



Environmental impact of milk production across an intensification gradient in Ethiopia



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ABSTRACT

This paper quantifies environmental performances of milk production systems differing in degree of intensification in the Mekelle milkshed area, Ethiopia. Life Cycle Assessment (LCA) methodology was used to estimate Land Use (LU), Fossil Energy Use (FEU) and Global Warming Potential (GWP) of the cattle sub-system in 8 large-scale, 8 (peri-)urban and 8 rural farms. The large-scale farms owned considerably more and other types of cattle (35.0 cattle units (cu); mainly Friesians) than the (peri-)urban (6.3 cu; mainly crossbreds) and rural farms (4.1 cu; mainly local breeds). The milk production per average cow per year was much lower in rural farms (730 kg) than in large-scale (2377 kg) and (peri-)urban farms (1829 kg). Milk was the main contributor to the economic benefits of the large-scale (90%) and (peri-)urban (80%) farms, whereas milk (sold and consumed at home) contributed only about 40% to the economic benefits in the multifunctional rural farms. The environmental impacts per cu, reflecting the absolute impacts of cattle keeping, were considerably higher in the large-scale and (peri-)urban farms than in the rural farms. LU and FEU were for the great majority caused by the land use for hay, straws and grasses, and harvesting, transport and processing of feeds, in particular wheat bran. On-farm emissions from enteric fermentation and manure storage were the main contributors to GWP. The impacts per kg milk did not differ significantly between the three systems. The LU per kg milk estimates (9.4, 11.2 and 8.8 m² in the large-scale, (peri-)urban and rural farms, respectively) were relatively high compared to LCA studies of milk production in developed countries due to large amounts of low-quality forages and wheat bran fed, whereas the FEU values per kg milk (7.5, 11.1 and 6.6 MJ in the large-scale, (peri-)urban and rural farms, respectively) were relatively low compared to studies of milk production systems in developed countries. The GWP estimates per kg milk (1.75, 2.25 and 2.22 kg CO₂-equivalents per kg milk in the large-scale, (peri-)urban and rural farms, respectively) were slightly higher than GWP values for the same types of farms in other developing countries, due to the relatively large amounts of low quality feeds fed. The quality of cattle management practices seems more important than the choice for a specific cattle keeping system in reducing environmental impacts of milk production.

1. Introduction

A large volume of explorative studies at regional and whole continent levels indicates that environmental impacts per unit animal source food are highest in livestock systems in developing regions and lowest in large-scale systems in developed regions (e.g. Steinfeld et al., 2006; FAO, 2010; Herrero et al., 2013; Gerber et al., 2013). The before-cited studies propose intensification through improving feed qualities, using more productive breeds, improving management practices, and so reducing animal numbers to produce the same amount of animal source food, to mitigate detrimental effects of livestock on the environment, in

particular on climate change.

In developing countries, large numbers of smallholders keep livestock in support of their livelihoods. The recommendations to reduce the environmental impact of their livestock are also expected to improve their livelihoods (Steinfeld et al., 2006; Herrero et al., 2013; Gerber et al., 2013). However, smallholder farmers often lack sufficient capital, land, labour or feed resources for the intensification practices, or these practices and keeping less animals do not fit their sociocultural reality (Owen et al., 2011; Herrero et al., 2015; Udo et al., 2016). A relatively successful intensification strategy for smallholders is dairying based on European breeds or crossbreds. It contributes to increased

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household incomes and an increased market share for smallholder milk producers, although it does not match the resources of the poorest rural households (McDermott et al., 2010; Udo et al., 2011). Many countries promote smallholder dairy production as well as market-oriented specialised dairy farms to meet the increasing demands and to reduce imports of dairy commodities.

Evidence from field studies on how intensification of dairy production in developing countries affects environmental impacts is limited and contradictory. Life Cycle Assessment (LCA) is commonly used to evaluate the environmental impact of all processes in the life cycle of a specific animal source food. LCA results of field studies vary with the specific differences in farming practices due to ecological and socio-economic conditions and with the methodological choice as most notably posed by allocation of impacts to physical products only, or allocating these impacts to all functions livestock have in local communities (Weiler et al., 2014). In Peru, Bartl et al. (2011) found about 4 times as high carbon footprints per kg milk produced in roughage-only and low productive milk production systems in Andean Highlands compared to coastal more productive systems. Weiler et al. (2014) and Garg et al. (2016) found that if one allocates greenhouse gas (GHG) emissions to the various livelihoods functions of the animals, GHG emissions per kg milk in smallholder dairy systems in Kenya and India, respectively, were comparable to GHG emissions per kg milk in developed regions.

Studies at local levels are needed to assess whether local intensification strategies contribute to improved environmental performances of livestock systems. In Sub Saharan Africa (SSA), Ethiopia is a prominent country with regard to promoting intensification of milk production to meet the increasing demand. The Ethiopian Livestock Master Plan expects a substantial increase in national milk production over the period 2015–2020 as a result of providing quality feeds, improved extension and health services and crossbreeding by using semen of European dairy bulls (Shapiro et al., 2015). The proposed strategies are expected to create opportunities for market-oriented specialised dairy farms (Wouters and van der Lee, 2010; Land O'Lakes, 2010).

