Carbon footprint of cows’ milk: a case study of peri-urban and urban dairy farms within Mekelle milk-shed, Ethiopia

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\section*{Abstract}
In Ethiopia, there is an urge to enhance milk production where urban and peri-urban farms play important role. Therefore, the role of such production system in Greenhouse gas (GHG) emissions should be known. This study was conducted with the objective of estimating the carbon footprint (CF) of milk within Mekelle milkshed, Ethiopia. 50 urban and 42 peri-urban dairy farms were selected randomly and both primary and secondary data was collected. Lifecycle Assessment (LCA) approach was employed to quantify GHG emissions using cradle to farm gate approach. The mean GHG emissions per cattle unit (000 kg CO\textsubscript{2}-e y\textsuperscript{-1}) were 2.84 ± 1.23 and 3.19 ± 1.99 for peri-urban and urban farms, respectively. The share of enteric fermentation was 75.5% and 73.6% for peri-urban and urban farms, respectively. Milk contributed for 88.5% and 90.8% to the economic value of peri-urban and urban farms, respectively. Overall, the CF of milk production in urban and peri-urban farms was 2.2 kg CO\textsubscript{2}-e/kg and 3.2 kg CO\textsubscript{2}-e/kg without economic allocation, and 2.0 kg CO\textsubscript{2}-e/kg and 2.8 kg CO\textsubscript{2}-e/kg with economic allocation. In order to reduce GHG emission intensity from dairy farms it is important to adopt climate smart dairy practices.

\section*{Introduction}
Globally the livestock sector contributes 14.5% of global Greenhouse Gas (GHG) emissions, driving further climate change\cite{1}. In Ethiopia alone, the sector is an enormous contributor for climate change through emission of GHGs, generating 65 million tons Carbon Dioxide equivalent (CO\textsubscript{2}-e) (43.3\% of emissions in 2010) GHG, and is predicted to contribute 124 million tons in 2030 \cite{2}. From the livestock sector, meat and dairy sector is reported to be an important source of GHG emissions \cite{1, 3}.

Greenhouse Gas (GHG) emissions amount to 2.4 kg CO\textsubscript{2}-e per kg milk at farm gate (including emissions for transport and processing). It ranges from approximately 1.5 kg CO\textsubscript{2}-e per kg milk in Europe and North America to 7.5 kg CO\textsubscript{2}-e per kg milk in Sub-Saharan Africa. The very high carbon footprint (CF) of milk in Sub-Saharan Africa is mainly due to low milk yield (less than 500 kg per cow per year), poor husbandry practices, poor quality feed, and a high age of cows at first calving \cite{1, 4}.

In developed countries, where there are dairy oriented production systems, the production of milk is the most important function of dairy cattle \cite{5}. However, in developing counties like Ethiopia, dairy cattle could have additional functions: a buffer role in case of emergencies, as a source of food or income when cash is needed, a symbol of social status and as insurance. Furthermore, cattle manure can be of high value for usage in crop production and as fuel, while dairy animals can be a source of energy as draught animals \cite{6}.

Dairy animals release GHGs during digestion of feed with further emissions during handling of their manure. GHGs from dairy farms include carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}) and nitrous oxide (N\textsubscript{2}O). Emissions are very dependent upon farm management, the climate and other factors, so large differences can occur among farms \cite{7}. As a result of growing concern over GHG emissions, a need arose for expressing the total emission associated with a product. The term referring to this

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quantification is the CF which originated from a methodology known as the ecological footprint [8]. A CF is the net GHG exchange per unit of product which is best determined through a life cycle assessment (LCA) that includes all important emission sources within the production system as well as those associated with the production of resources used in the system [7]. Lifecycle assessment 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 could have in local communities [9].

The principles of LCA are usually applied to assess the environmental impact of a product [10]. This enables to identify where in the life cycle the main environmental burden occurs, i.e., identification of ‘hot spots’. In this way, it is possible to analyze where the largest reductions can be achieved. In the dairy value chain, raw milk is the food item most frequently assessed [11] since the greater part of GHG emissions for dairy products originates before farm gate [4].

Several studies at regional and continental level indicated that environmental impacts per unit of animal source food are highest in livestock systems in developing regions and lowest in large-scale systems in developed regions [12–14]. However, [9] and [15] reported that if one allocates GHG emissions to the various functions of dairy cattle, emissions per kg milk in smallholder dairy systems in Kenya and India, respectively, were comparable to GHG emissions per kg milk in developed regions.

