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# Carbon footprint in the downstream dairy value chain in Ziway-Hawassa milk shed, Ethiopia

**Godadaw Misganaw[1,2] · Robert Baars[1] · Marco Verschuur[1] · Biruh Tesfahun[1,3] · Sara Endale[1,3] · Demeke Haile[1,3]**

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## Abstract

**Purpose** The carbon footprint for the downstream dairy value chain, milk collection and dairy processing plants was estimated through the contribution of emissions per unit of collected and processed milk, whereas that for the upstream dairy value chain, input supply and production was not considered. A survey was conducted among 28 milk collectors and four employees of processing plants. Two clusters were established: small- and large-scale milk collectors. The means of carbon dioxide equivalent per kilogramme ($CO_2$-eq/kg) milk were compared between clusters by using independent sample t-test.The average utilisation efficiency of milk cooling refrigerators for small- and large-scale collectors was 48.5 and 9.3%, respectively. Milk collectors released carbon footprint from their collection, cooling and distribution practices. The mean kg $CO_2$-eq/kg milk was 0.023 for large-scale collectors and 0.106 for small-scale collectors ($p < 0.05$). Milk processors contributed on average 0.37 kg $CO_2$-eq/kg milk from fuel (diesel and petrol) and 0.055 from electricity. Almi fresh milk and milk products processing centre emitted the highest carbon footprint (0.212 kg $CO_2$-eq/kg milk), mainly because of fuel use. Generally, in Ziway-Hawassa milk shed small-scale collectors released higher $CO_2$-eq/kg milk than large-scale collectors.


**Keywords** Carbon footprint · $CO_2$-eq · Downstream dairy value chain · Milk collectors and processors · Milk shed

## 1 Introduction

Greenhouse gas (GHG) emission is one of the main causes of climate change which has become a worldwide challenge to the living environment (Mantyka-Pringle et al. 2015). Agricultural production is one of the main sources of GHG emissions, accounting up to 25% of the total anthropogenic global GHG emissions, of which the livestock sector

✉ Godadaw Misganaw
godadaw@gmail.com

[1] Van Hall Larenstein University of Applied Sciences, PO Box 9001, Velp, The Netherlands

[2] University of Gondar, Gondar, Ethiopia

[3] Dilla University, Dilla, Ethiopia

contributes 14.5% (Hawkins et al. 2015). Dairy creates 2.7% of global GHG emissions or 4.0% including meat from dairy animals (Hill 2017). On the other hand, climate change affects livestock production and consequently food security, especially in arid and semi-arid regions (Rojas-Downing et al. 2017). The potential impacts of climate change on livestock result in reduced quantity and quality of feed and water availability which subsequently negatively affect animal growth, milk production, health, reproduction and animal genetic diversity. The effect of heat stress on livestock accounts for 60% economic loss of dairy farms around the world, and it has also been associated with the impairment of embryo development and increase in embryonic mortality in cattle. Climate change may eliminate 15 to 37% of all animal species in the world which are at high risk of extinction (Ahmedin and Negasi 2018).

The dairy sector in the highlands of Ethiopia is dominated by smallholders and growing numbers of (semi-) commercial farmers. It is characterised by low productivity of 2–3 L per cow per day, limited availability of chilling in rural areas, processing plants working below capacity, prices volatility, fluctuating demands (fasting) and informal dairy markets. Nevertheless, the demand of milk in Ethiopia is projected to grow by 47%, and the country's Livestock Master Plan envisions a 93% increase in national cow milk production over the period 2015–2020 (Shapiro et al. 2015; GTPII 2015). Given the expected vast increases in Ethiopian cow milk production and consumption, the Ethiopian dairy value chains are facing tremendous challenges of limiting the increase in GHG emissions as well as enhancing resilience to climate change. In 2013, the dairy cattle sector in Ethiopia emitted 116.3 million tonnes carbon dioxide equivalent (CO2-eq) (FAO and NZAGRC 2017).