Ethiopian cattle production systems are classified into four different categories: large-scale, urban and peri-urban (here described as (peri-)urban), rural, and pastoral systems. These systems differ in production objectives, types of animals kept, availability of feed, and land and capital resources (Redda, 2001; Yilma et al., 2011). The large-scale system involves institutional farms and private companies. Their high-grade Friesian cattle are stall-fed. Milk production is for the market. The (peri-)urban system comprises smallholders located in and around urban areas. These smallholders primarily keep crossbred cattle for milk production (Ahmed et al., 2003). Milk is directly sold to consumers (Redda, 2001). Feeds are mainly purchased fodders and concentrates. Large-scale and (peri-)urban systems comprise only 2% of the total milk production (Tariku, 2006). The rural system produces the great majority of the milk. It can be found in most highlands. Rural smallholders not only keep cattle to produce milk for the market but also for home consumption; added to this cattle support crop production via manure and draught power, give ready access to money when an animal is sold, and are a security for future financial needs and for asking assistance from fellow farmers when needed (Behnke and Metaferio, 2011). The rural system is dominated by local *bos indicus* breeds. Feeding depends on grazing communal pasture land and supplementation with crop residues. The traditional pastoral cattle system is multifunctional, milk is for home consumption, and communal pasture land provides the bulk of the feed (Tonamo, 2016).

Cattle, are a main contributor to GHG emissions in Ethiopia; by means of their enteric fermentation and manure management they contribute 45% to the total methane emissions of 52 MT CO₂-equivalents (Anonymus, 2011a). Enhancing intensification is expected to have large mitigation potential. Are more intensive dairy systems indeed beneficial for the environment? This paper quantifies environmental performances of the three production systems (large-scale, (peri-)urban

and rural systems) that produce milk for the market in the Mekelle milkshed area in Ethiopia. These systems represent different steps in intensification of dairying in Ethiopia. The pastoral system is not included in this study as it is not producing milk for the market.

2. Materials and methods

2.1. Approach

This study applied the LCA methodology. An LCA starts with the specification of the goal and scope of the study which includes the definition of the system and the system boundary, the Functional Unit (FU) to which environmental impacts are allocated, the applied allocation principles, and the impact categories to be evaluated. Then LCA quantifies the resources consumed and the emissions to the environment in a product's life cycle (inventory analysis). Next, LCA evaluates the contribution of these resource consumptions and emissions to relevant environmental impact categories (impact assessment) (ISO, 2006).

The LCA of milk production in large-scale, (peri-)urban and rural cattle farms was based on the inventory of all processes related to cattle keeping up to farm gate, including the animals (enteric fermentation and manure storage), forages and feed supplements used, feed production and transport, and the different products of cattle keeping. Emissions of manure were assigned to the cattle sub-system of the farms during time of storage (8 months) on the farm. Thereafter, manure is used for the crop sub-system on the own farm, sold, or used as fuel.

Impact assessment was based on two FUs: a) 1 adult cattle unit (cu), and b) 1 kg of milk produced by a cow. A cow (lactating or dry) or an adult bull represented 1 cu, a heifer or young bull accounted for 0.7 cu and a calf for 0.2 cu. The environmental impacts per cu reflect the absolute impacts of keeping cattle, whereas the environmental impacts per kg milk reflect the impact of the production of milk.

The inventory analysis comprised the input and output data collection and processing for each activity in the cattle production system. Economic allocation was used to allocate the environmental inputs and outputs from the inventory analysis to the various outputs from the cattle based on the economic values of these outputs.

The impact categories considered were land use (LU), fossil energy use (FEU) and Global Warming Potential (GWP). LU represents the common concern that livestock systems occupy a considerable part of the terrestrial surface area and that the arable land base cannot be expanded (Yilma et al., 2011; Cook et al., 2015). LU is a main driving force behind biodiversity loss (Baan et al., 2013). FEU represents the concern that fossil energy gets exhausted, furthermore farmers face great difficulties in access to energy services (Best, 2014). GWP represents the general concern about climate impact of livestock through emission of greenhouse gases. The main greenhouse gases related to cattle keeping are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Emission of CO₂ results from the combustion of fossil energy to power machinery such as generators or harvesters. CH₄ results mainly from enteric fermentation and manure management. N₂O results mainly from manure management. Eutrophication and acidification as impact categories were not included in the present study; although they are widely used impact categories in LCAs of animal source foods produced in industrialised systems they were considered less relevant for the cattle keeping situation in Ethiopia. Other impact categories, such as ecotoxicity, human toxicity or ozone layer depletion are generally not included in LCAs of milk production due to limited data availability or limited impacts found in specific studies (Berlin, 2002; Hospido et al., 2003; Yan et al., 2011).

2.2. Study area

The study area was the Mekelle milkshed area. Mekelle is the capital of the Tigray region, located in the Ethiopian Highlands, approximately

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