In Ethiopia, urban and peri-urban dairy farming are important components of the milk production system contributing immensely towards filling the large demand-supply gap for milk and milk products in urban centers where consumption of milk and milk products are remarkably high [16]. Rapidly increasing population size with a growing rate of urbanization is driving the growth in demand for dairy products [5]. As a consequence of this, there is an urge from policy makers to enhance milk production. However, this could lead to a rise to GHG emissions [17] if climate smart dairy practices are not implemented. According to the Climate Resilient Green Economy (CRGE) strategy of Ethiopia [2] the emission intensity from the livestock sector should be cut significantly and it is indicated that this sector has 1/5th of the mitigation potential of the country. Among livestock, cattle took the lion’s share of the emission and working in this sector in general and the dairy sector in particular is expected to have a significant mitigation potential [18]. This requires understanding the current status of GHG emission from different dairy production systems and reduces GHG emissions from dairy products towards a more sustainable dairy sector.

So far there are few studies on GHG emission intensity of milk production in Ethiopia [6, 19, 20] with various assumptions and methodologies. Such kind of studies show the gaps and existing potentials in the sector to reduce the carbon footprint of milk in the different production systems by adopting climate smart farm practices [21]. Ref. [20] studied the environmental impact of milk production across an intensification gradient around Mekelle where they compared the global warming potential per kg of milk among specialized, (Peri-) urban and rural dairy farms. However, it did not show the global warming potential for peri-urban and urban farms separately and considered very few numbers of farms. As CF could have variations between farms with different management systems [22], the peri-urban and urban farms should be assessed separately.

This study was therefore conducted in Mekelle milk-shed, which is one of the major eight milk-sheds in Ethiopia. Tigray region is projected to have a big jump in urbanization from 19.5% in 2007 to 42.7% in 2037 [23]. As a result, it is expected that market-oriented peri-urban and urban dairy farms will increase significantly as compared to other regions of the country. The study focused on farms with at least a regular selling of dairy products to markets (urban and peri-urban dairy farms); since these are the farms that are expected to increase their production as a response to increases in demand. Therefore, the objective of the study was to estimate CF of milk production from urban and peri-urban farms within Mekelle milk-shed, Ethiopia. The research also attempted to analyze household and farm characteristics. In addition, the difference between peri-urban and urban production systems in terms of GHG emission was analyzed. Moreover, it assessed what difficulties/uncertainties come from the study in terms of input data use, assumptions and methodologies.

Materials and methods

Description of study area

The study was conducted from January to April 2020 in Mekelle milk-shed (Ethiopia) (Figure 1).
Sampling was made in peri-urban and urban dairy farms. The urban production system deals with primary dairy supply chains in major towns, while the peri-urban system includes farms found in the periphery of major and secondary towns [24]. Important towns found within Mekelle milk-shed include: Mekelle and Wukro [25]. According to [26], the total cattle population of Tigray was around 4.8 million (97.6% indigenous and 2.4% exotic and cross breeds). The total dairy cow population of the region was 936,945. Tigray regional state is situated between 12°15’ and 14°57’ N and 36°27’ and 39°59’ E. The average annual rainfall ranges between 350 and 710 mm, with the main rainy season from June to September.

**Sampling and data collection**

Prior to dairy farm visits an official visit to the Bureau of Agriculture and Rural Development of Tigray (BoARD) was made to get an overview of the Mekelle milk-shed. In addition, the list of dairy farms registered under an ongoing project on dairy farms in the milk-shed was obtained in order to get sampling frame of urban and peri-urban dairy farms in the study area. From the sampling frame, 50 urban and 50 peri-urban dairy farms were randomly selected.

A pre-tested semi-structured questionnaire (S1 file) adopted from [6] was administered by resident pre-trained technicians providing artificial insemination services. For each farm, data concerning household characteristics, crop production, herd composition, milk yields, manure production, animal sale, quantities of the different feed types, and feed transport means were collected.

After data entry and cleaning, 8 peri-urban dairy farmers were dropped due to incomplete data for the major parameters of the study. There were some inconsistencies in estimation of the amount of feed offered and some of the important information required for estimation of GHG emissions was not filled. Live weight for the animal categories in the farm was taken from [27]. The analysis presented in this paper focuses on GHG emission intensity measured in kg CO₂-e/kg of cow milk. GHG emissions were calculated for 50 urban and 42 peri-urban farms using a Life Cycle Assessment (LCA) approach. Zero-grazing was applied for all dairy cattle in the urban and peri-urban farms visited.

**Carbon footprint methodology**

Life cycle assessment (LCA) was used to quantify greenhouse gas emission associated with the
production of milk in the current situation as suggested by [6] and [9]. Attributional life cycle assessment method was used since this method uses allocation for different functions (milk, meat, draught power, manure, finance) [9]. The LCA was used to assess GHG emissions over one year on each of the 92 farms surveyed, and the CF was expressed as kg CO₂-e per kg milk. Carbon dioxide equivalent CO₂-e units were calculated by applying global warming potentials for carbon dioxide, methane and nitrous oxide from the IPCC fourth assessment report [28]. This method was selected to make comparisons of our findings with previous works which used the same approach for estimating GHG emission from dairy sector. Calculation of CF was implemented using Microsoft Excel version 2010.