Ethiopia has the ambition to shift towards green economy development and growth by reducing net GHG emissions and improving resilience to climate change towards 2030 (FDRE 2011). Reduction of losses in the milk supply chain will lead to increased efficiency and is one of the strategies to reduce GHG emissions from dairy value chains. FAO (2018) estimated that food loss (post-harvest and distribution losses) in the dairy value chain in Sub-Saharan Africa is about 30%. The same report showed that post-harvest and distribution losses in well-developed commodity chains in Europe and North America are on average 1%. Post-harvest loss of milk in Hawassa district was estimated up to 40% from milking to consumption (Azeze and Haji 2017).

Even though the production of raw milk contributes more than 80% of the GHG emissions, the subsequent supply chain process has also non-negligible impact on climate change (Guerciaet al. 2016). The global food supply chain accounts for 18% of GHG emissions with a contribution of processing (4%), transport (6%), packaging (5%) and retail (3%) (Ritchie 2019). Therefore, analysis of the dairy supply chain from production through the ultimate disposal of packaging is necessary to provide the dairy industry with a documented baseline of the carbon footprint of fluid milk for one's country (Thomas et al. 2013). Life cycle assessment (LCA) is an internationally accepted approach to analyse the environmental impact of milk, considering all phases of its "life cycle" (Nutter et al. 2013; FAO 2010). Hence, the objective of this study was to estimate the carbon footprint of milk collection and processing and examine the roles and contributions of downstream dairy chain actors in order to support climate change mitigation practices leading to climate-smart supply chain development in the Ziway-Hawassa milk shed. The carbon footprint of the upstream dairy value chain, input supply and production was not considered as this was targeted in a parallel study of the same programme.

## 2 Methodology

### 2.1 Study area

The study was conducted in the Mid-Rift Valley of Ethiopia. It covered six districts: Dugda, Adami-Tulu, Arsi-Negelle, Shashemene, Kofele and Hawassa city (Fig. 1). The study area stretched 142 km from Dugda to Hawassa. The districts are famous for milk production and comprise one of the major milk sheds of the country.

### 2.2 Research unit selection

The milk shed and respective study districts were selected purposively based on the interest of the commissioner of this study. Through stakeholder meetings and preliminary assessments, the available milk collection points/traders and processing units throughout the milk shed were identified and mapped. Twenty-eight milk collection points were randomly selected out of the total of 40 in the study area, and all processing units considered for further redefining the study unit. One respondent per collection point (28) and one respondent per processing unit (totally four) were interviewed in a survey. Additionally, six interviewees' were selected randomly among milk collectors and processors for focus group discussion.

