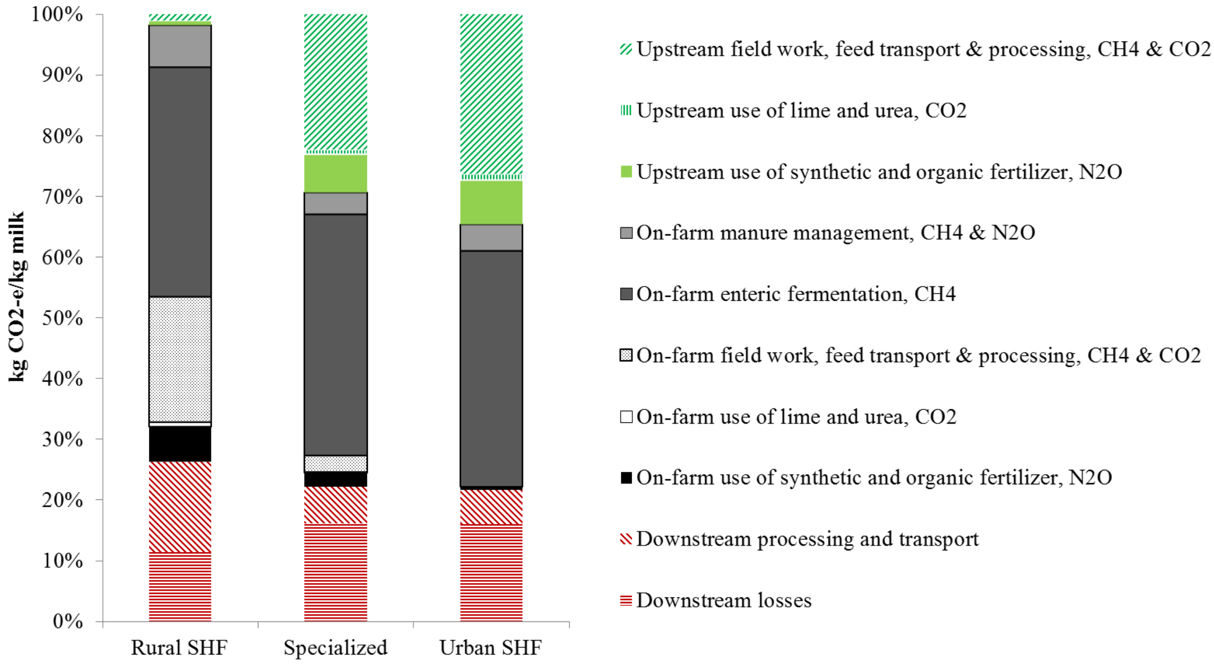

Figure 5: *Relative contribution of processes in the dairy value chain to total farm GWP per typology.*

Adult and replacement females contributed most to total farm GWP in all typologies, but in rural SHF, 40% of total farm GWP was caused by male stock (Figure 6). This was caused by a relatively high number of oxen in rural SHF and a relatively high emission of methane per animal from oxen compared to non-traction males. Emission of methane from enteric fermentation is directly related to gross energy (GE) feed intake. GE feed intake is higher when animals demand more energy, e.g. for maintenance, grazing, pregnancy, lactation, growth, or labour.

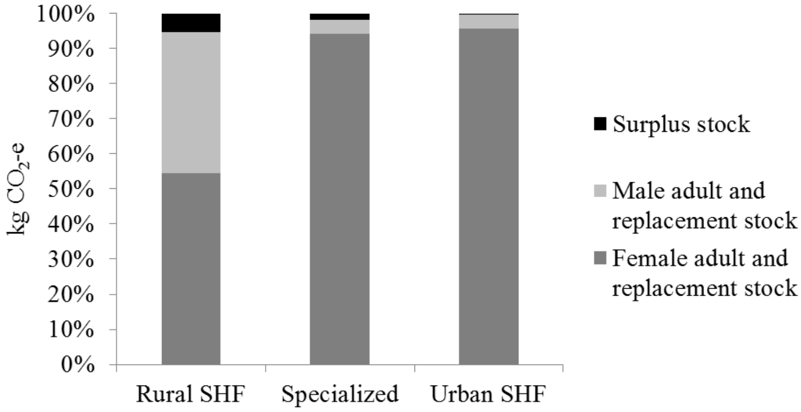

Figure 6: *Contribution of different cattle types to total GWP from animals per typology.*

3.4 Post farm-gate Environmental Impacts

Milk processing at farms.

Milk processing took place at many farms, and depended on the season (dry and wet season) and fasting days (Figure 7). The figure shows the fraction of farms where more than half of the milk is processed. Processing was more frequent on rural farms than on specialised and urban farms. However, in the wet season on fasting days, most of the rural, specialised and urban farms process a large part of the milk.

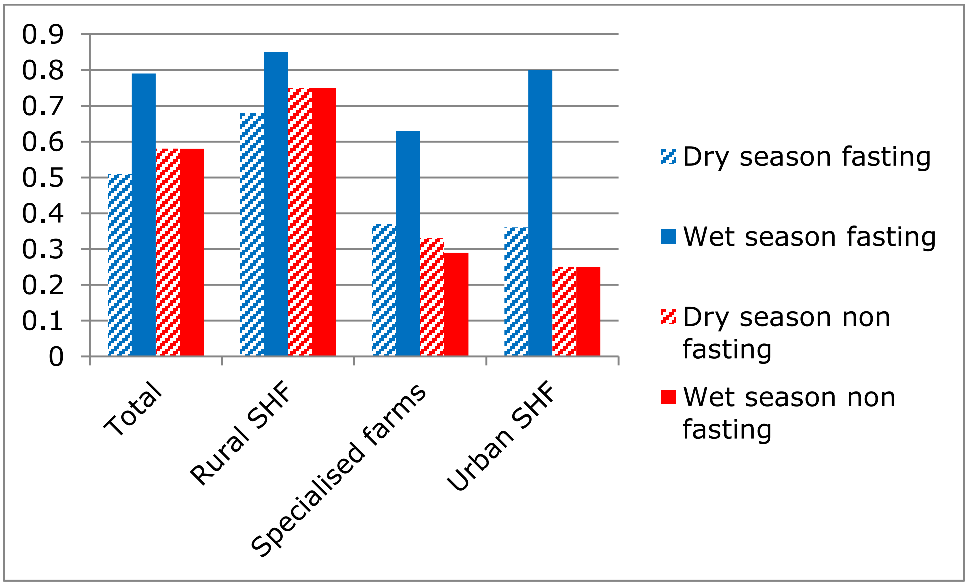

***Figure 7**: Percentage of farms that processed milk on fasting and non-fasting days in wet and dry seasons.*

Milk consumption and sales

Although many people didn't respond to the question about the home consumption, it could be seen that home consumption occurs mostly in the smallholder (rural and urban) farms, where total milk production is relatively low. In specialised farms, the total milk production is higher, due to the larger herd and, as a consequence, home consumption is only limited (Figure 8).

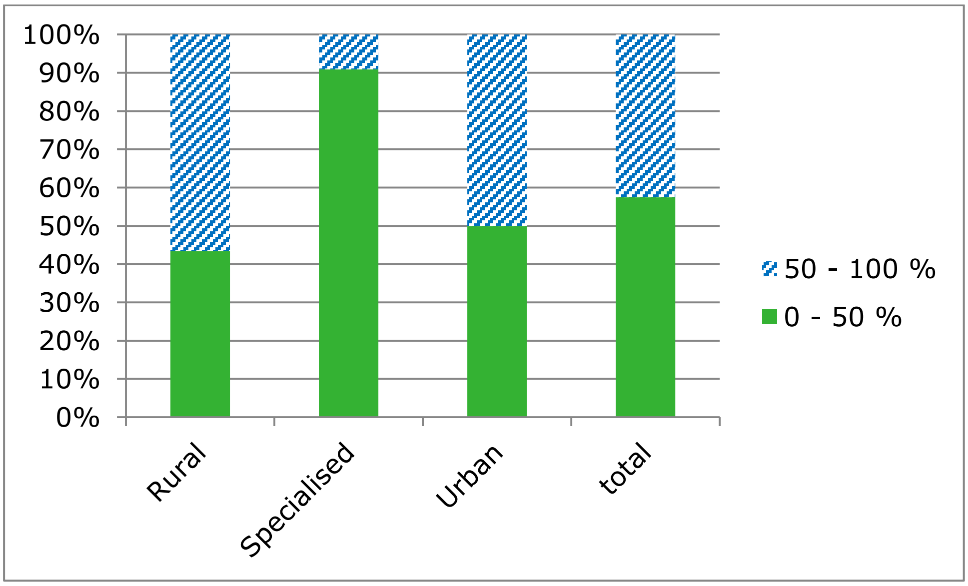

***Figure 8**: The fraction of farmers consuming less than half or more than half of the produced milk at the farm.*

Out of the 63 surveyed farmers, 47 responded to the question about milk sales. Almost all farmers sold 50% or more of the milk, and 47% (rural) to 81 % (specialised) sold 100% of the produced milk. Of the 17 non-responding farmers, 15 were rural. Assuming that the blanks don't sell milk, it is clear that milk sales are much lower in rural farms compared to the specialised and urban farms.

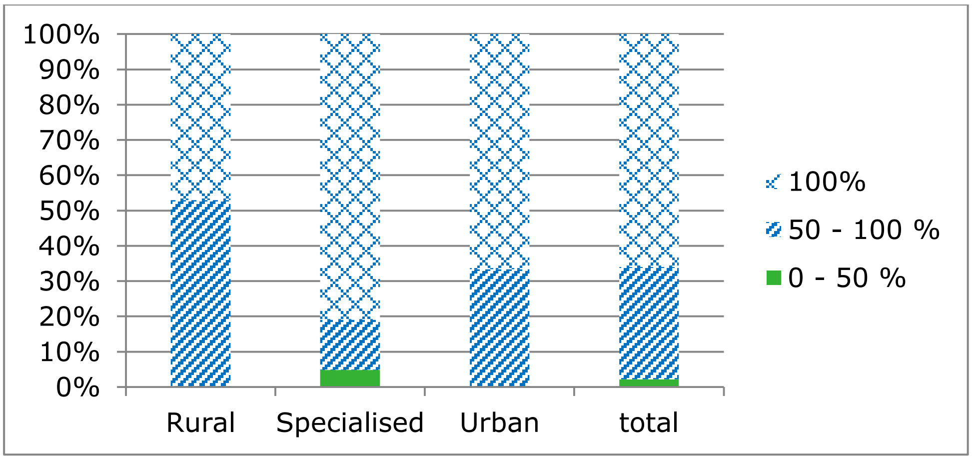

***Figure 9**: Fraction of farmers selling 0-50%, 50-10% or 100% of the fresh milk.*

Hardly any of the farmers reported losses during transport and selling milk, except for one farmer. There was no chilled transport reported at all. Milk was sold in various ways, most important ones were the dairy cooperative, the local market and at home (Table 11).

Table 10
Destination of sold fresh milk.

Dest Fresh milk sold	Rural SHF cereal	Rural SHF perennial	Specialized medium land-based	Specialized medium landless	Urban SHF	Grand Total
dairy coop	8		1	2	3	14
hotels/cafes	2		1		1	4
local market	1	3	1		3	8
other	2	1	2	1	2	8
sold at farm			1	6	2	9
(blank)	11	4	2	4		21
Grand Total	24	8	8	13	11	64

The total GHG emissions per kg of milk and milk products at the end of the observed post farm chain (without retail and consumer), were 6.2 kg CO_2-e per kg milk for the rural SHF, and 4.5 and 4.8 for the specialised farms and the urban SHF. Milk losses in the commodity chain were 11, 16 and 16% respectively. The large fraction of sold fresh milk is responsible for the relatively large loss in the peri-urban and urban commodity chains. The increase in GHG between farm gate and the end of the observed processing chain can be explained by losses (0.70 to 0.78 kg CO_2-e) and by processing (0.27 kg CO_2-e for specialised and urban, 0.90 kg for rural; Figure 10).