**System boundary definition**

The system boundary was ‘cradle to farm gate’. A schematic diagram of the system boundary is shown in Figure 2. The system boundary included on-farm processes (i.e. feed production, dairy cattle management and manure management) and off-farm processes (i.e. fertilizer production, production of concentrates and transport of purchased feeds). All major emissions of methane (CH₄), nitrous oxide (N₂O, direct and indirect) and carbon dioxide (CO₂) were accounted for.

**Functional unit and allocation**

Since there was no sufficient data on fat and protein content of milk in the study areas, we could not normalize the milk to units of fat and protein corrected milk. For this reason, the functional unit was kg CO₂-e to produce a kg of cow milk. Milk yield (liters) was converted to kg using a standard density of 1.032 kg/L [29]. Dairy farming plays multiple roles in peri-urban and urban dairy farms (milk, meat, draught power, finance and manure [6, 20]. Emissions were attributed to milk production using economic allocation based on the prices of milk, animals sold and manure; and no allocation where all GHG emissions were allocated to milk production at the farm level.

**Inventory analysis**

By using questionnaire survey, data was collected on farm management activities in the year prior to the survey. Hence, the GHG emissions estimated were representative for the 365 days prior to the date of survey. Emissions were calculated for each farm and then summed for all farms. The values of default parameters and other values used in calculating GHG emissions were according to recommendations of [30, 31] (S2 file). To specify the variation in emission rates among animals, the population of animals were divided into subgroups: dairy cows, mature males and young stock [27].

For each of the defined representative animal subcategories, the average daily feed intake (megajoules (MJ) per day and/or kg per day of dry matter); and methane conversion factor (percentage of feed energy converted to methane) were determined. The animal daily feed intake and type of feed intake was estimated based on farmer-reported estimates of the mass of each feedstuff fed with some adjustments. The dry matter (DM) composition, Gross energy (GE) and crude protein (CP) composition of each feed was collected from www.feedipedia.org. According to [30] guideline,
methane conversion factor (Ym) of cattle that are primarily fed low-quality crop residues and byproducts or grazing was taken as 6.5%. An emission factor for each animal subcategory was developed following Equation 10.21 of [30] and the emission factor was multiplied by the number of animals in each category which was then summed up to get the total CH\textsubscript{4} emitted from enteric fermentation per farm.

There were no emissions related to energy use during husbandry or cropping as all works on the farm were done manually or using animal power. Direct and indirect methods were used to estimate total anthropogenic emissions of N\textsubscript{2}O from managed soils for crop production. Tier 1 approach of IPCC was used to compute both direct and indirect emission of N\textsubscript{2}O from managed soils. Nitrous oxide emissions from managed soils was computed using equations of [31] (Direct: Equation 11.1; Indirect: Equations 11.9 and 11.10). Moreover, emission from off-farm synthetic fertilizer was estimated based on the quantity of nitrogen from synthetic fertilizer applied to crop production multiplied by emission per kilogram of nitrogen in synthetic fertilizer. Emission factor per kg of nitrogen in synthetic fertilizer, 1.8 kg CO\textsubscript{2}-e/kg N [32], was considered for the current estimation. The emission from managed soil and fertilizer production was summed up and multiplied by the total economic value of crop residue to find the emission from crop residue production.

Emission from off-farm feed production was estimated based on the quantity of concentrate feed offered to dairy cattle multiplied by emission per kilogram of concentrate feed production and processing. Since no country-specific feed emission factors for commercial feeds were available for use, emission factor related to off-farm concentrate feed production and processing of 1.36 kg CO\textsubscript{2}-e/kg [9] in Kenya was considered for the current estimation.

For the estimation of emission from feed transportation, information on type of transport used, total kilometers covered, the quantity of feed transported, fuel consumption by vehicle per kilometers (by conducting market survey) was collected, and the emission factor 2.42 kg CO\textsubscript{2}-e/liter for gasoline and 2.67 kg CO\textsubscript{2}-e/liter for diesel [33] was used. The total CO\textsubscript{2} emissions from feed transport were a product of the distance of feed transported, fuel consumption per kilometer and CO\textsubscript{2} emissions per liter of fuel.

Direct and indirect N\textsubscript{2}O and CH\textsubscript{4} emissions from manure management were calculated for each animal category using the IPCC Tier 1 and Tier 2 methods [30, 31]. A methane emission from manure management was calculated by using Equation 10.22. Due to lack of country specific data on volatile solids (VS) rates, manure conversion factor (MCF) values, maximum methane producing capacity (Bo) values specific to Ethiopia, tier 1 methodology using IPCC default emission factor were used to estimate CH\textsubscript{4} emission from manure management. Direct emission of Nitrous oxide from manure management was computed by using equation 10.25 and indirect emissions using equations 10.27 and 10.29. The tier 2 method was applied using IPCC default N\textsubscript{2}O emission factors, default nitrogen excretion data, and default manure management system data.