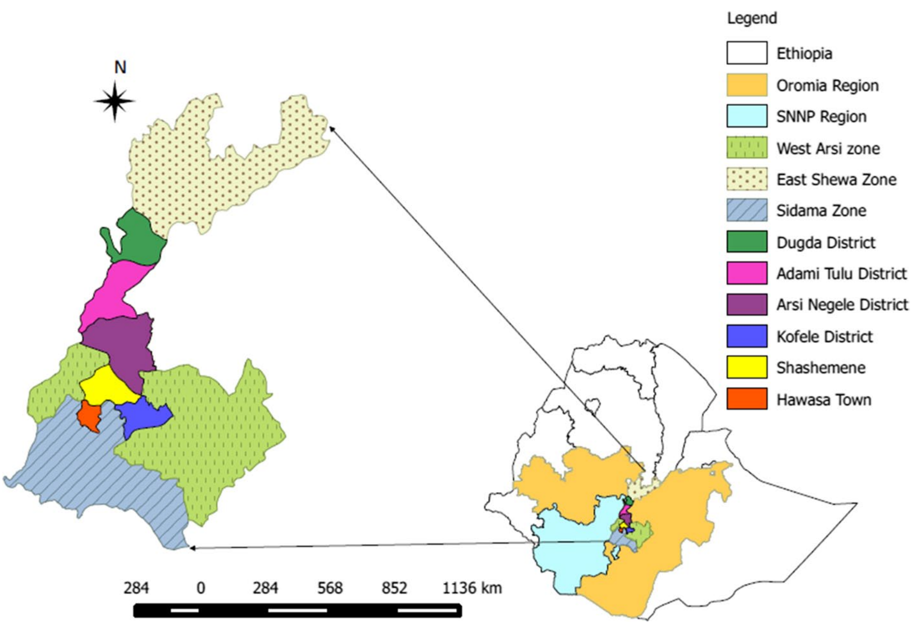


**Fig. 1** Map of study districts

### 2.3 Data collection

A survey was conducted using a questionnaire to quantify the carbon footprint of milk along with the channel among 28 milk collectors and four employees of milk processing plants. A questionnaire was designed to assess the types of milk transportation, distance from or to collection points, fuel consumption, loading capacity of vehicles, average volumes of milk collected per day, sources of power for cooling and processing machines. One relatively large-and three small-scale milk processors were selected. Additionally, observations were carried out using a recording sheet for machines' power consumption and electric bills. The arrangement of the operating systems, energy utilisation, collection points and processing plants were recorded. The observations allowed triangulation of the data obtained through the questionnaire.

### 2.4 Data analysis

Milk collectors were clustered into two groups based on the volume of milk collected per day. Those who collected more than 150 kg milk per day were considered large-scale collectors ($N=13$), and the remaining as small-scale collectors ($N=15$). The means of CO2-eq/kg milk were compared between clusters by using independent sample t-test.

### 2.5 Life cycle analysis (LCA)

Life cycle analysis is important to evaluate the possible environmental impact of a product based on the quantitative survey and assists to estimate GHG emissions of all materials and energy, to seek opportunities to the improvement of product safety and environmental performances. LCA was used to evaluate the possible environmental impact of a product throughout its life cycle based on GHG emissions energy (Huysveldet al. 2015). There were two main sources of GHGs at factory level, process energy consumption and fossil fuel consumption for transport. The post-farm gate emissions occurred through transportation, cooling and processing systems.

### 2.6 Emission from milk transportation

To estimate the carbon footprint of milk in the transportation phase, the following protocol was used (Torquati et al. 2015):

1. Type of transport used (either public or private), kilometres travelled and the quantity of milk transported.
2. Fuel consumption by the vehicle per kilometre and its full capacity of loading. The age of vehicles was not considered although all were undoubtedly more than 10 years old.
3. Collectors have their own regular customers at specific place, and the chance of public transport moved across different places with under loading capacity is not usual in Ethiopia. Even during Orthodox religion fasting season, the milk is still collected because these are formal milk chains. Therefore, if the milk was carried in public transport or with other commodities, allocation of fuel was estimated per commodity (milk versus non-milk) to find the quantity of fuel consumed for milk transportation only:

- Total travelled distance divided by the number of persons or weights of materials travelled within that vehicle.
- The quantity of fuel consumption per person (milk trader) or unit (kilogram).

4. Total estimation of carbon dioxide ($CO_2$).

$$F = D \times L$$

where $F$ is the total kg of fuel consumed by the vehicle to transport the milk (kg). $D$ is the distance that the milk is transported (km). $L$ is the kg of fuel consumed by the vehicle per kilometre to transport the milk (kg).

Carbon footprint was estimated as:

$$\mathrm{CF} = F \times \mathrm{EF}$$

where CF is the total carbon footprint of milk due to transportation. $F$ is the total kg of fuel consumed by the vehicle to transport the milk (kg). EF is the emission factor of $CO_2$ from fuel consumption estimated for Ethiopia.

5. The emission per kg milk was obtained by dividing the total CF for the corresponding quantity of milk delivered in each step of the supply chain.

### 2.7 Emissions from cooling and processing

Total emission from cooling and processing systems was estimated by using the energy consumption data of the equipment. The following procedure and estimations were followed:

1. Electricity use for cooling, processing and packaging of milk.
2. Energy consumption of the cooling and processing machines was collected from electricity bills and/or equipment specification (kWh).
3. The emissions of $CO_2$ by multiplying the total energy consumptions (Kwh) and the emission factors:

$$\mathrm{CF} = \sum_{i=n}^{n} Ei(Kwh) * \mathrm{EF}$$

where CF is the total carbon footprint of milk due to cooling and/or processing. $Ei$ is the total energy used by the cooling and/or processing machines in Kwh. EF = emission factor estimated for the use of Ethiopian electric power.

### 2.8 Emission factors

Standard emission factors were converted to CO2 emissions. Emission factors for diesel and gasoline cars in Ethiopia were 2.67 and 2.42 kg CO2-eq/kg, respectively (Gebre 2016), and for electricity 0.13 kg CO2-eq/kWh (Brander et al. 2011).