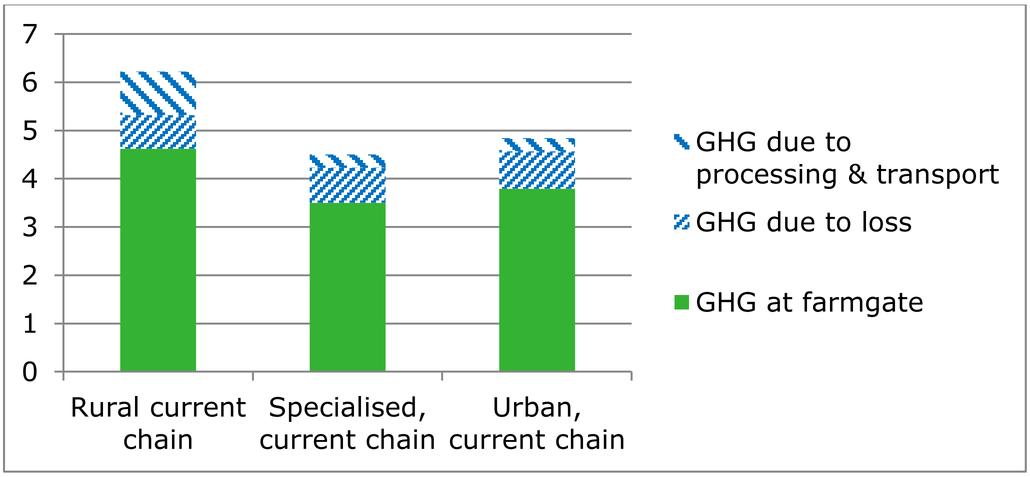

Figure 10: *GHG emissions (CO2-e/kg milk) at farm gate (solid) and post farm chain due to loss (thin lines) or processing and transport (thick lines).*

Processing emissions at rural farms are high, because they are considered to use fuel wood for heating and processing. The increase in land use after the farm gate is only caused by losses of milk. With 16% of loss, the land use increases by 1/0.84 = 19% (Figure 11).

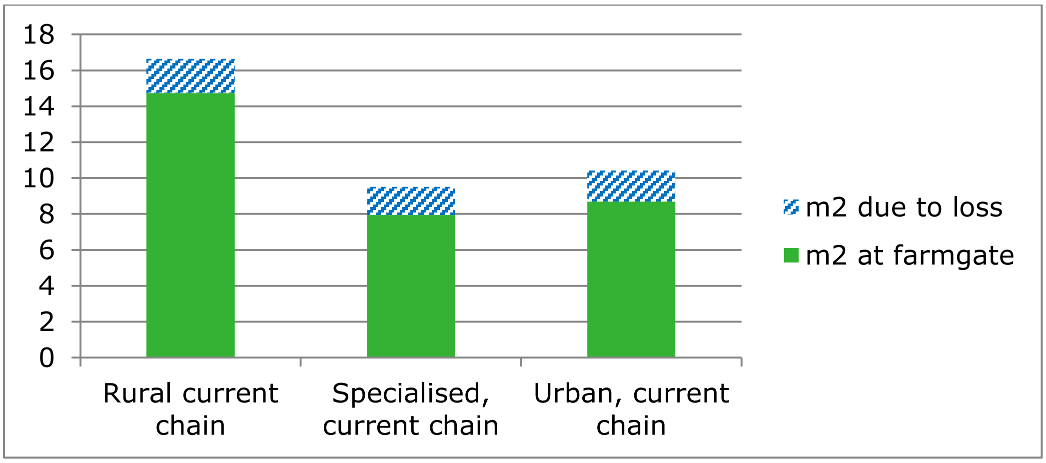

Figure 11: *Land use (m2/kg milk) at farm gate (solid) and post farm chain due to loss (thin lines).*

The energy use after the farm gate is much more important, especially for rural farms, where a lot of the milk is processed at home (Figure 12). The energy use for home processing is assumed to be very inefficient, based on the heating by open fire, fuelled by firewood. The post farm energy use is much less for the specialised and urban farms, due to the higher fraction of fresh milk sold.

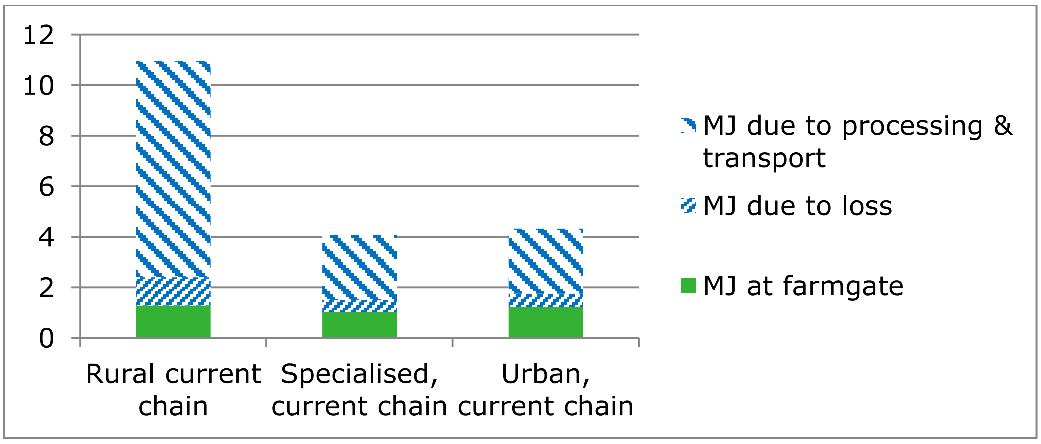

Figure 12: *Energy use (MJ/kg milk) at farm gate (solid) and post farm chain due to loss (thin lines) or processing and transport (thick lines).*

PART 2: IDENTIFICATION AND PRIORITIZATION OF INTERVENTIONS IN ETHIOPIAN DAIRY VALUE CHAINS

4 Material and Methods

4.1 Simulation of Mitigation Interventions

Based on the results of the LCA in the customized GLEAM model and resulting identification of processes and activities with a large contribution to environmental impacts, a number of potential mitigation scenarios were defined for each dairy value chain typology. Mitigation scenarios were simulated in GLEAM to evaluate their potential reduction in environmental impacts of dairy value chains.

For simulation of improved digestibility of forage, we used maize stover as a theoretical example of a forage with a high digestibility. Maize stover is not available everywhere. On average 9,111,000 MT of maize stover is produced in Ethiopia annually (average 2007-2011; Ethiopian Feed Association 2011). Most of the maize stover is utilized within the farm (99%). Price is dependent on season, succulent or dry stover and also on regions.

For rural SHF, seven mitigation interventions were defined and simulated in GLEAM:

1. Improved feeding:

   a) Increased milk production per cow due to **increased concentrate feeding**. For this scenario, we increased the proportion of concentrate feed in the diet from 2% to 10%, at the expense of roughage feed. All concentrate feed was purchased off-farm. Based on the increase in gross energy feed intake and a fixed feed intake capacity (2-3% of body weight), milk production was increased from 1534 kg to 2000 kg milk per cow per lactation. **(Scenario R1a)**
   b) Increased milk production per cow due to **improved digestibility of forages**. Crop residues were replaced with maize stover, being an example of a forage with a high digestibility. Many crop residues and hay have a digestibility of about 45%, whereas maize stover is assumed to have a 62 % digestibility. For this scenario, about 37% of the crop residues and hay in the animals ration were replaced by maize stover. Improved digestibility leads to higher milk production and growth rates with similar feed intakes. For this scenario, we explored effects of an increase in milk production only. Based on the increase in gross energy feed intake and a fixed feed intake capacity (2-3% of body weight), milk production was increased from 1534 kg to 3000 kg milk per cow per lactation. **(R1b)**
2. **Improving utilization of animal manure** as a fertilizer. According to results of our field survey, about 20% of the dung was used for fuel among rural SHF. For this scenario, dung was used as fertilizer instead of burning it for fuel. To simulate increased use of dung as a fertilizer, the amount of organic manure applied on farm land was increased by 27%, reducing the need for synthetic fertilizer. Due to the increased supply of potassium, trace elements and organic matter, yields were assumed to increase by 5%. **(R2)**
3. **Improving the post farm-gate chain.** The original post farm-gate processing was assumed to be 70% home processing for sale or home consumption, 20% milk sales at a local market and 10% milk sales to an industrial processor. We shifted this division strongly, by reducing the home processing to 30%, all the remaining milk being sold to an industrial processor. This might lead to somewhat lower milk prices, but saves a lot of labor at farm level **(R3).**
4. Improved breeding and reproduction:

   a) **Replacement of unproductive adult females.** For this scenario, unproductive cows were replaced by purchased pregnant heifers (same breed). Proportion of lactating cows was increased to a proportion reflecting an average calving interval of 365 days; from 71% to 82%. **(R4a)**

b) I**ncreased crossbreeding**. For this scenario, proportion of crossbred cows was increased from 32% to 50% at the expense of local breed cows (decreased from 57% to 39%). Based on average milk production per lactation of the different breeds in the surveyed farms, milk production was increased from 1534 kg to 1830 kg milk per cow per lactation. Average weight of adult cows was increased from 324 to 358 kg **(R4b)**

5. **Replacing oxen by mechanization.** For this scenario, we evaluated excluding 80% of adult males from the farm. Adult males were not fully (i.e. 100%) excluded because bulls were needed for reproduction. Animal labor for land preparation and harvesting was replaced by land preparation and harvesting by a two-wheeled tractor. Since it was assumed that time-efficiency of the two-wheeled tractor was 4 times higher than oxen, rental and fuel costs were based on 203 hours per year. Excluded oxen were replaced by cows with the same (re-) production as other cows in the herd. Extra bull calves born were sold around weaning. Extra feed available due to the exclusion of oxen was assumed to be used as buffer feed for seasonal fluctuations in feed availability, and for feeding the added milking cows (16% higher gross energy need compared to oxen). **(R5)**

For specialized farms, three types of mitigation interventions were defined and simulated in GLEAM:

1. Improved feeding:

   a) Increased milk production per cow due to **increased concentrate feeding**. For this scenario, the percentage of concentrate feed in the diet was increased from 10% to 20%, with all concentrate feed being purchased off-farm. Based on the increase in gross energy feed intake and a fixed feed intake capacity (2-3% of body weight), milk production was increased from 2515 kg to 3500 kg milk per cow per lactation. **(S1a)**

   b) Increased milk production per cow due to **improved digestibility of forages**. As an example, crop residues were replaced with maize stover. For this scenario, about 37% of the crop residues and hay in the animals ration were replaced by maize stover. Increase in milk production was based on the increase in gross energy feed intake and a fixed feed intake capacity (2-3% of body weight), but was limited to the highest production among herds in the sample. Because milk production based on gross energy feed intake crossed this limit, milk production was increased from 2515 kg to 4629 kg milk per cow per lactation. **(S1b)**

2. **Improved utilization of animal manure** as a fertilizer. In the case of specialized farms, about 40 – 50 % of the dung was used as a fuel. Shifting the manure to fertilizer, organic manure rates at off-farm land will double and synthetic N and P fertilizers have been replaced. Due to the higher supply of potassium, trace elements and organic matter, yields were assumed to increase by 15%. **(S2)**

3. **Improving the post farm-gate chain.** The original post farm processing was assumed to be 20% home processing for sale or home consumption, 70% milk sales at a local market and 10% milk sales to an industrial processor. We have shifted this strongly, by reducing the home processing to 10%, all the remaining milk being sold to an industrial processor. This might lead to somewhat lower milk prices. **(S3)**