**Economic allocation**

Economic allocation is used in LCAs of livestock production systems with multiple products if the interest is on one particular product such as milk in the present study. The urban and peri-urban farms included in the study had tangible products like milk (sold and consumed at home), animals sold for meat and finance purposes, manure used or sold. The prices for each item considered the amount each individual farm received for the sale of the items. The economic value of animals sold was based on the selling prices of different categories of animals. For calculation of economic value of finance, interest rate from the local microfinance was considered. For the economic allocation of GHG emissions, the economic values of milk, meat, and manure as fertilizer, cattle as draught power and cattle for finance were computed as follows:

Milk is the total economic value of the milk produced from cattle for one year. Milk output was estimated as liters of milk produced per farm per year, based on farmers’ estimates on milk consumed at home and milk sold. The economic value of milk was calculated based on producer prices 0.86 US$ (25 birr) by peri-urban producers and 1.03 US$ (30 birr) by urban producers.

Draught power is the economic value of cattle as draught for one year. Rent is the economic value of a pair of oxen rented for draught purpose. The rent value was multiplied by the number of days for which the ox was rented. In the urban and peri-urban farms, cattle were used for draught power for cultivation of crops. A rent value of 20.65 US$ (600 birr) per day for a pair of oxen was considered for the calculation of economic value of draught power.
Meat is the total economic value of cattle utilized or sold for beef purpose in one year. This is obtained by multiplying the head of cattle used or sold for beef purposes by the price paid by the purchaser.

The economic value from finance is based on the idea of not having to pay interest for borrowing money from a bank or informal money lender when an animal is sold for urgent cash needs [9]. The financing value is calculated as the total value of cattle sold in a farm per year multiplied by an estimate of the interest rate of credit [6]. This financing factor was estimated at 17% based on Dedebit Microfinance interest rates.

Manure is the economic value of manure that was used as fertilizer in a year (this value refers to the manure that is sold). The economic value of manure as fertilizer was computed based on synthetic nitrogen fertilizer equivalents according to [34]. The economic value of manure was obtained by multiplying the local price of nitrogen in synthetic fertilizer by N amount in manure. Nitrogen in manure used for fertilizing was computed by multiplying the amounts of manure applied to crops based on farmers’ estimates and the nitrogen content in cattle manure, 1.4% was taken for this study as per [9]. The most commonly used synthetic fertilizer was Diammonium Phosphate (DAP). Nitrogen contents of DAP are 18% and DAP prices were based on local market values.

Economic allocation was employed to assign the emission related to the use of crop residues, applied based on the economic value of the crop for human food use and the value of its by-products as cattle feed. These prices were based on local market prices. The revenue from crop was calculated by multiplying the amount of crop produce (kg) per year by the local price (per kg) of the crop in the market. The crop residue produce in kg was computed by multiplying the crop produce by the conversion factor for each crop (Eragrottis teff = 3, Wheat = 0.8, barley = 1.2, maize = 2, sorghum = 3, pea = 1)[35]. The revenue from each crop residue was calculated by multiplying residue produce by its price per kg based on local prices. Economic allocation of feed production is computed by dividing total economic value of crop residues by economic value of all crops. This was then multiplied by the N\textsubscript{2}O emission from managed soil to get the emission due to crop residue production.

Life cycle impact assessment
The most important GHGs related to dairy production are CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O. Greenhouse gas emissions are expressed in CO\textsubscript{2}-e. For conversion to this common unit, the three gases were multiplied by their equivalence factor in terms of CO\textsubscript{2}-e: 1 for CO\textsubscript{2}, 25 for CH\textsubscript{4} and 298 for N\textsubscript{2}O [28].

Data management and analysis
The collected data was organized, coded and filled into excel spreadsheet. Statistical Package for Social Science (SPSS) software version 26 was used for data analysis. Descriptive statistics (mean, minimum, maximum) was applied to summarize and present data in graph and table to compare between urban and peri-urban dairy farms. Emission factors and Greenhouse Gas emission estimation equations of different sources were applied from [30] and [31] document to quantify GHG emission. T-test was performed to analyze the variation in relevant farm characteristics: milk yield/farm, CF per kg milk between urban and peri-urban production systems. For all statistical tests, significance was set at \( p < 0.05 \). The total GHG emission from farms were divided by the total milk yield per year from farms to calculate carbon footprint. The emission intensity for each cattle unit was calculated by dividing the total emission by cattle unit (cu). For each individual farm, cattle unit was calculated using the following equivalents: lactating cow, dry cow, mature bull and ox = 1; heifer = 0.7; calf = 0.2 [20].