# 3 Results

## 3.1 Milk sourcing and distribution channels

The downstream dairy value chain actors in Ziway-Hawassa milk shed included collectors, processors and retailers. All collectors had their own retailing outlets that linked them to the consumers, and they also sold milk to retailers. The overlays shown in the chain (Fig. 2) are milk purchasing and selling prices. Large-scale collectors purchased and sold with relatively low prices compared to small-scale collectors. As milk processors also produced milk on their own farms, they performed milk producing to retailing functions and they used the same purchasing prices as large-scale collectors. Since they produced different types of products, the selling prices varied based on the product types.

As indicated from the chain map, the downstream chain actors had multiple roles. The roles of small- and large-scale collectors as well as processors in relation to chain sustainability are shown in Table 1.

Part of the milk was sourced from urban and peri-urban dairy farmers by small- and large-scale milk collectors and then distributed via small-scale processors to kiosks and finally to consumers, and part of the milk went directly to milk processors (Fig. 2).

Milk collectors emit GHG through transport and cooling machines. Transport was used in two phases along the milk supply chain (Fig. 3). The first one was used to collect raw milk from producers to collection points and/or processing plants (transportation 1), whereas the second was used for distribution from collection points to retailers and/or consumers (transportation 2).

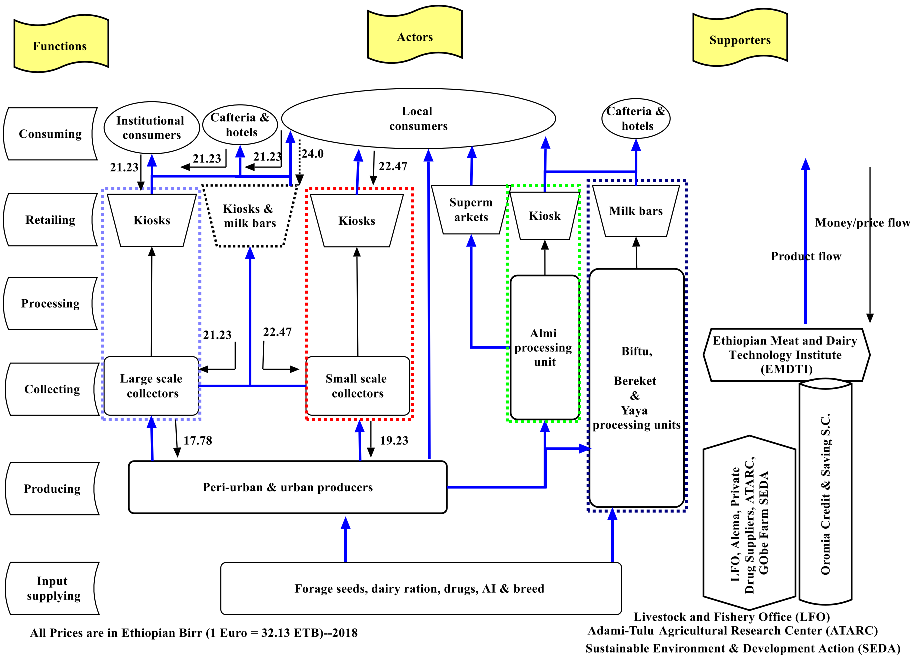


**Fig. 2** Dairy value chain map in Ziway-Hawassa milk shed

**Table 1** Roles and contributions of collectors and processors for the sustainability of the dairy chain. ETB = Ethiopian Birr