For urban SHF, four types of mitigation interventions were defined and simulated in GLEAM:

1. Improved feeding:

   a) Increased milk production per cow due to **increased concentrate feeding**. For this scenario, the percentage of concentrate feed in the diet was increased from 10% to 20%, with all concentrate feed being purchased off-farm. Based on the increase in gross energy feed intake and a fixed feed intake capacity (2-3% of body weight), milk production was increased from 2664 kg to 3500 kg milk per cow per lactation. **(U1a)**
   b) Increased milk production per cow due to **improved digestibility of forages**. As an example, crop residues were replaced with maize stover. For this scenario, about 37% of the crop residues and hay in the animals ration were replaced by maize stover. Based on the increase in gross energy feed intake and a fixed feed intake capacity (2-3% of body weight), milk production was increased from 2664 kg to 4500 kg milk per cow per lactation. **(U1b)**

2. **Improved utilization of animal manure** as a fertilizer. In the case of urban farming, about 40 – 50 % of the dung was used as a fuel. Shifting the manure to fertilizer, organic manure rates at off-farm land will double and synthetic N and P fertilizers have been replaced. Due to the higher supply of potassium, trace elements and organic matter, yields were assumed to increase by 15%. Though not analyzed in this scenario, introduction of anaerobic digestion is very helpful to shift from dung to biogas as an energy source. **(U2)**

3. **Improving the post farm-gate chain**. The original post farm processing was assumed to be 20% home processing for sale or home consumption, 70% milk sales at a local market and 10% milk sales to an industrial processor. We have shifted this strongly, by reducing the home processing to 10%, all the remaining milk has been sold to an industrial processor. This might lead to somewhat lower milk prices. **(U3)**

4. Improved breeding and reproduction:

   Replacement of unproductive adult females. For this scenario, unproductive cows were replaced by purchased pregnant heifers (same breed). Proportion of adult cows lactating was increased to a proportion reflecting an average calving interval of 365 days; from 70% to 82%. **(U4)**

Because proportion of adult cows lactating was already high in specialized farms (79%), this scenario was not simulated for specialized farms. Besides this, average age at first calving (AFC) was acceptable for western standards for lactating cows in both specialized farms (27 months) and urban SHF (29 months; optimal AFC is ~24 months). Therefore, AFC value was not changed. AFC varied largely among herds, however, which could affect herd productivity and emission intensity per farm. This aspect is discussed in the Results and Discussion section.

4.2 Cost Benefit Analyses

A simple cost benefit analyses was carried out to evaluate cost effectiveness of mitigation interventions and effects on (additional) farm income. Costs and benefits of mitigation scenarios were evaluated assuming expected expenses and benefits described in Table 6. Prices of agricultural items are in Annex 2f.

Table 11

Assumptions on expected farm-level expenses and benefits of mitigation interventions in cost benefit analyses.

Intervention	Expected expenses	Expected benefits
Rural SHF		
R1a. Increased concentrate feeding	• 70% higher feed costs[1] / year	• 41% higher milk sales / year
R1b. Improved digestibility of forage	• 8 times higher feed costs/year	• 130% higher milk sales / year
R2. Improved utilization of animal manure	• 50% less synthetic fertilizer use	• no sales of dung cake
R4a. Replacing unproductive adult females	• 10% higher feed costs[1] / year • single investment[3] 0.3 purchased pregnant heifers	• 22% higher milk sales / year
R4b. Increased crossbreeding	• 50% higher AI costs / year	• 26% higher milk sales / year • 5% higher live weight sales / year
R5. Replacing 80% of adult males[4] by mechanization and cows.	• rental and fuel costs[2] of machinery for land preparation and harvesting 203 hours per year • single investment 2.2 purchased crossbred pregnant heifer[3]	• 86% higher milk sales / year • 1% lower live weight sales / year
Specialized farms		
S1a. Increased concentrate feeding	• 15% higher feed costs[1] / year	• 44% higher milk sales / year
S1b. Improved digestibility of forage	• 76% higher feed costs/year	• 94% higher milk sales / year
S2. Improved utilization of animal manure	• 50% less synthetic fertilizer use	• no sales of dung cake
Urban SHF		
U1a. Increased concentrate feeding	• 7% higher feed costs[1] / year	• 37% higher milk sales / year
U1b. Improved digestibility of forage	• 343% higher feed costs/year	• 82% higher milk sales / year
U2. Improved utilization of animal manure	• 50% less synthetic fertilizer use	• no sales of dung cake
U4. Replacing unproductive animals.	• 10% higher feed costs[1] / year • single investment[3] for 0.43 purchased pregnant heifers	• 21% higher milk sales / year

[1] Assuming additional purchased feed consists of the same feedstuffs as already bought.
[2] Assumption that time-efficiency of the two-wheeled tractor was 4 times higher than oxen
[3] A 5-year loan was assumed for purchased animals, with an interested rate of 10% per year. Breed composition stays the same.
[4] Returns from sold unproductive females or replaced oxen were neglected

4.3 Climate Resilience Indicators

Parallel to identification of mitigation strategies, potential indicators of climate resilience in dairy value chains were identified, as well as potential adaptation strategies along the chain. Because the main focus of this study was on dairy systems, climate resilience and adaptation was evaluated in relation to livestock and crop-livestock interactions only. Resilience indicators and adaptation strategies relating to technical aspects of climate resilient crop production (e.g. tillage practices, resilient crop/fodder varieties, rainwater harvesting methods) were not taken into account, unless related to feed availability.

Potential indicators of climate resilience and adaptation strategies in dairy value chains were identified in three steps:

- In the first step, potential farm-level indicators for climate resilience and adaptation strategies were identified, largely based on adaptation strategies available in the ATA climate CB analysis and adaptation strategies in the EU AnimalChange project (www.animalchange.eu). Climate resilience of surveyed dairy farms was evaluated for indicators for which data was available from the field survey among 64 farms.
- In the second step, additional climate resilience indicators and adaptation strategies were identified as part of key-informant interviews and farmer group discussions, which was later prioritized by stakeholders in key informant interviews and focus discussion groups.
- In the third step, climate resilience indicators and potential adaptation strategies with a high priority were mapped along dairy value chains, and trade-offs and synergies between mitigation and adaptation strategies for dairy value chains were evaluated.

4.4 Organizing Feedback from Stakeholders

Feedback from stakeholders was organized in two steps. First, interviews were organized with key stakeholders, and focus group discussions were organized with farmers. Second, a stakeholder validation workshop was organized by ATA.

Group discussions were held in the 4 regions (Mekele, Bahir dar, Oromia (Addis Ababa zuria) and Hawassa). In each of the 4 groups discussions held in the four cities 8 farmers participated. Farmers were selected to represent the three farm typologies (rural SHF, specialized farms, and urban SHF). An introduction about the purpose of this study briefing was followed by oral presentation of results about the first survey. Farmers were asked to list major problems and challenges for dairy production, which was followed by pair-wise-ranking on a clip board. Accordingly, their major problems were ranked in chronological order.

A stakeholder validation workshop was organized by ATA, where results of the study were presented to representatives of various organizations that included donors, Ministry of Livestock and Fishery, ATA, non-governmental dairy projects, research organizations and regional livestock development bureaus. Following presentations of the results of this study, small group discussions were held, to validate the implementations of recommended mitigation and adaptation strategies. The discussion emphasized on prioritizations of the interventions, suggestions for key implementing organizations, supporting organizations and also funding sources.

5 Results and Discussion

5.1 Effects of Mitigation Interventions on Environmental Impacts

Figure 13-15 show effects of mitigation interventions on dairy value chain GWP, land use, and energy use of the three typologies of dairy value chains. Effects are shown for one kg of milk as a functional unit in these figures, but trends are similar beef (detailed cradle to farm-gate results are in Annex 4). For all typologies, improving digestibility of feed rations had the largest effect on reduction of environmental impacts, varying from 24% to 29% reduction. For this study, maize stover with a relatively high digestibility was used as a theoretical example of a forage with improved digestibility, but other forages with high digestibility can be effective as well. The increase in concentrate level from 2 to 10 % is still within the range that local and crossbred animals can utilise. The reduction in environmental impacts can be explained in two ways. Firstly, the higher digestibility led to less enteric fermentation in cows, which implies a reduction of methane emissions. In rural SHF, for example, farm methane emissions were reduced by 15%. Second, the reduction in environmental impacts was due to the fact that total farm output (milk) was higher. Therefore, farm resource use and emissions were divided over a larger farm output, leading to lower emissions per unit of product.

Mitigating Environmental Impact in Rural SHF

For rural SHF, improving digestibility of forage was most effective for lowering GWP per kg milk, followed by replacing oxen with mechanization (Figure 13a). For land use, improving digestibility of forage was most effective, followed by increasing concentrates (Figure 13b). For energy use, improvements in the post farm-gate chain were most effective, whereas replacing oxen with mechanization strongly increased energy use (Figure 13c). The high energy use was due to the use of fuel for land preparation and harvesting activities by the two-wheeled tractor. Combustion of fuel led to higher GHG emissions in the form of carbon dioxide, but this increase was not as large as the reduction in GHG emissions in the form of methane from the traction animals.

The lower GHG resulting from replacing oxen by mechanization was mainly due to the fact that the system produced a higher amount of outputs (i.e. milk and meat) while the total number of farm animals remained the same (oxen were replaced by adult females in this scenario, which have only slightly higher GE feed requirements than oxen). Mechanization provides the opportunity to replace the oxen, and leaves more feed for milking cows and young stock. It could thus contribute to a better feeding management for other animals, resulting in higher production levels and better growth rates. Due to better feeding, animals might get pregnant easier, which again contributes to animal productivity. An additional advantage is the fact that mechanization reduces the time requirements for land preparation for planting crops, which is important given the expected changes in rainfall and rainfall patterns. Also, mechanization can save much labour on the farm.

One could think that replacing of oxen would not have an effect on emissions of the livestock system because impacts related to traction (i.e. all resource use and emissions related to the maintenance and labour of oxen from the moment the animal started to perform draught activities) were allocated to crop production. These impacts were re-allocated to the livestock system, however, because parts of the crops were consumed by the animals. In the feed module, use of oxen for crop production resulted in higher emissions per kg crop than use of mechanization. These impacts were allocated among crops and crop residues, with crop residues being used as animal feed.

Reductions in GWP, land use and energy use were less prominent for increased crossbreeding, improved utilization of manure and improved reproductive performance (Figure 13a-c). For crossbreeding, decrease in GWP was not proportional to increase in milk production. GWP decreased by 4% whereas milk production per lactation was increased by 19%. In these herds this was especially due to the fact that local cows were replaced by crossbred cows to realize a higher production per cow. Crossbred cows had a higher productivity, but also a higher live weight, which means that their feed intake for maintenance is higher. Methane emissions are directly related to feed intake. Because of higher live weights of the crossbred animals, production of live weight per farm increased by 5%.

Changes in the post farm chain reduced the emissions per kg of milk by about 0.85 kg CO_2-e compared to the baseline situation (i.e. 12% reduction). The most important contribution came from the reduction of post farm losses, due to the implementation of a cold chain in industrial milk processing. GHG emissions from milk processing were low, because emissions for electricity in Ethiopia are low. The total milk production increased slightly, due to the reduction of losses in the post farm stages. Energy use was reduced because energy requirements for processing at home were assumed much higher compared to the industrial energy requirements. The energy source for home processing was assumed to be fire wood, whereas the energy source for industrial processing was electricity, produced with very low emissions in Ethiopia (7.5 grams CO2-eq per MJ).