Results
Milk production system
Table 1 shows household characteristics of the case study farms. The mean age of the respondents was higher in peri-urban farms though it was not significant. Household size was lower for the urban dairy farms. In both urban or peri-urban dairy production majority of dairy farmers attended either primary or secondary education; and most of the respondents were male in both systems. The number of respondents who received secondary and higher education was more for urban farms than peri-urban farms. In both cases the majority of respondents received primary education. The peri-urban farms owned larger area of land (1.91 ha) than urban farms (0.34 ha) which is used for cropping for most of the time.

Most cattle were a cross of Friesian with local breeds. The number of cattle differed between the farm types: urban farms owned more cattle (6.1 cattle units (cu)) than the peri-urban farms (5.8 cu).
Herd structure

The herd size of cows was also more in urban farms (4.2 cu) compared to peri-urban farms (2.7 cu). The number of oxen and bulls was fewer in urban farms than peri-urban farms. However, the number of young stock (calves and heifers) was more in urban farms than peri-urban farms (Table 2).

Urban dairy farms obtained a statistically significant large volume of milk per cow per day (13.8 liters) than the peri-urban dairy farms (12 liters). Furthermore, the average daily amount of milk used for home consumption was more in peri-urban farms (19%) than urban farms (9%). There is also significant difference in milk yield per cow for both systems in dry and wet periods with production being more in wet period (Table 3).

Table 4 shows estimates of the daily amounts of Dry Matter (DM) per cu of the different feeds offered. In both peri-urban and urban farms, wheat bran was considerably used. Next to wheat bran hay and straws were the other major feeds offered. Dairy ration was not commonly used in the study area except few urban farms. Nug seed cake and cotton seed hull was more commonly used in urban than peri-urban farms. Forages like alfalfa, elephant grass, Rhodes grass and sesbania were also offered to cattle. However, due to shortage of land for cultivation, its use in the urban farms was limited. The amount of ‘Atella’ used was more in urban farms than peri-urban farms. In a year, urban farms produced around 5.7 tons of manure while peri-urban farms produced 7.3 tons. Twenty nine percent of manure was utilized for fertilizer in peri-urban farms whereas only 9% of it was used as fertilizer by urban farms. The manures were applied to forages and crop cultivation.

Manure management and utilization

As shown in Table 5, peri-urban farms (50%) used manure for burning as fuel more commonly than urban farms (10%). The accumulation of manure as solid storage was reported by 30.9% of peri-urban farms while 16% of urban farms applied this method. The number of farms using manure for biogas production was generally small in both systems. Majority of the urban farms (92%) discharge the manure mostly by selling. The application of composting and anaerobic digester was generally very low in both systems, though few peri-urban farmers applied it.

GHG emissions per cattle unit

There is significant difference in mean GHG emission per cu between peri-urban farms (2840 CO2-e y−1) and urban farms (3190 CO2-e y−1) (Table 6). About 75% and 70% of the total GHG emissions for peri-urban and urban farms respectively was due to emissions from enteric fermentation. Other hotspots were off-farm feed production (13.6% and 22.1% of the total GHG emissions in peri-urban and urban farms, respectively) and manure management (8.3%, and 7.3% in peri-urban and urban farms, respectively).

Economic allocation

The economic values of milk, meat, manure as fertilizer, finance and draught power were quantified for the time period of one year (Table 7). Milk contributed on average 88.5% and 90.8% to the economic value of peri-urban and urban farms, respectively. The milk sold and consumed at home was accounted while milk suckled directly by the calf was not accounted for. Meat played a role on the two systems for different reasons. In the case of peri-urban farms, cattle were slaughtered for various occasions like wedding, feast etc. with economic value of 4.2%. In the urban farms mostly,
male calves were sold for meat purposes with 7.4% economic value. The economic value of manure was higher in peri-urban farms. The value of cattle as finance contributed on average 0.7% and 0.6% to the economic value of peri-urban farm and urban farms, respectively.

**Carbon footprint of milk**

The carbon footprint per kg of milk without economic allocation was higher in peri-urban (3.2 kg CO₂-e) than the urban (2.2 kg CO₂-e). After economic allocation, the carbon footprint per kg of milk was 2.8 kg CO₂-e and 2.0 kg CO₂-e for peri-urban and urban farms, respectively.

### Discussion

**Milk production system**

The higher household size in peri-urban farms influences labor capacity available for crop and livestock production. The peri-urban and urban dairy production system in Mekelle milk shed was
dominated by resource-poor farmers with either primary or no formal education. This low level of education of dairy farm owners might affect the level of potential intensification of dairy production [36].