| Actors | Roles in the chain | Contributions for sustainability (3P) |
|---|---|---|
| Large-scale collectors | Milk collection, retailing and supporting their milk suppliers | *People*: Most large-scale collectors distributed relatively quality tested milk for a relatively low selling price to consumers compared to small-scale collectors. They also established firm relationships (strong and long-term) with producers and created gender inclusive job opportunities for a considerable number of people<br>*Planet*: Better utilisation efficiency in cooling machine (48.5%) and vehicles. These practices help to emit low carbon footprint/kg milk (0.021 kg) compared to small-scale collectors<br>*Profit*[a]: Generated a better gross income (ETB 2.89/kg milk), had relatively lower average variable cost (ETB 18.30/kg milk) than small-scale collectors |
| Small-scale collectors | Milk collection and retailing | *People*: Small-scale collectors had no milk quality testing equipment, and most of them were unlicensed traders that distributed inferior quality milk to consumers. They interrupted collection of milk during fasting season and were not able to establish stable relationships with their raw milk suppliers. No or insignificant job creation was reported<br>*Planet*: Inefficient utilisation of cooling machines (9.3%) and vehicles. The carbon footprint to the environment was higher (0.089 kg $CO_2$-eq/kg) than large-scale collectors<br>*Profit*[a]: Generated relatively low gross income per kg milk (ETB 2.21). They had no stable purchasing and selling price of milk throughout the year. A higher variable cost per kg milk (ETB 19.70) was found compared to large-scale collectors |
| Almi-fresh milk and milk products processing unit | Milk collection, processing, distribution, retailing and supporting its suppliers | *People*: Almi presented a variety of processed quality milk and milk products to consumers, created jobs for 32 male and 28 females, and established long term relationships with producers and customers<br>*Planet*: Almi emitted relatively a high carbon footprint (on average 0.21 kg $CO_2$-eq/kg to process). Almi also used proper waste disposal tanks and cultivated dense forest in the surrounding of the processing unit by compensating for climate change<br>*Profit*[a]: Generated ETB 6.45 and 12.45/kg milk pasteurised milk and yoghurt, respectively. The gross margin was higher than producers and retailers |

**Table 1** (continued)

| Actors | Roles in the chain | Contributions for sustainability (3P) |
|---|---|---|
| Biftu, Bereket and Yaya milk processing units | Milk production collection, processing, retailing and supporting its suppliers | *People*: Presented good quality products for local consumers, created gender inclusive jobs for some persons (up to 9 persons per unit)<br>*Planet*: Contributed a low amount of carbon footprint (on average 0.024 kg $CO_2$-eq/kg milk). Converting spoiled milk and milk products into biogas<br>*Profit*[a]: -The gross income and margins were the same as Almi |

[a]Information about the profit was calculated from parallel studies in the same programme (Tezera 2018; Hailemariam 2018; Haile 2018) and shown in the chain map

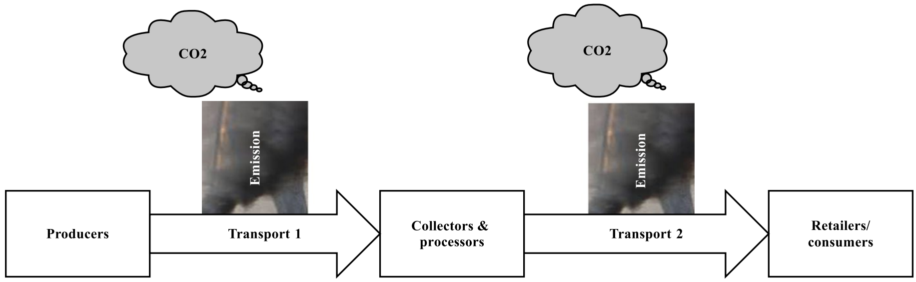


**Fig. 3** Supply chain of milk in the shed

### 3.2 Types of vehicles, volumes of milk

In the Ziway-Hawassa milk shed, mainly minibuses older than 10 years and three wheelers were used for collection and distribution of milk (Table 2). Chilled transportation was not reported in the shed. Some milk collectors had their own minibus that was used for milk transportation by removing the chair (the so-called milk car), whereas others used public transport minibuses. No differentiation between private and public transport neither new or old vehicles was made in the study due to lack of information, and same Ethiopian conversion factors were applied to all. The developed conversion factor is assumed to consider the variations on the status or condition of vehicle types in the country. Accordingly, the milk car was used for collection of 13.7 kg of milk/km of travelled distance and three wheelers 23.05 kg of milk/km.