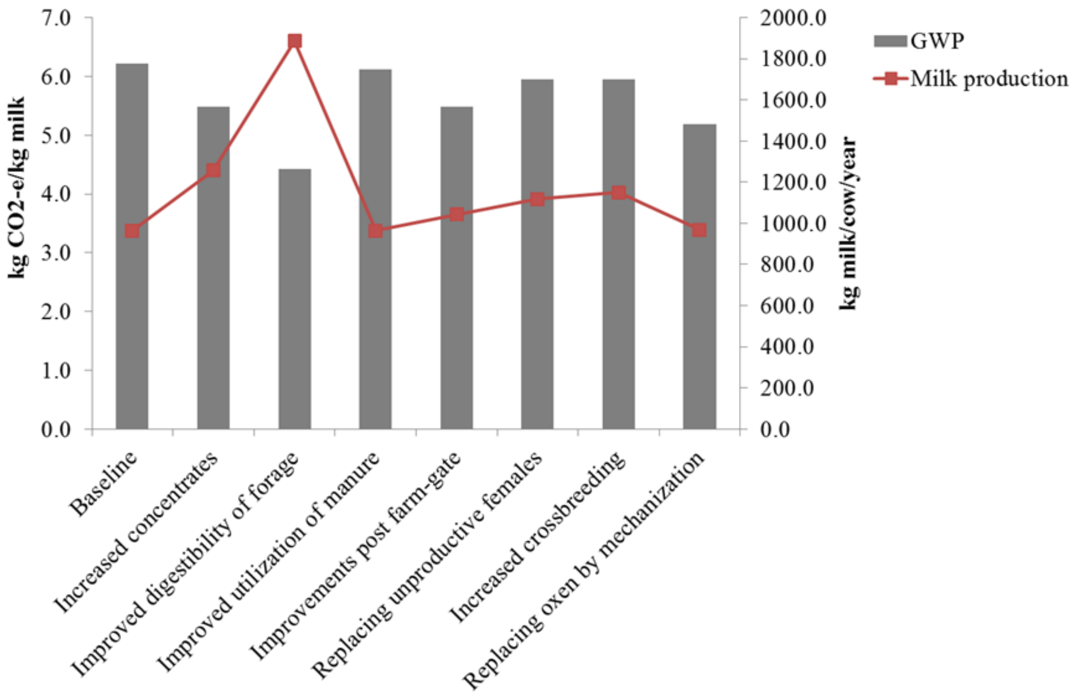

***Figure 13a**: Effects of mitigation interventions on global warming potential (GWP) in rural SHF.*

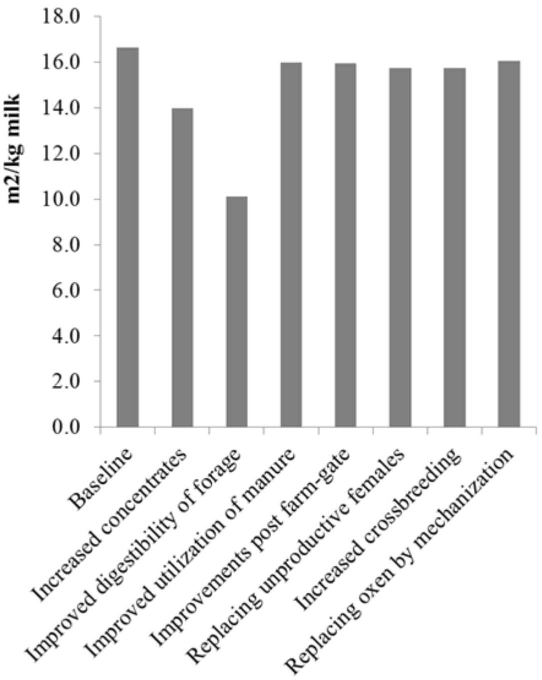

Figure 13b. Effects of mitigation interventions on land use per kg milk in rural SHF.

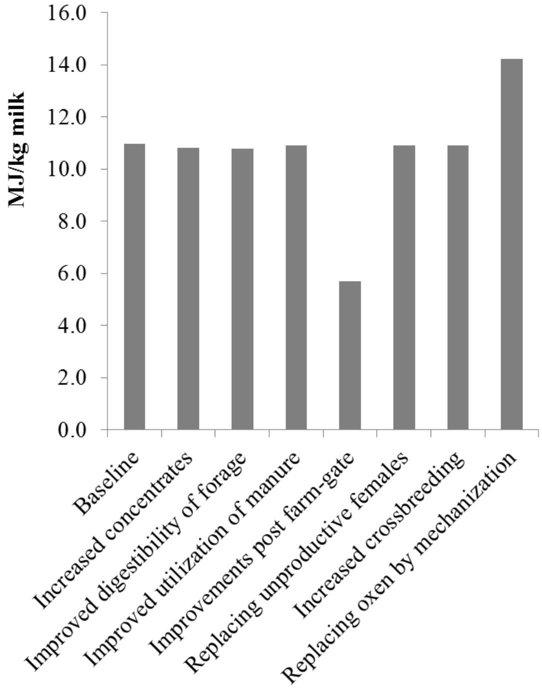

Figure 13c. Effects of mitigation interventions on energy use per kg milk in rural SHF.

Mitigating Environmental Impact in Specialized Farms

For specialized farms, improving digestibility of forage and improvements in the post farm-gate chain were most effective for reducing GWP per kg milk (Figure 14a). Improving digestibility of forage was also most effective for reduction of land use (Figure 14b), whereas improvements post farm-gate were most effective for reducing energy use (Figure 14c). For increasing concentrate use, GHG and energy use were lower despite an increase in GHG and energy use from feed production. This was because the use of concentrates also increased milk production, which led to lower GHG and energy use per unit of product.

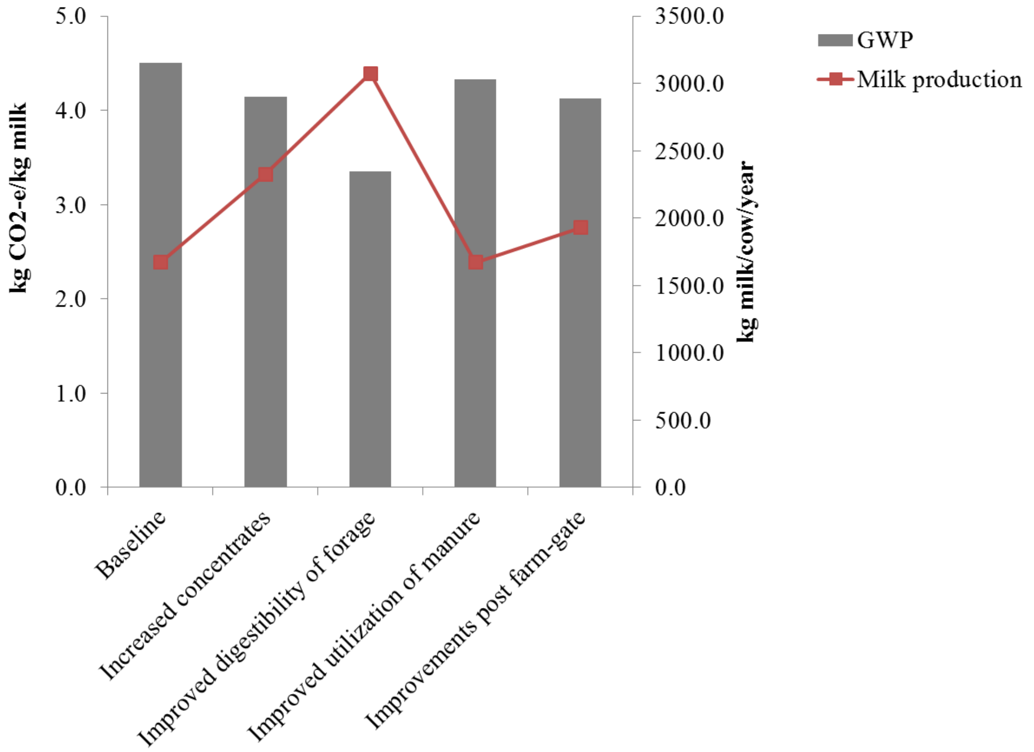

***Figure 14a**: Effects of mitigation interventions on global warming potential (GWP) in specialized farms.*

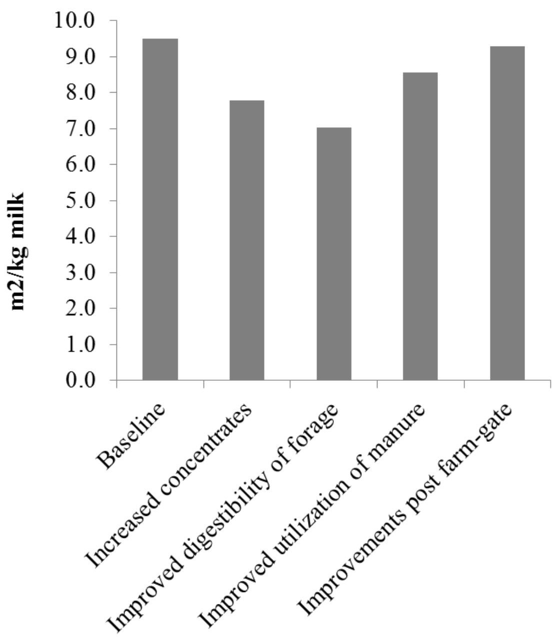

***Figure 14b.** Effects of mitigation interventions on land use per kg milk in specialized farms.*

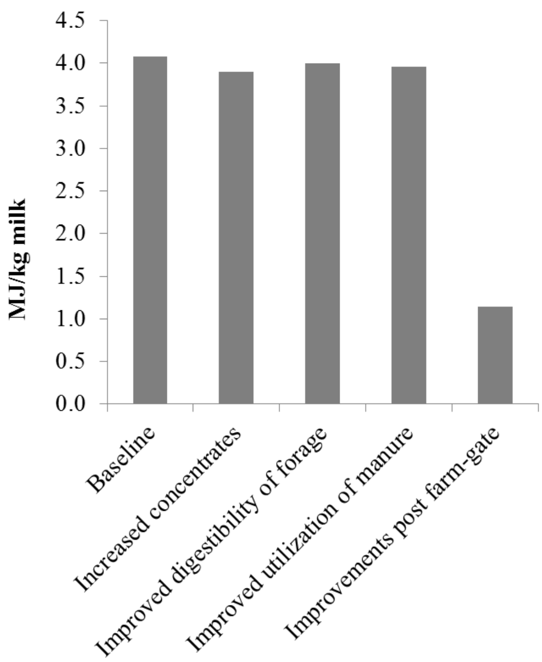

***Figure 14c.** Effects of mitigation interventions on energy use per kg milk in specialized farms.*

For urban SHF, improving digestibility of forage and replacing unproductive females were the most effective interventions for lowering GWP per kg milk (Figure 15a). Improving digestibility of forage and increasing the use of concentrates were most effective for reducing land use (Figure 15b), and improvements in the post farm-gate chain was most effective for lowering energy use (Figure 15c).

For herd reproductive performance, reductions in environmental impacts were due to the fact that fewer animals were needed per unit of output because the number of unproductive milking cows in the herd was reduced. Removal of unproductive cows from the herd affects can lead to an upward cycle of increasing milk production and off-spring. When (often older) unproductive cows are replaced by younger animals, not only do the new animals produce more milk per year, but also they produce more calves per year. These calves can be used to replace (older) unproductive milking cows in an early stage, which will again improve herd productivity in terms of milk and off-spring. In addition to the advantages of increasing the replacement rate, removal of unproductive cows leaves more feed for other animals, which can increase their productivity and enhance resilience in periods of scarce resources.