The present result showed that there are differences between peri-urban and urban dairy systems in the study area. The peri-urban farms possessed larger area of land for cropping and cultivating forages. In addition, the herd structure of the two systems differed where there are more dairy cows in urban farms than peri-urban farms. This is probably due to the dependence of urban farms on dairy as their primary source of income whereas peri-urban farms could also get incomes from crop cultivation. It is because of these reasons that the peri-urban farms owned more oxen and bulls in comparison with urban dairy farms. Though there are slight differences in the amount of feed provided per cattle unit, the types of feed provided in both systems were almost the same. These were comparable to the reports of [37]. The use of forages like alfalfa green, Rhodes grass, elephant grass and Sesbania was more common in the peri-urban farms than urban farms. All the farms in the milk shed did not purchase forage for feeding their cattle and those who feed forage to their cattle grew it in their farms.

Generally, the majority of the feeds offered are low in Crude Protein (CP) and the average CP percentage of the DM of all the average diet offered is below 10%. However, according to [38], a lactating cow, for instance, requires 12–18% CP in her diet, depending on the stage of lactation, whereas a dry cow requires 10–12% CP in her diet. Hence, the feeds offered were far below requirements for milk producing cows. The feed refusals could not be estimated, so amounts actually consumed cannot be estimated. The dry matter (DM) intake was, therefore, estimated by assuming that cattle take all the feeds offered.

Economic allocation of cattle functions

The result shows that peri-urban and urban farms keep cattle for multiple functions. Hence the total value of cattle in the farm is a complex combination of functions (milk, meat, manure, draught power and finance). Multi-functionality demonstrates the various ways cattle serve their owners. Those outputs of a systems are referred to as products or in LCA terms, co-products, which are one or more products coming from the same production system [10]. Since the different functions had their own economic importance, economic function allocation should be used to quantify functions in money terms [9]. The peri-urban and urban farms sold their milk to milk collection centers and hotels. Milk was the main contributor to the economic benefits of urban (90.8%) and peri-urban (88.5%) systems. Both the amount of milk sold and consumed at home was considered for the calculation.

To quantify the economic value of meat, the head price of cattle sold or slaughtered for meat purposes was considered. The economic share of meat in peri-urban farms was less than the economic value of meat in urban farms. Peri-urban farms slaughter cattle for occasions like feast, marriage, mourning and the like. They also sell ox and bull for meat purposes to the nearby butcher shops. However, the economic value of meat for urban farms was higher mainly due to the sale of male calves. Since they do not want to keep male calves, they usually sell them within weeks to nearby butcher shops and hotels. In case of peri-urban farms, male calves are kept to grow and help in crop cultivation. This trend was also observed by [6] in Hawassa-Shashemene milk shed, Ethiopia.

The dairy farms especially in the peri-urban areas use manure for fertilizing their crop land. As a result, the economic value of manure was higher in peri-urban farms (0.6%) than urban farms (0.1%). Cattle also served as means of finance for the farms in case of urgent cash requirements. A cattle sales history of farms showed that cattle were sold for paying debts, arranging marriage, constructing houses. They were sold due to financial pressures and reduced productivity. In both cases, its

| Function     | Mean Economic value | % | Mean kg CO₂-e | Mean Economic value | % | Mean kg CO₂-e |
|--------------|---------------------|---|---------------|---------------------|---|---------------|
| Milk         | 6,488.2             | 88.5 | 21,838.1      | 7,525.7             | 90.8 | 24,615.3      |
| Meat         | 306.7               | 4.2  | 1,033.7       | 616.9               | 7.4  | 2,016.5       |
| Draught      | 435.7               | 5.9  | 1,465.4       | 86.5                | 1.1  | 281.9         |
| Manure       | 46.1                | 0.6  | 155.4         | 8.5                 | 0.1  | 27.1          |
| Finance      | 52.5                | 0.8  | 177.6         | 49.99               | 0.6  | 162.6         |

1USD = 29.05 birr, from 01-Jan-2019 to 31-Dec-2019 (Source: https://combanketh.et/...).
economic share was almost the same. The percentage of economic contribution of manure and financing in the current milk shed was comparable to the report of [6]. Regarding the economic value of cattle as draught power, its economic share was significantly higher for peri-urban farms (5.9%) than urban farms (1.1%). This is expected as the number of oxen and bulls was higher in peri-urban farms than urban farms as most of the peri-urban farms practiced mixed-crop livestock farming.