**Table 2** Total travelled distance and collected volumes of milk in the Ziway-Hawassa milk shed

| Transport type[a] | Total distance travelled (km/year) | Total kg milk transported or collected (kg/yr) | kg of milk/km |
|---|---|---|---|
| *Transport 1 (N = 28 collectors)* | | | |
| Public transport (minibus) | 75,816 | 130,000 | 1.72 |
| Milk car (minibus) | 120,484 | 1,650,740 | 13.70 |
| Pickup truck | 6240 | 41,600 | 6.67 |
| Bajaj (3 wheeler) | 26,718 | 615,888 | 23.05 |
| Motorbike | 728 | 13,104 | 18.00 |
| On-foot collected | | 539,812 | |
| *Transport 2* | | | |
| Public transport (minibus) | 114,660 | 315,764 | 2.75 |
| Milk car (minibus) | 23,244 | 871,192 | 37.48 |
| Three wheeler | 3099 | 144,528 | 46.64 |
| On-foot and carts (donkey + horse) | | 1,650,660 | |
| Sub-total motorised transport 1 ($N$ = 28) | 229,986 | 2,451,332 | |
| Sub-total transport 1 ($N$ = 28) | | 2,991,144 | |
| Sub-total motorised transport 2 ($N$ = 13) | 141,003 | 1,331,484 | |
| Sub-total transport 2 ($N$ = 28) | | 2,982,144 | |

[a]Variations in life cycle of the vehicle were not considered

**Table 3** Average utilisation efficiency of types of transport in Ziway-Hawassa milk shed

| Transport type | Large-scale collectors | | Small-scale collectors | |
|---|---|---|---|---|
| | *N* | Average loading efficiency (%) | *N* | Average loading efficiency (%) |
| Milk car | 8 | 30 | 4 | 9 |
| Three wheeler | 5 | 74 | 10 | 10 |
| Motorbike | | 1 | 72 | |

**Table 4** The utilisation efficiency of cooling facilities by milk collectors

| Size (no. of refrigerators) | Large-scale collectors | | Size (no. of refrigerators) | Small-scale collectors | |
|---|---|---|---|---|---|
| | *N*[a] | Efficiency (%) | | *N*[a] | Efficiency (%) |
| 250 kg (3) | 3 | 44 | 250 kg (12) | 10 | 11 |
| 500 kg (23) | 5 | 50 | 500 kg (3) | 3 | 6 |
| 2000 kg (2) | 2 | 45 | | | |
| Weighted average efficiency | 48.5 | | | 9.3 | |

[a]Some collectors did not have cooling facilities

Annually, 2.9 million kg of milk was collected by 28 collectors, out of which 2.4 million kg was collected by emission-based transportation (transportation 1), the remaining being emission-free collection. In the milk distribution phase (transportation 2), annually 1.3 million (out of 2.9 million) kg of milk was distributed through emission-based transportation. Unlike milk collection, the milk distributed through emission free transportation was higher than emission-based transportation.

To reduce carbon footprint per kg milk, it is required to efficiently utilise vehicles' loading capacity. To estimate utilisation efficiency, vehicles only used for milk transportation were considered. Thus, vehicles used for transportation of milk with public or other items were not included in this efficiency estimation. Few collectors used the full loading capacity of the vehicles during milk collection and distribution. Large-scale collectors utilised milk cars up to 30% of their loading capacity, and this was only 9% for small-scale collectors (Table 3). Using less loading efficiency of vehicles leads to increased carbon footprint per kg milk.

Cooling facilities also contributed to carbon footprint through power utilisation. All collection points used only electric sources for their power requirement; no one did report a generator. Efficient utilisation of cooling machines can reduce carbon footprint per kg milk. Most large-scale collectors used a relatively high number of medium-sized refrigerators. Large-scale collectors utilised their cooling machines up to 48.5% of its holding capacity on average (Table 4).However, small-scale collectors preferred and mostly used low-size refrigerators with an average utilisation efficiency of 9.3%.

### 3.3 Carbon footprint of milk by collectors

Large-scale collectors collected on average 166,880 kg of milk per year for which 1582 kg of diesel and gasoline fuel was consumed. Small-scale collectors collected on average

18,793 kg of milk per year that consumed 793 kg of fuel (Table 5). The mean kg CO2-eq/kg milk was 0.023 for large-scale collectors and 0.106 for small-scale collectors ($p < 0.05$).