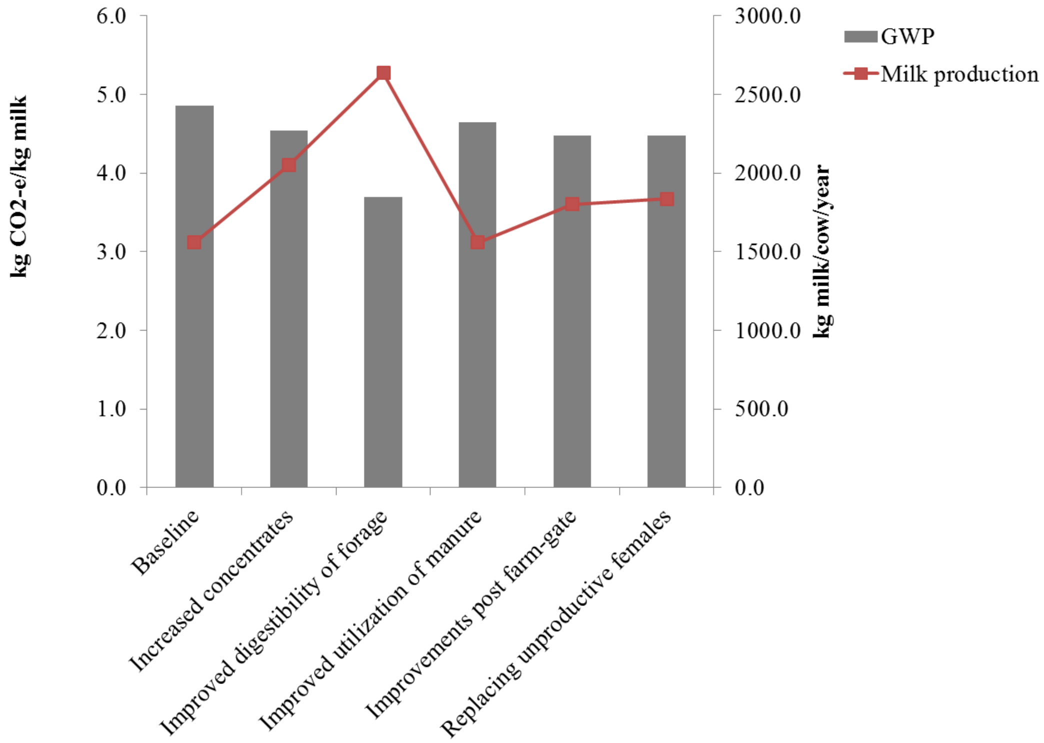

Figure 15a: *Effects of mitigation interventions on global warming potential (GWP) in urban SHF.*

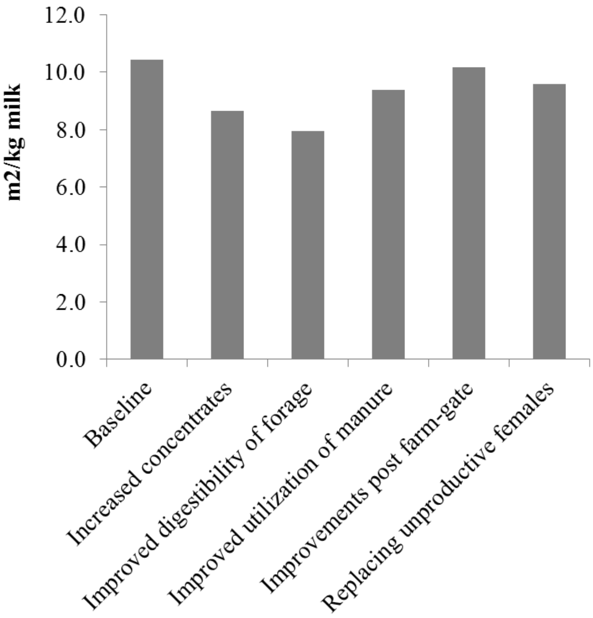

Figure 15b: ***Effects of mitigation interventions on land use per kg milk in urban SHF.***

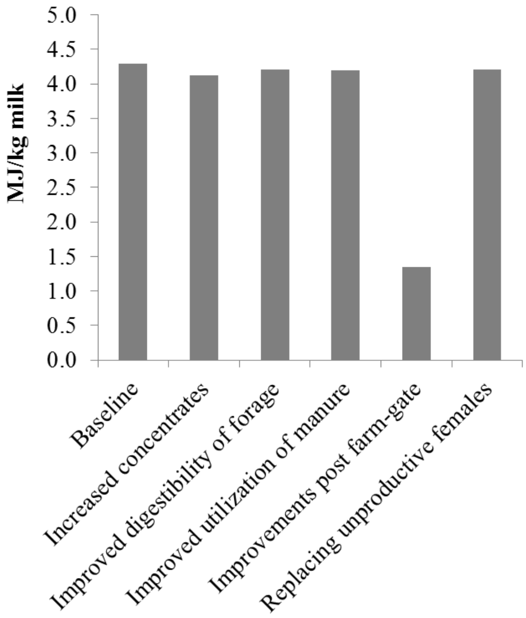

Figure 15c: ***Effects of mitigation interventions on energy use per kg milk in urban SHF.***

5.2 Cost Effectiveness of Mitigation Interventions

Figure 16 shows cost effectiveness of mitigation interventions, with effect of the intervention on farm income on the y-axis and effect of the intervention on GHG emissions on the x-axis. Dots in the lower right corner represent cost-effective interventions contributing to GHG mitigation, whereas dots in the lower left corner represent interventions that contribute to GHG mitigation, but are costly. Effect on GHG emissions concerns cradle to farm-gate emissions only and the intervention of improving post farm-gate stages was not included, because we did not have sufficient data on costs and benefits for the post farm-gate stage.

It should be emphasized that results of this cost benefit analysis are rough estimates, because it involves a number of assumptions on relations between farm inputs and outputs in the dairy production system. Results in this paragraph, therefore, should be interpreted with care. Also, in this study we evaluated cost effectiveness of interventions at the farm level. Successful implementation of interventions, however, often requires extra investments in the public domain, such as education of farmers and infrastructure. Therefore, additional external costs can be expected.

Increased crossbreeding, improved reproductive performance, and replacing adult males by mechanization showed to be cost-effective. Improved feeding (increased use of concentrate feed and improved digestibility of forage) was cost-effective in specialized farms and urban SHF, but costly in rural SHF. Inversely, improved utilization of animal manure was cost effective in rural SHF, but not in specialized farms and urban SHF.

Cost-effective Interventions in Rural SHF

For rural SHF, replacing adult males by mechanization was the most cost effective mitigation intervention. Improving digestibility of forage was most effective in terms of reduction of GHG, but not cost effective because the increase in milk production did not compensate for the increased costs of purchased maize stover. Increased use of concentrate feed was also not cost-effective. To limit the costs of feed production, improvements in feeding should be directed at improving on-farm production of feed and fodder in land-based systems, while efforts should be focussed on provision of affordable concentrate feed in landless systems.

Cost-effective Interventions in Specialized Farms and Urban SHF

For specialized farms and urban SHF, improving digestibility of forage was the most effective in terms of GHG mitigation and economic benefits. Improved utilization of animal manure was only little effective in terms of mitigation, and somewhat costly. Improved utilization of animal manure was costly due to missed income from selling dung cakes. The option of selling of manure as a fertilizer instead of selling dung cakes for fuel was not evaluated in this study, and might be a cost effective alternative. Using manure as a fertilizer can contribute to less depletion of nutrients and organic matter in soils used for crop production in rural or peri-urban areas, and less accumulation of nutrients in urban areas. Although not calculated in the present study, improved manure management can be expected to contribute to reduction of GHG emissions indirectly via improvements in productivity of agricultural soils and avoidance of productivity loss due to soil erosion and degradation.

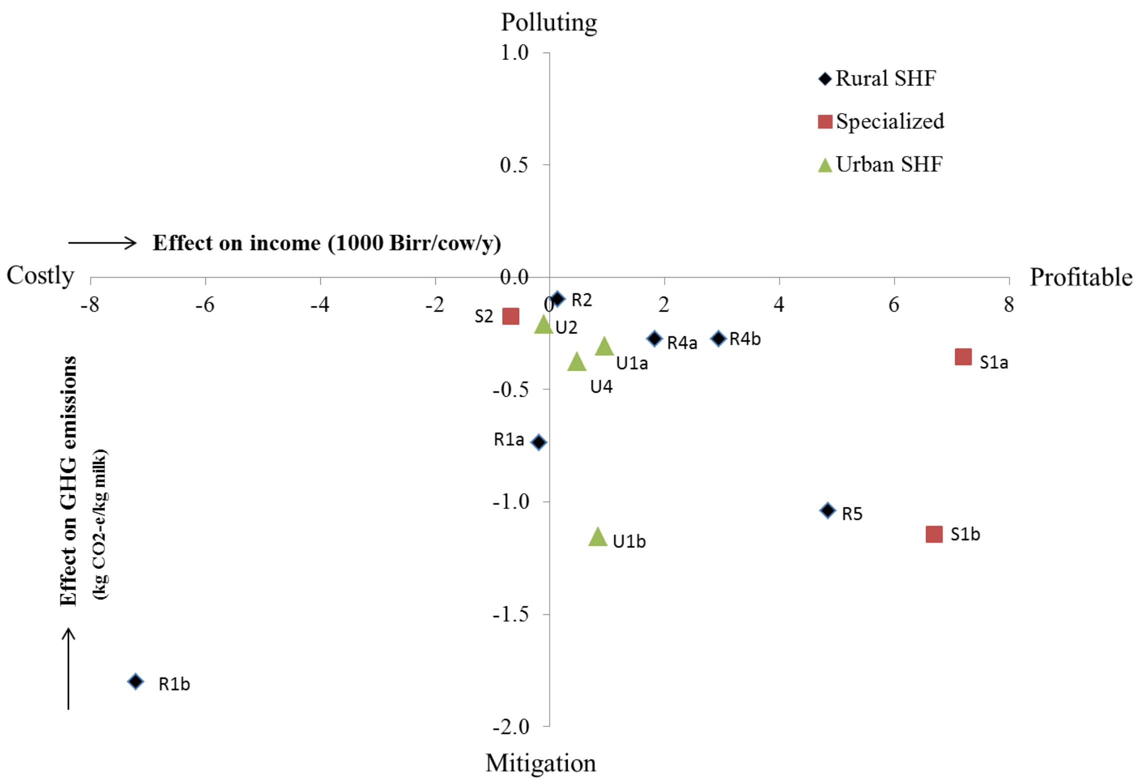

Figure 16: *Cost effectiveness of mitigation interventions for rural SHF (R), specialized farms (S) and urbans SHF (U).*

Interventions are: increased use of concentrate feed (1a), improved digestibility of forage (1b), improved utilization of animal manure (2), replacing unproductive females (4a), increased crossbreeding (4b), and replacing adult males by mechanization (5).

5.3 Climate Change Resilience Indicators

Potential adaptation actions were focussed mainly on: 1) general improvement of farming practices, and 2) reducing risks of limited resource availability and environmental degradation, 3) dairy value chain losses:

- General improvement of crop and livestock production practices can contribute to climate adaptation due to improved resilience of animals and increased farm productivity and income (Bryan et al., 2011). Improvements should lead to animal and economic buffers for periods of resource scarcity. General improvements for livestock production are related to dairy cattle feeding, breeding and health management.
- Reducing risks of limited resource availability, i.e. feed and water, can be realized through both on-farm and off-farm solutions for appropriate storage to avoid feed losses, conservation of feed (e.g. drying or making silage), and resilient crop production techniques (e.g. diversity of crops and forages, climate resilient crop varieties). Technical solutions should be accompanied by a feeding plan to anticipate on seasonal variations in feed supply, e.g. ensuring a buffer of 25% extra feed.
- It has been shown in the mitigation section that the development of a professional value chain can reduce post farm-gate losses from about 10 – 15% to about 4 – 6%. This highly depends on the fraction of the milk sold to professional processors. With the goal to increase national milk production by about 100 %, this step can have a significant contribution.