**Greenhouse gas emission**

Methane emission from enteric fermentation was the major hotspot of GHG emission per cattle unit in both peri-urban and urban dairy farms. This is in line with reports of [15] in Anand district of India, [20] in Mekelle milk shed and [6] in Hawassa-Shashemene milk shed. The other hotspots of GHG emissions were off-farm production and processing of concentrate feed (13.6% and 22.1% of the total emission per cu in peri-urban and urban farms, respectively). The emission intensity due to off-farm concentrate production was high because we considered the default emission factor due to lack of country-specific data. The emission factor (1.36 kg CO₂-e kg⁻¹ concentrates) from Kenya was considered. The emission intensity from off-farm feed production was more in urban farms than peri-urban farms. This is mainly due to the fact that urban dairy farms used more purchased concentrate feeds while peri-urban farms used more of crop residues produced on farm. The emission from feed processing in the current milk shed for the peri-urban farms was higher than Shashemene-Hawassa milk shed (Ethiopia) [6]. This indicates that the use of concentrates by peri-urban farmers was more in Mekelle milk shed than Shashemene-Hawassa milk shed.

Although there is no significant difference in emission intensity per cattle unit between the two production systems, it was slightly higher in urban dairy farms. This is mainly due to the higher consumption of concentrates in urban farms, which raised the total production of GHG per farm. The finding from the current study was higher than Kaputo smallholder dairy farms in Kenya [9] and Anand and district of western India [15]. This might be associated with the variation in methodology, herd structure and quality of feed. The higher proportion of methane production is mainly associated with the nature of enteric fermentation and the quality of feed [1, 15]. Since sub-categorization of suckling and older calves was difficult, they were both considered as young stock. This might have influence on the methane amount from enteric fermentation. Enteric emissions related to young stock could be overestimated as emissions differ between age groups, i.e. younger calves produce very small or no methane.

High-quality forages can reduce CH₄ production by altering the fermentation pathway. This is mainly because these forages contain higher amounts of easily fermentable carbohydrates and less non-digestible fiber leading to a higher digestibility and passage rate [39]. However, in the current study the feeding of forages to animals in the farms is low in both systems. Only a few (2%) urban farms and 14% peri-urban farms cultivated forages in their respective farms, and all the farms do not purchase forages. In addition to forages, peri-urban and urban farms having land also cultivated crops. The provision of more crop residues also contributed for more methane production due to enteric fermentation.

Farmers used synthetic fertilizer (Diammonium phosphate and urea) on part of the land for crop production instead of cattle manure. Production and application of synthetic fertilizer contributes to additional emissions [40] in the form of nitrous oxide. More peri-urban farms were involved in crop production than urban farms which resulted in higher share of emission intensity per cattle unit in peri-urban farms (1.4%) than urban farms (0.2%). Since all the farms did not utilize farm machines, the emissions were associated with the use of fertilizers. The emission was higher in peri-urban farms as most of them practiced mixed-crop livestock farming.

Majority of peri-urban and urban dairy farms did not produce or process feed in their farms. They had to buy it from retailers in the market. For the transport of crop residues, “Atella” and water, both peri-urban and urban farms used donkeys. Both systems used ISUZU and BAJAJ as means of transport for concentrates and crop residues. These activities contribute to emission of CO₂ due to burning of fuel by the vehicles. The share of emission from transport out of the total emission intensity per cattle unit per year was higher in peri-urban farms (0.5%) than urban farms (0.2%). This was mainly due to the kilometers covered for the transport of the feeds. The peri-urban farms purchase the feeds from urban centers and the kilometers travelled are higher for peri-urban farms. The share of emission intensity per cattle
unit in Shashemene-Hawassa milk shed [6] was lower than the present study. This variation could be due to variation in distance between farms and feed shops, frequency of feed purchase and amount of feed purchased per year.

The total amount of manure produced by the peri-urban and urban farms in the milk shed was 307,855 kg DM year−1 and 289,080 kg DM year−1, respectively. This was higher in the peri-urban farms due to the higher cattle unit (cu) in peri-urban farms. Manure management was the third major hotspot of emission source with contribution of 8.3% and 7.3% of total emissions per cattle unit per year for peri-urban and urban farms, respectively. Both CH₄ and N₂O emissions were considered from manure management systems. Manure should normally be collected and managed from the time of excretion, during storage, possibly by treatment, and finally during spreading to land[41].

A lot of the manure in the milkshed was stored rather than managed and it was difficult to quantify the amount of manure utilized for the different management systems. Daily spread shows large potential for mitigation of GHG emissions [40], however, only a few farms especially in the urban area adopt this method due to lack of land for cultivation. Hence a lot of the urban farms discharge the manure in the open field where it will be left to accumulate for a number of months. It will later be sold to be utilized as organic fertilizer. This kind of manure storage leads to pollution of the environment and release of GHG to the environment. On the contrary, a lot of peri-urban farms prepare cow dung cake which is burned as fuel. This is detrimental to the environment as it leads to the release of CO₂ into the atmosphere. Except few peri-urban farms, most of the peri-urban and urban farmers did not adopt composting and anaerobic gas digester which play significant role in mitigating GHG emission.