The carbon footprint of milk from collectors' cooling machines was estimated through energy consumption (Kwh) utilised per year. The refrigerators of large-scale collectors were used for cooling of 94,535 kg of milk per collector per year. This, in turn, printed averagely 763 kg CO2 per collector to the environment annually (Table 5). Similarly, small-scale collectors contributed 103 kg CO2 per collector to the environment. The mean emission of cooled milk was 0.0081 kg CO2-eq/kg for large-scale collectors and 0.0083 for small-scale collectors ($p > 0.05$).

In Ziway-Hawassa milk shed, milk was mainly distributed by consumers. However, some collectors were responsible for the transportation and distribution of milk to some customers especially for institutional consumers and large volume retailers through vehicles. Therefore, only 13 collectors were considered for estimation of carbon footprint in the distribution phase (transport 2). On average, these collectors released 0.060 kg $CO_2$-eq/kg milk to the environment (Table 5).

### 3.4 Carbon footprint of milk by processors

The products processed by all four processors were butter, yoghurt and cottage cheese. The small-scale processors used locally made electrical churner machines (Fig. 4), and the cottage cheese was prepared by using firewood. Carbon footprint was estimated for processors based on electrical power and fuel used in generators. Estimation of carbon footprint per product was not carried out in this study due to information limitation.

**Table 5** Carbon footprint of milk at collectors' level

| Sources of emission | Parameters | Large-scale collectors ($N = 13$) | Small-scale collectors ($N = 15$) |
|---|---|---|---|
| Collection (transport 1) | Average milk collected (kg/year/collector) | 166,880 | 18,793 |
| | Average fuel consumed (kg/year/collector) | 1582 | 793 |
| | Average $CO_2$ emission (kg/year/collector) | 3837 | 1991 |
| | *$CO_2$-eq/kg milk* | 0.023[a] | 0.106[b] |
| | Weighted average $CO_2$-eq/kg milk | 0.033 | |
| Cooling (electricity) | Average milk cooled (kg/year/collector) | 94,535 | 12,507 |
| | Average energy utilised (Kwh/year/collector) | 5867 | 793 |
| | Average $CO_2$ emission (Kg/year/collector) | 763 | 103 |
| | *$CO_2$-eq/kg milk* | 0.0081 | 0.0083 |
| | Weighted average $CO_2$-eq/kg milk | 0.0082 | |
| Distribution[c] (transport 2) | Average milk distributed (kg/year/collector) | 102,422 | |
| | Average fuel consumed (kg/year/collector) | 2427 | |
| | Average $CO_2$ emission (kg/year/collector) | 5885 | |
| | $CO_2$-eq/kg milk | 0.060 | |

[a],[b]Means with different superscripts within effect differ ($p < 0.05$)

[c]Only 13 collectors were involved in milk distribution

**Fig. 4** Milk churner machine used by small-scale processors

Almi fresh milk and milk product processing centre is one of the modern milk processing plants in the shed and processed a relatively large volume of milk per day. The largest proportion of the collected milk was allocated to pasteurised milk and yoghurt. The prices of these two products were affordable, and they had a high demand by consumers. Butter and cottage cheese were mainly demanded by institutional consumers such as hotels and pizzeria houses. For processing of milk and milk products, Almi utilised 0.610 kWh energy per kg milk from the electric source. As a result, a total of 61,799 kg CO2-eq per year was made by this processing plant, that is 0.080 kg CO2-eq/kg milk (Table 6). The other three small-scale processors used relatively low amounts of energy. Initially, they were collectors and retailers of milk, but through time processing started to save unsold milk from spoilage. Bereket and Biftu milk processing plants contributed the same amount of carbon footprint per kg of milk from electric source (0.013 kg CO2-eq/kg).

Except for Biftu, the milk processing plants had a generator as a reserve for electric power interruption. Since Almi fresh milk and milk product processing plant is a relatively big factory, a high-power generator was used that could adequately supply the required power for the machines. Therefore, the generator consumed a huge quantity of fuel and caused an emission of 220,472 kg CO2-eq per year which induced 0.398 kg CO2-eq/kg processed milk (Table 6). On average, milk processors emitted 0.370 kg CO2-eq/kg processed milk to the environment from fuel source. Consequently, at processors level the average carbon footprint emitted for processing of kg milk was found to be 0.160 kg from both electric and fuel sources.