A complete list of potential adaptation actions and related climate resilience indicators for Ethiopian dairy value chains is in Table 12, listed per stage in the life cycle of dairy products. Implementation of technical adaptation actions in Table 12 requires establishment of an enabling environment, such as cooperative solutions for storage or transport, infrastructure, and extension and veterinary services.

Table 12:
Potential adaptation options and indicators for climate resilience relating to crop-livestock interactions in dairy value chains.

Life Cycle stage	Adaptation option	Climate resilience indicator
Upstream	Off-farm conservation of roughage as a buffer for seasonal variations in feed supply[1,2]	Conserved roughage (%) Proper off-farm feed storage facilities (y/n)
	Provide high quality concentrates	Quality control (y/n)
Soil	Apply mulching[1,2]	Mulching (% land)
Forage/crops	Feeding plan (1 year term) with cultivation scheme	Feeding plan (y/n)
	Alternative feeding plan for worst case scenario	Alternative feeding plan (y/n)
	On-farm conservation of roughage as a buffer for seasonal variations in feed supply[1,2]	Conserved roughage (%) Proper on-farm feed storage facilities (y/n)
	Grow climate resilient fodder crop for livestock, and agroforestry practices[1,2]	Climate resilience of fodder crops grown (-), on-farm agroforestry (% in cattle diet)[5]
	Natural pasture management and improvement[1]	Climate resilience, yields, and nutritional values of natural pastures (-)
	Manage grazing optimally (e.g. avoiding overgrazing) to avoid vegetation degradation and weed invasion[1,2]	Optimal grazing (-)
	Diversity of crops and forages, and mixed swards[1,2]	Types of crops and forages, and variety of grass/legume species in grassland
Animals	General improvement of feeding and health[1], e.g. improved diets, veterinary services, and vaccines.	
	Selective breeding of livestock[1], e.g. heat and (novel) disease tolerant breeds[2]	Selective breeding for climate resilience as a trait
	Cooling (e.g. shade, water, ventilation) and water provision[2]	Shade/ventilation (y/n), sufficient access to water (y/n)[5]
Manure	Use of animal manure as fertilizer[1,2]	All animal manure is applied to crops (y/n)[5]
	Equipment for urine storage	Urine stored (y/n)[5]
Downstream	Reduced losses in value chain, e.g. cooling, increased storage capacity	Post farm-gate losses (%)

[1] Source: ATA climate CB analysis or focus areas Ethiopian Climate Resilience Strategy
[2] Source: AnimalChange (www.animalchange.eu)
[3] Source: key informant interview
[4] Source: focus group discussion
[5] Data was collected for this indicator in field survey among 64 farms

Potential Synergies between Mitigation and Adaptation Options

Improved milk production and improved reproductive performance will improve adaptation of dairy production systems, because in general, improved productivity increases resilience to climate change (Bryan et al., 2011). In a similar vein, increased use of exotic breeds or crossbreds to increase milk production per cow can increase resilience of systems to climate change (Bryan et al., 2011).

Reduced use of inputs for dairy systems will put less pressure on different resources, such as carrying capacities of land and water. Therefore, reduction of the pressure on feed resources by lowering the number of male cattle in the Ethiopian cattle population can contribute to increased resilience of dairy farms.

Land application of manure can enhance mitigation of environmental impacts and contribute to climate adaptation of land-based dairy farms trough improvement of soils. From the mitigation side, manure management technologies can produce energy, enhance effective nutrient management, and reduce GHG emissions during storage and field application. With regard to adaptation, manure nutrients are gratis and help to improve soil fertility and water-holding capacity, and avoid wind and water erosion.

Potential Trade-offs between Mitigation and Adaptation Options
The increased use of inputs for improved (re) productive performance will put a greater pressure on different resources, such as carrying capacities of land and water. Degraded lands are a threat to food and feed production, and proper management of (grazing) land is needed to ensure yield improvement and reduce variability in yields. In addition, on-farm technical solutions to ensure efficient use of resources, such as feed conservation techniques and proper nutrient management, will be needed to secure sufficient farm inputs on the long-term.

Resilient crops often have low digestible crop residues, which will increase environmental impacts when fed to animals. Therefore, in the selection of resilient crops, suitability of crop residues as feed for livestock should be considered.

Use of exotic breeds might be a threat to resistance of animals against a more variable climate, variations in feed quality and quantity, and novel diseases. These aspects should be considered when improving local genetics, e.g. through cross-breeding with heat and disease tolerant breeds.

5.4 Feedback from Stakeholders

The farmers' ranking of major problems and challenges for dairy production is presented in Table 13. Prioritization of entry points for mitigation strategies by farmers and key-stakeholders is presented in Table 14, and prioritization of actions for adaptation in Table 15.

According to farmers' group discussions and ranking on the importance of major problems/challenges, variation existed between farm typologies and regions. However, farmers in all regions and typologies mentioned the high price of formulated ration as highly important. As rain fed agriculture, where urban dairy is also indirectly affected by this, major problems are associated with feeds of animal. This is more pronounced in moisture stressed Tigray region, while in regions where moisture and feed availability is not a challenge, market outlets for their produce becomes the major challenge.

As outlined in Table 14, five categories of mitigation options which followed the LC stages were presented to farmers and stakeholders. Qualitatively, priority levels were given by farmers and stakeholders. Additionally, strategic bottlenecks that may hinder the implementation of each intervention were indicated. The result shows that farmers' opinion on the mitigation options might not necessarily be in line with scientific recommendations whereas stakeholders' opinion is in close agreement with the recommendations.

Results of the stakeholder workshop are summarized in Annex 8. Stakeholders proposed key implementers of the recommended interventions/sub-interventions, with additional interventions that were not proposed from this study. The list of interventions/sub-interventions, might be of help for various implementing organizations, in order to incorporate in their projects/programs and also to initiate further development projects/programs. This list of interventions might also help to give clear deliverables by various stakeholders, which also minimizes overlap among interventions. .

Table 13:

Farmers' perceived problems and challenges of dairy production in the four study regions.

Major problems	Level of importance in urban/peri urban areas of				Level of importance in rural areas of			
	Oromia	Amhara	SNNPR	Tigray	Oromia	Amhara	SNNPR	Tigray
Roughage feed availability	++	++	+++	+++	-	-	++	++
Formulated ration_availabilty					+	+++	+	++
Formulated ration_high price	+++	+++	+++	+++	+++	+++	+++	+++
Formulated ration_quality	-	+++	-	-	-	+++	-	-
Absence of improved forage seeds	-	-	-	-	++	+++	+++	+++
Shortage of land for expansion	+++	+++	+++	++	-	-	-	+
Current drought (serious effect)	-	-	-	+++	-	-	-	+++
Shortage of clean and adequate water	-	+	+	+++	+	+	++	+++
Inefficient AI service	-	-	-	-	++	+++	++	+++
Absence of livestock extension service	++	++	++	++	-	-	-	-
Inadequate vet service and drug provision	+	++	++	+	++	-	-	++
Lack of market for milk	+	+++	-	-	++	+++	++	+
Seasonal/fasting milk market	+	+	-	+	+	+	-	+
Lack of systematic waste/dung disposal system	++	+++	+++	++	-	-	-	-

Prioritization level (+++ highly important, ++important, + less important, and – refers not important)

Table 14:
Entry points for environmental mitigation interventions prioritized by farmers and key-stakeholders.

Aim	Mitigation interventions	Category	Life cycle stage	Priority level by farmers	Priority level by stakeholders	Strategic bottle necks
1: Improved feeding / increased milk production per cow						
Increase production per cow through improved management	Improved feeding, breeding, housing, supplementations, and health care	Genetics, animal health and nutrition		++	+++	Extension limited to rural farmers
	Increase off-take level (milk): rural SHF	Market development		+++	+++	Few processing plants exist- majority centering Addis due to infrastructure. Price and consumer awareness on commercial dairy products
Increase production of concentrate feeds to reduce low quality diets	Promote ration formulation from various feed ingredients	Industry/ Business development Crop sector	Upstream	+++	++	Tax systems, input prices
	Value chain development for molasses, food mill by products and oilseed cakes from the growing industries	Industry/ Business development Crop sector	Upstream	+++	++	
Increase use of high quality feeds	Promote on-farm forage development programs	Nutrition Natural resource Extensions	Feed	+++	+++	Land competition for crop agriculture. Availabilities of seeds that suit for all agro-ecologies, resources
	Crop residue treatments		Feed	+	++	
2: Improved breeding and reproduction						
Increase resource use efficiency and production efficiency	Reduce unproductive herds: in rural SHF	Genetics	Dairy herd	++	+++	Multiple livelihood functions of livestock.
	Reduce calving interval: in	Genetics	Dairy	+	++	Breed effect, and forage

	rural SHF		herd			availabilities
	Increase dairy type crossbreeding programs (AI service) in selected high potential areas: MS zones, proximate to market	Genetics	Dairy herd	+++	+++	Availability and cost of improved breeds, forage and management
3: Improved utilization of animal manure						
Improve nutrient and energy use efficiency through proper manure management	Establish waste disposal systems and use it in rural settings: urban dairy	Environment Energy	Manure	+++	+	Cost of investment and expansions
	Reduce cattle dung use for fuel by substitution of biogas and electric power : rural SHF	Energy Technology	Manure	++	+++	Cost of investment and expansions
4: Replacing oxen by mechanization						
	Increase off-take of male stock for meat (reduce oxen): rural SHF	Extension, Market development		+	++	To find cost effective and sustainable mechanization (investment at macro- and micro-level)
5: Reducing post farm-gate loss						
Reducing post farm-gate loss and promote dairy processing plants to increase milk off-take from producers	Market chain development	Business development	Down-stream	+++	+	Awareness of domestic consumers towards processed dairy products Power
	Milk quality and safety through proper cooling and processing systems	Livestock Dairy		++	+++	

Rating: +++ highly important, ++ important, + less important, - not important, **the adaptation/resilient strategies mainly applies to the rural farming systems that is particularly prone to climate change (esp. in moisture deficient regions)

Table 15:
Entry points for adaptation actions prioritized by farmers and key-stakeholders.