Carbon footprint of milk

In general, the number of non-lactating animals (49.3% in urban farms and 23.6% in peri-urban farms) has a strong effect on the CF of milk as the total emissions are later divided by the kg of milk produced. Therefore, the importance of valuing multi-functionality begins to have great effect [9]. If we target only milk as a commodity, it will be inefficient to keep animals that do not produce milk. However, multi-functionality of cattle allows us to see those animals as still being productive, though serving other functions than producing milk [15]. Collection of milk production data of cows was a challenging task since the farms did not keep record of milk yield. The CF per kg of milk without economic allocation was higher in peri-urban farms (3.2 kg CO₂-e) than the urban farms (2.2 kg CO₂-e). Similarly, after economic allocation, the carbon footprint per Kg of milk was higher in peri-urban farms (2.8 kg CO₂-e) than urban farms (1.8 kg CO₂-e). The significant difference (p < 0.05) in CF between the two farming systems could be due to differences in the proportion of lactating animals and total milk yield. Although the GHG emission per cattle unit was more in urban farms, the urban farms had higher milk outputs per animal than peri-urban farms.

The CF of milk in the present study is higher than the 3.3 kg CO₂-e for peri-urban farms and 1.76 kg CO₂-e for urban farms in Shashemene-Hawassa milk shed [6]. The differences could be attributed to differences in production systems (e.g. productivity and feeding system) and herd structure. Moreover, the results of different studies are sometimes difficult to compare, as they are conditioned by the researcher’s choices [42]. Comparing the present finding with results of other studies was difficult as there had been limited research on CF on dairy systems in the country. However, the CF in urban farms was comparable to [15] who calculated a CF of 2.2 kg CO₂-e/kg milk in small holder farms in Anand district in India without economic allocation for multifunction.

The carbon footprint of milk in this study using economic allocation is not worse compared to the global average (2.4 kg CO₂-e/kg milk). It was also well below GHG emissions of dairy systems of Sub Saharan Africa, 7.5 kg CO₂-e/kg milk [4]. The present CF values of milk in the peri-urban and urban dairy farms were higher than CF values (0.8–1.3 kg CO₂-e / kg milk) in Organization for Economic Cooperation and Development (OECD) countries [43], 1.6 kg CO₂-e/kg milk in Kenya [9] and 1.7 kg CO₂-e in smallholder farms in India [15]. Generally, the comparison of several CF studies is difficult as they use different functional units. In the present study, the functional unit (FU) is kg of uncorrected milk. For instance, the CF estimate of [4] considered the FU as Fat corrected milk (FCM). Therefore, in comparing CF studies, it is important to take note of the FU considered for the estimation. The
CF of milk in the present study could be higher or lower than previous research finding if it was possible to make corrections for fat and protein.

**Uncertainties in methodology**

Uncertainties associated with the input data could affect the results of LCA studies. The result of the study shows that enteric fermentation is the major hotspot of emission. Therefore, the estimates of feed inputs could have a major impact on the result. Feed use on farms in daily practice is difficult to properly determine. The estimates of the use of roughages are rough approximations by farmers. Milk production is also an essential parameter to assess impacts per kg milk [44]. The milk yield records of cows in the peri-urban and urban farms were not regularly kept. So, milk production estimates were mainly based on recall information from the farmers. The lack of record keeping in farms could be source of uncertainty of environmental impacts per kg of milk. These uncertainties could be tackled by regular monitoring of feeds used at farm level and milk yields of individual cows, though the task is resource intensive. Due to lack of country specific emission factors and information required for estimation, the default values from IPCC and neighboring countries were used which also could contribute to uncertainties. Since the amount of manure used for the different manure management systems were not properly measured the present study used estimations from previous studies which could be source of uncertainty.

**Conclusion**

Dairy farmers in the current milk-shed kept dairy cattle for different function and the total milk yield per cow was more in urban farms than peri-urban farms. In both systems cattle are fed more of low-quality feeds contributing to enteric methane emission which took the highest share of the total emission. The use of improved forages was not common in the farms and most farms in the milkshed did not produce forages in their farms. Emission intensity of milk was higher in peri-urban farms than urban farms. Emission from manure management system was also high due to lack of manure management systems like biogas production and composting which could have helped in mitigating GHG emission. It is therefore important to engage dairy farmers to adopt climate smart dairy practices in order to reduce GHG emission intensity from the dairy sector. The methodology used to estimate the CF of dairy cows in the present study was based on the LCA which could be influenced due to uncertainties associated with the input data and assumptions. Thus, it is very important to ensure data quality to reduce uncertainties.

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**Disclosure statement**

No potential conflict of interest was reported by the author(s).

**Data availability statement (DAS)**

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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