LC stage: Problem area	Interventions	Category	Priority level by farmers	Priority by stakeholders
Farm level: feed and water shortage due to drought and erratic rainfall	1. Expand water harvesting technologies:	Water and Soil	+	++
	2. Introduce and grow drought tolerant forage crops	Nutrition	+	+++
	3. Crop conservation programs based on weather forecasts		+	++
	4. Irrigated agriculture	Irrigation	+++	+++
	5. De-stocking and re-stocking programs during severe drought seasons	Livestock	++	++
Farm level: soil infertility and land degradation grazing area	6. Use of manure for compost production	Soil	+	++
	7. Avoid overgrazing, plan for stocking adjustment	Livestock	+	++
	8. Integrate forage production and conservation programs	Livestock, Natural resource	+++	+++
Farm level: low performance, mortality and health problems of cattle	9. Choice of adaptive breed and selective breeding programs for climate resilient	Genetics	++	+++
	10. Establish diseases surveillance and preventive methods	Animal Health	+++	+++
	11. Extension programs on housing designs, health and management	Livestock		
Downstream: product quality and safety	12. Establish, regulations, standards and control methods	Standard authority	-	++

Rating: +++ highly important, ++ important, + less important, - not important, **the adaptation/resilient strategies mainly applies to the rural farming systems that is particularly prone to climate change (esp. in moisture deficient regions)

6 General Discussion

Technical Remarks about the Analyses

In this study a limited number of mitigation scenarios were evaluated. The GLEAM model was customized to the Ethiopian context in this study, and can be used in future studies for evaluating environmental impacts of a variety of scenarios, for example for distinct farming systems and simulations in diet compositions.
The use of primary data in combination with Tier 2 (rather than Tier 1) analyses of livestock emissions was essential for a proper evaluation of mitigation options for the different types of farming systems. However, there are a few challenges that should be tackled in future to properly evaluate environmental impacts for the Ethiopian context using the GLEAM model:

- Increased quality of secondary data is needed for more accurate estimates of environmental impacts, especially for crop yields and inputs and detailed information about fertilizer use.
- There is a strong interaction between animal nutrition, manure management, crop production, health management, improved reproduction and the animal and farm productivity, supply to commodity chains, the farmer's income and emissions to the environment. On the farm, this will affect herd composition, production of milk, meat and live animals, and the feed requirements for these animals. These complex interactions could not be evaluated in the present version of the GLEAM model, because this is a static rather than a dynamic model, and interactions have to be assessed by the user.
- Improving the animal productivity is always a combination of good management practices, particularly feed quality and quantity and the genetic potential. This implies that the type and percentage of increase in higher quality feed or fodder used in this study should not be applied as a standard but only serves as theoretical evidence that feed improvements will contribute to a reduction of emission intensities and sustainable intensification. The local conditions (availability of feed materials, the animal's condition and potential) will define the best strategy for feed improvement. The use of general emission parameters is good enough to analyze emissions and mitigation options for Ethiopian livestock systems. The LEAP Guidelines and other methodological tools provide enough flexibility to provide reliable calculations for Ethiopian situations. Feed intake and feed digestibility are the key factors defining the enteric methane emissions and that the standard emission factor is higher with lower feed digestibility, due to the longer retention time in the animal's digestive tract. Relatively little variation has been found between breeds and production levels.
- This study showed mitigation pathways without taking care of the required actions that lie behind it. GLEAM has not been built or that purpose. It is important to explore the macro effects of some options and to develop an implementation strategy to realize the most promising mitigation options.

6.1 Key Findings and Recommendations for Concrete Actions

This study yielded baseline environmental impacts and entry points for mitigation of environmental impacts in three distinct Ethiopian dairy value chains, as well as prioritization of mitigation actions by farmers and stakeholders. An overview for the integral evaluation of mitigation interventions and mitigation actions for rural SHF, specialized farms and urban SHF is shown in Table 16.

Table 16:
Overview of effects of mitigation interventions on greenhouse gas (GHG) emissions, productivity, farm income, and climate resilience, and prioritized actions of farmers and stakeholders.

Mitigation intervention / action	GHG emissions	Productivity (animal protein)	Income	Resilience	Farmer priority	Stakeholder priority
1: Improved feeding						
– rural SHF	+ +	+ + +	+/-	+/-		
- specialized farms / urban SHF	+ + +	+ + +	+ +	+/-		
➢ Improved feeding, breeding, housing and animal health					+ +	+ + +
➢ Improved input supply of concentrate feed					+ + +	+ +
➢ Improved on-farm production of quality feed					+ + +	+ + +
2: Improved breeding and reproduction						
– rural SHF	+	+ +	+	+		
- urban SHF	+	+ +	+	+		
➢ Replace unproductive stock					+ + +	+ +
➢ Reduce calving interval					+ +	+
➢ Improved AI service					+ + +	+ + +
3: Improved utilization of animal manure						
– rural SHF	+/-	+/-	+/-	+ +		
- specialized farms / urban SHF	+/-	+	+/-	+		
➢ Organize waste disposal urban areas					+	+ + +
➢ Reduce use of dung for fuel					+ + +	+ +
4: Replacing oxen by mechanization						
– rural SHF	+ + +	+ + +	+ + +	+ +		
➢ Increase off-take meat (bulls)					+ +	+
5: Reducing post farm-gate losses						
– rural SHF	+ +	+	N.A.	+		
- specialized farms / urban SHF	+ +					
➢ Increased off-take by dairy processing plants					+ + +	+
➢ Improved cooling and processing systems					+ +	+ + +

Based on this integral evaluation, the following conclusions were drawn from the analyses in this report. Areas of mitigation interventions are listed in order of potential (highest to lowest) for reducing GHG emission intensity (a list of initiatives on this topic is in Annex 7):

➢ **Improved feeding**

Key findings: In all value chain typologies, improving the rations digestibility showed most potential compared to other interventions for reduction of GHG emission intensity. In specialized farms and urban SHF, this intervention had also most potential for increasing total farm milk production and farmer income. However, costs of increased inputs such as feed and fodders were considered a major constraint by stakeholders and farmers, which was confirmed by our analysis of cost effectiveness of feeding interventions in rural SHF. Improvement of quality of on-farm produced feed was prioritized by stakeholders and farmers, but competition with crop agriculture was indicated as a constraint.

Concrete actions in dairy value chain:

- Upstream: Promote ration formulation from various feed ingredients. Development of low cost compound feeds, based on agro industrial by products, assuring high quality. Value chain development for molasses, food mill by products and oilseed cakes from the growing industries. Feed trade will become increasingly important and trading agents should be aware of the quality of feed materials and provide good information about feed quality. The availability of an independent agency to analyse feed will be most helpful.

- On-farm: dairy support services for improved feeding practices, e.g. training, advisory and extension services, access to finance, and input supply. Besides improved digestibility, fodder varieties, fodder conservation, and formulation of balanced diets can help to improve animal productivity and at the same time reducing GHG emissions (Gerber, 2013). Good results have been shown in India with the Ration Balanced Feeding Program, based on available feed resources (Garg, 2013). Because of high feed costs, efforts to increase milk production through improved feeding should be directed at improving quality of feed and fodder production **on the farm** in land-based rural SHF and specialized farms, whereas they should be directed at promoting availability of high quality and affordable feed inputs **upstream** for landless specialized farms and urban SHF. Because there is little room to grow primary feed crops and crop residues are important as cattle feed, improvement of straw via urea (Virtanen method), physical treatment or fungi can offer possibilities for improved feed digestibility. There is ongoing research about the improvement of digestibility of wheat straw by using fungi. This is still done under laboratory conditions and not yet tested in the field. Wageningen UR is planning to test this under field conditions in the next years.
- Downstream: stakeholders in the commodity chain can play a role in the on-farm support services, as there are synergies in feeding, animal health and milk quality. It can also help to develop low cost strategies for milk production, keeping the milk at affordable prices.

Potential implementation organizations: priority of improving feeding was ranked high in the stakeholder validation workshop, especially for developing an efficient value chain for industrial by-products, ration formulation, supplementation, on-farm forage development, and crop residue treatment. Potential piloting and implementing organizations indicated were MLFRD, regional bureaus, LMD, EDGET, Cooperative Unions, Dairy CIG's, and youth groups. Potential financing organizations are in Annex 8.

Links with existing plans for action:

- Proposed mitigation interventions for improved feeding are in line with actions planned in Ethiopian agricultural transformation agendas. The Livestock Master Plan (LMP) envisions improved feeding in the improved family dairy (IFD) farms by increasing feed supplementation, improving pasture productivity (including communal land), increasing availability of seeds and cuttings, and trainings on feeding and forage production. In specialized systems, LMP envisions increasing quantity and quality of forage production by outsourcing improved forage production to non-dairy farmers and changing land use and investment policy to encourage large scale feed production. Also, a large number of activities proposed in the dairy cow investment implementation plan (FDRE, 2015) are directed at improved on-farm and off-farm feeding, such as formation of feed cooperatives for off-farm production of forages and supplements, and improvement of rangeland management. Improvement of management of rangeland and pastureland is also included in Ethiopia's Green Economy Strategy (CRGE, 2011).
- More generally, the Livestock Transformation Agenda includes a large number of planned activities that can be expected to contribute to mitigation of GHG emission intensities; improvement of animal health (e.g. improving veterinary services, disease control programs, and field animal health services), livestock genetic improvement and improved AI services, and actions for sustainable supply of quality feeds and fodders. It can be expected, therefore, that realization of activities in existing national agendas on livestock transformation will contribute to mitigation of environmental impacts of Ethiopian dairy value chains.

Potential risks for dairy systems:

- Rising costs for improved forage and seeds due to increasing demand.

➢ **Replacing oxen by mechanization and female stock in rural SHF**

Key findings: In rural SHF, replacing oxen by mechanization and female stock showed high potential for reduction of GHG emission intensity, as well as for increasing total farm milk production and farmer income. This intervention may also contribute to climate resilience of dairy value chains due to a reduction in the number of cattle at the population level and reduction of pressure on limited (feed and water) resources. However, stakeholders and farmers were concerned about costs and long-term availability of mechanization, which will require investments and good organization at macro- and micro-level. Besides this, insufficient off-take of milk and meat was considered a threat in rural areas, which could lead to insufficient returns from investments.

Concrete actions in dairy value chain:

- Upstream: catalyse mechanisation technologies production (already on Transformation Agenda); facilitate mechanisation infrastructure; stimulate sufficient availability of pregnant crossbred heifers at markets to replace oxen;
- On-farm: promote use and guidance on mechanization, e.g. education/trainings, promotion, and pilot farms;
- Downstream: stimulate development of milk and beef/live animals markets for increased off-take.

Potential implementation organizations: priority of replacing oxen by mechanization was ranked low in the stakeholder validation workshop, whereas improving off-take of meat from male stock and reducing idle time of oxen were ranked higher. Potential piloting and implementing organizations indicated were government (MoA and MoLF), Agri mechanization, private sector enterprises and NGO's. Potential financing organizations are in Annex 8.

Links with existing plans for action:

- Development and roll out of a sustainable agricultural mechanization supply chain and service provider model is on the Agricultural Transformation Agenda for mechanisation. The CRGE Agricultural Strategy plans to introduce mechanical equipment for ploughing/tillage that could substitute around 50% of animal draft power (CRGE, 2011).

Potential risks for dairy systems:

- High investments costs;
- Low availability of materials and knowledge for maintenance of machines, and fuel;
- Insufficient rural market demand compared to increased milk production and meat from male calves.

➢ **Reduced post farm-gate losses**

Key findings: Shifting from home processing of milk products and selling fresh milk on local markets towards selling milk to industrial processors reduced GHG emission intensity and energy use. This was especially due to the reduction of post farm-gate losses, but also because industrial processing was considered less polluting due to the use of electricity instead of charcoal or firewood. Opportunities to reduce post farm losses highly depend on the future developments of the commodity chain, and might differ per region. In rural areas, where development of urban markets will be limited and local markets remain important, a small scale "cold chain" might reduce post farm-gate losses in direct sales and in home processing. (Bio) gas driven refrigerators or power supply by solar or wind power might solve these problems, although investments in equipment can be a barrier. Training of farmers in improving processing is another option. A series of opportunities is given by the Postharvest Education Foundation (2013). In the case of the development of an urban (or urban-like) market, dairy coops have to invest in the development of local milk collection centres and frequent chilled transport to processing factories.

Concrete actions in dairy value chain:

- Upstream: enhance provision of equipment and energy for milk chilling, such as (bio) gas or power grid (renewable energy) for refrigerators, in rural areas;
- On-farm: trainings of farmers on improved milk storage and processing;

- Downstream: catalyse industrial processing milk in (peri) urban areas, in combination with milk collection centres and frequent chilled milk transport; enhance off-take of industrial processed products.

Potential implementation organizations: priority of reducing post farm-gate losses was ranked moderate in the stakeholder validation workshop, especially for promoting consumption of dairy products and improving milk quality and safety. Potential piloting and implementing organizations indicated were cooperatives, government (MoLF, MoI, MoH, MoT), EFMACH, donor projects and private sector. Potential financing organizations are private sector/processors, government, donors, and banks.

Links with existing plans for action:

- Plans for construction of additional processing plants are part of the Livestock Master Plan (LMP) and the dairy cow investment implementation plan (FDRE, 2015), aiming at 12 additional fresh milk processing plants and 2 milk powder processing plants around large cities, as well as provision of rural infrastructure (e.g. electricity and roads). The FDRE program also includes actions for improving milk off-take and increasing awareness on importance of milk quality.
- SNV-EDGET (Enhancing Dairy Sector Growth in Ethiopia, funded by the Embassy of the Kingdom of the Netherlands) provides (power grid) refrigerators for primary rural dairy processing cooperatives in 51 woredas in Oromia, Amhara and SNNP regions and provides training, coaching and equipment for improved milk storage and processing. AGP-LMD (Livestock Market Development, funded by USAID), supports through a grant program, investments in industrial dairy processing, chilled milk transport, as well as the roll out of 100 Milk Collection Centers with chilling tanks. Training and coaching is provided on improved milk storage and processing.

Potential risks for dairy systems:

- Returns on investment / milk price; Selling almost all milk to a professional processor may reduce the price of milk compared to a farmer selling it. In the first case, all of the milk can be sold and post farm losses are the processor's responsibility, whereas the latter leaves the risk of post farm loss at the farmer. It is not easy to say what the net result will be, and much depends on the fraction of the market price that is paid to the farmer. Indian dairy cooperatives are able to pay up to 75 – 80 % of the consumer price to the farmer. Beside the financial aspect, much labour becomes available at the farm, which can be used in an alternative way. For example, it is known from surveys that labour is an important constraint in manure management. Such constraints could be solved by reducing labour for processing milk. However, when there is no alternative employment on or outside the farm, there is little prospect to create added value.

➢ **Improved breeding and reproduction**

Key findings: Though less effective than other mitigation interventions, improving herd reproductive performance showed potential to reduce environmental impacts in rural SHF, was a cost effective intervention, and was expected to increase farmer income. Moreover, implementation of interventions for improving herd reproductive performance was considered feasible by stakeholders and farmers, especially the replacement of unproductive female adults and improved cross-breeding programs.

Concrete actions in dairy value chain:

- Upstream: stimulate sufficient availability of pregnant heifers at markets to replace unproductive stock;
- On-farm: improve AI service; promote replacement of unproductive stock; reduce calving interval through extension on reproduction management (e.g. heat detection). There is a clear link between feeding management and animal fertility. Improved feeding is a prerequisite for good reproductive performance.

- Downstream: stimulate development of milk and beef/live animals markets for increased off-take.

Potential implementation organizations: priority of improved breeding was ranked very high in the stakeholder validation workshop, especially for increased crossbreeding in high potential areas and improved bull stations. Potential piloting and implementing organizations indicated were NAIC, MLFRD, regional bureaus, EAIR, ALPPIS, RARIs, Heifer International, Private sectors, PAID, and ADGG. Potential financing organizations are GTP2, and microfinance institutions.

Links with existing plans for action:

- A large number of planned activities directed at livestock genetic improvement and improved AI services are included in the Livestock Transformation Agenda and dairy cow investment implementation plan (FDRE, 2015), whereas replacement of unproductive stock has not received much attention in existing agendas. The dairy cow development roadmap in the Livestock Master Plan (LMP) envisions an 8-fold increase in the number of crossbred dairy cattle in improved family dairy systems in the MRS zone towards 2020. Improvements in genetic potential in LMP will be realized through improving AI services and improving young stock management, combined with integral improvements of feeding, animal health, marketing, and policy. The present report showed that these activities will likely contribute to mitigation of environmental impacts, though the extent of impact might differ as changes in production parameters envisioned in the LMP are not the same as those in this report. To know effects of these activities, monitoring and quantitative evaluation of environmental impacts during the transition of dairy production systems will be valuable.
- LMP also envisions large increases in crossbred cattle in specialized systems. Effects of increased crossbreeding were not calculated for these systems in the present study because the proportion of crossbred and exotic cows was already high in surveyed farms.

Potential risks for dairy systems:

- Insufficient availability and high market prices of heifers.

- **Improving utilization of animal manure as a fertilizer.**

Key findings: Manure is not a very large contributor to GHG emissions, but has a high potential to increase fodder and animal productivity. In addition, we estimated that approximately 40% of cattle manure was used as dung cake for fuel across farm typologies. This implies a large amount of valuable nutrients is lost from farm and regional nutrient cycles, thus reducing the potential fodder and animal productivity if not substituted by artificial fertilizer, besides negative human health effects of burning dung cakes. Reducing the use of animal manure for fuel requires that alternatives are promoted, such as (bio) gas or electricity, in combination with training on good manure management. Biogas production also contributes reduced GHG emissions due to reduced use of firewood and deforestation (e.g National Biodigester Programme Ethiopia (NBPE - II); Global Methane Initiative, 2011) while at the same time slurry from the digester can be utilized as organic fertilizer, replacing more expensive chemical fertilizer (Bonten et al., 2014).

While rural systems are threatened by depletion of nutrients, nutrients might quickly accumulate in urban and peri-urban dairy farms when animal manure is not burned for fuel, leading to pollution of ground water and public health risks in these areas. Given the lack of land in (peri-) urban dairy farms, solutions are needed to organize the use of animal manure as a fertilizer in areas with crop production, such as marketing and transporting manure, and improvement of on-farm manure management.

Concrete actions in dairy value chain:

- Upstream: As feed is partly supplied by external partners, these should accept manure in exchange for feed to replenish nutrients and organic matter. This requires knowledge about fertilizer value of manure, application rates and the technology for transport.
- Farm: To improve manure management, simple investments can already be very helpful. Construction of watertight floors and roofs is essential to reduce leaching losses of nutrients. Urine becomes an important nutrient source when animal nutrition is improved, which means

that storage of urine will save a lot of potassium and nitrogen and can be a good fertilizer. This however, requires special equipment.

To reduce burning of dung for fuel, alternatives sources of energy should be promoted such as biogas. Larger size bio-digesters can be realized in medium scale commercial dairy farms, for biogas to be used for milk processing (chilling, boiling, etc.) as well as for electricity generation and replacement of diesel from diesel generators or kerosene from households in the vicinity. Utilization of bio-slurry is often not incorporated in biogas projects, whereas this fertilizer has more readily available nutrients than manure (Bonten et al., 2014). Training material on manure management has been developed for extension workers for training courses in Malawi, Ethiopia and South East Asia, coupling biogas production and utilization of bio-slurry as a fertilizer (Teenstra et al., 2015).

- Downstream: proper manure management is related to on-farm hygiene and affects milk quality and food safety. Commodity partners should scrutinise their milk suppliers and give advice.

Potential implementation organizations: priority of improving manure management was ranked moderate in the stakeholder validation workshop, especially for increasing use of bio-digesters, composting of bio-slurry, and marketing of manure products. Potential piloting and implementing organizations indicated were MOWIE, MOLFRD, MOANR, and regional bureaus. Potential financing organizations are EU and DGRIS.

Links with existing plans for action:

- Proposed interventions to improve manure management are in line with actions planned in the Agricultural Transformation Agenda on soil health, i.e. to identify best combinations of organic, inorganic and bio fertilizers and cropping practices to enhance nutrient supply, storage and availability. Involving cattle manure management in the soil health agenda can offer opportunities to promote utilization of the valuable nutrients and organic matter in cattle manure.
- Activities for promotion of forage production and trade in the Livestock Master Plan may offer possibilities for simultaneous facilitation of manure trading and utilization by forage producers. This should be combined with practical solutions for manure handling and transport, such as manure treatment on dairy farms previous to transportation.

Potential risks for dairy systems:

- The issue of land rights might refrain farmers from applying animal manure on grazing land.

7 Conclusions and recommendations

This study showed that three categories of interventions contributed to reduction of environmental impacts of Ethiopian dairy value chains:

- Improving productivity of dairy herds in terms of milk and meat, both at animal and herd level. Interventions include improvements in feeding, breeding, herd composition, health and housing, and are mainly focussed at increased specialization and professionalization of the dairy value chain. This study showed that improvements in feed quality were most effective in terms of reduction of greenhouse gas emissions per unit of product. All other mitigation options tested were effective in reducing environmental impacts.
- Professionalization of the post farm-gate dairy value chain to reduce milk losses.
- Improving nutrient use efficiency for sustaining dairy production in the long term.

Key recommendations for greening of Ethiopian dairy value chains are:

- Improve quality of feed rations, especially digestibility, for specialized farms and urban SHF;
- Promote on-farm production of high quality forage and crop residues in rural SHF, as purchasing feed is too expensive for rural farmers;
- Replace oxen by mechanization and female stock in mixed systems;
- Reduce milk losses in post farm-gate stages of the commodity chain (transport, processing, and selling);
- Replace unproductive female animals with young productive females;
- Increase crossbreeding through improved AI services;
- Reduce the use of dung cake for fuel, and promote biogas as an alternative source of energy and animal manure / bio-slurry as a fertilizer;
- Promote manure management and selling of manure as a fertilizer in urban and peri-urban farms to prevent accumulation of manure;
- Provide a good enabling infrastructure and market orientation for specialization of dairy farms.

7.1 Position of the Technical Study in the Livestock Sector Development

The current analysis clearly showed effective mitigation pathways in the improved animal productivity in milk and meat. However, mitigation scenarios were based on theoretical assumptions for improvements in dairy value chains. To deal with the complexity in practical situations and to give more detailed recommendations for a range of situations, monitoring of real changes in herd and animal performance is needed to evaluate and simulate effectiveness of specific mitigation interventions in the different farming systems and locations. Evidence-based reporting will be needed to prove effects of interventions on realized emissions, productivity gains, and nutrient cycling in practice. Transformation of dairy systems should be supported in an evidence-based way.

The study has delivered a set of technical recommendations. Some of these recommendations can be easily implemented within the existing framework of improving dairy production in Ethiopia. This holds especially for improved feeding and manure management.
As feed has shown to be a key factor in productivity, a strategic exploration of feed resources in Ethiopia can provide insight in the potential of feed improvements under current conditions. An additional analysis can provide insight in future feed resource availability under climate change and explore scenarios for resilient and low-emission feeding strategies. The manure management improvement is a combination of the development both bio-digesters and manure storage facilities to utilise both the energy and fertilizer value of manure.

The other mitigation options, being the mechanisation, the change in the post farm chain and the changes in herd structure by replacing infertile and traction animals, can be characterised as a transformation towards more market oriented and specialised dairy production systems. The increase in milk demand, combined with the need to mitigate emissions, requires concerted actions in the whole dairy value chain. This is not only a matter of technical extension to farmers, but requires the involvement of other stakeholders to shape or improve the new parts of the dairy value chain, such as a sustainable supply and maintenance chain for mechanisation and processing facilities, transport, road infrastructure and access to an electricity grid for development of the post farm chain. An important condition of the development of the dairy value chain is that the improvements contribute to the added value creation and will have a positive revenue on its own. Only in this way, a sector can be viable and integral sustainable.
It is known from innovation processes in the livestock sector and industrial sectors, that the development of a business case and having the right stakeholders on board are the decisive success factors, and not technology.
Many of the current projects in the livestock sector have experience with this type of approach for successful adoption and innovation, Harvesting these experiences and building this to knowledge about innovation processes under Ethiopian farming systems and conditions will contribute to sector transformation.
Transformation processes take time and a good monitoring and evaluation program has to be put in place. This will help to monitor progress and adjust the strategy when necessary.

Transformation already takes place, as shown by the presence of specialised peri-urban and urban dairy farms with little or no land, having a different herd structure compared to smallholder farms and a strong market orientation. These farms and their management can in part be considered as frontrunners in the transformation. At the same moment,the development of a specialised landless dairy (sub)sector can be a threat to the environment and public health if waste is not managed properly as nutrients can accumulate quickly in these systems. At the same time, a lack of nutrients and organic matter can cause degradation of soils where feed for these systems is produced. A regulatory framework has to be developed to steer the intensification of the dairy sector in a sustainable way.

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