**Table 6** Carbon footprint of milk processing from electricity and fuel

| Processing unit | Power (kWh/year) | $CO_2$ emitted (kg/year) | Processed milk (kg/year) | $CO_2$ (kg/kg) |
|---|---|---|---|---|
| *Electricity*[a] | | | | |
| Almi | 475,373 | 61,799 | 774,384 | 0.080 |
| Bereket | 23,407 | 3043 | 238,680 | 0.013 |
| Yaya | 17,358 | 2257 | 159,120 | 0.014 |
| Biftu | 6987 | 908 | 67,704 | 0.013 |
| Sum | 523,124 | 68,006 | 1,239,888 | 0.055 |
| *Fuel*[b] | | | | |
| Almi | 91,104 | 220,472 | 554,216 | 0.398 |
| Bereket | 769 | 1860 | 34,320 | 0.054 |
| Yaya | 2197 | 5316 | 22,880 | 0.232 |
| Biftu | – | – | – | – |
| Sum | 94,069 | 227,648 | 611,416 | 0.370 |
| *Electricity and fuel* | | | | |
| Almi | 566,477 | 282,271 | 1,328,600 | 0.212 |
| Bereket | 24,176 | 4903 | 273,000 | 0.018 |
| Yaya | 19,555 | 7573 | 82,000 | 0.042 |
| Biftu | 6987 | 908 | 67,704 | 0.013 |
| Sum | 617,193 | 295,654 | 1,851,304 | 0.160 |

[a]Emission factor 0.13 kg $CO_2$/kWh (Brander et al. 2011), and indirect emission of electricity was not considered in this study

[b]Emission factors for diesel and gasoline 2.67 and 2.42 kg $CO_2$/kg, respectively (Gebre 2016)

## 4 Discussion

Large-scale milk collectors in Ziway-Hawassa milk shed contributed through transportation an average emission of 0.023 kg CO2-eq/kg milk. In the absence of studies from Africa, studies from other continents have been used for comparison. In the USA, relatively higher estimates of emissions 0.050 kg CO2-eq/kg milk by Ulrich et al. (2012) and 0.07 kg CO2-eq/kg milk by Thomas et al. (2013) were reported from transportation of milk. These figures are lower than the average carbon footprint of 0.106 kg CO2-eq/kg milk induced by small-scale collectors in the present study. Transport of national branded milk in Italy generated 0.115 kg CO2-eq/kg milk (Torquati et al. 2015), which is higher than the Ethiopian emissions of this study. A study in Sweden reported an emission of 0.070 kg CO2-eq/kg milk transported from farm to processing plant (Flysjö 2012), whereas 0.030 kg was reported in Europe and China (FAO 2010; Zhao et al. 2017). This last figure is comparable to the weighted average emission contributed by large and small-scale collectors together in the current study (0.033 kg CO2-eq/kg milk). The reasons why large-scale collectors in the current study emitted less CO2-eq/kg than those reported for the USA, Europe and China may have several reasons. Firstly, Ethiopian large-scale collectors used relatively small-sized vehicles compared to developed countries. Secondly, transport distances of milk and milk products in the study area were relatively short since production, processing and consumption all take place in the same area. Thirdly, in the USA, Europe and China milk is transported chilled in refrigerated trucks which consume extra energy for chilling.

The three reasons above did not apply to small-scale collectors due to counter balancing advantages by inefficient loading capacities of vehicles. In the development of a cold chain in Ethiopia, efforts have to be taken to introduce efficient energy consuming devices to keep upstream emissions low.

In Ziway-Hawassa milk shed, the average CO2-eq/kg milk emitted by transport from collection points to the retailers/consumers was 0.060 kg. Thomas et al. (2013) reported a slightly higher finding of 0.072 kg CO2-eq/kg milk for distribution of products from processing plant to retailers/consumers in the USA. In China, milk distribution and transportation of packaged milk contributed much lower emissions (0.007 kg CO2-eq/kg milk) (Zhao et al. 2017). Since this concerns a combined figure (transport 1 and 2, see Fig. 3), the higher emission in the current study compared to China might be contributed by small-scale collectors which heavily underutilised the loading capacity of vehicles.

The average emission released through milk cooling in the present study was 0.008 kg CO2-eq/kg. In other studies, higher findings have been reported, e.g. from Canada (0.019 kg CO2-eq/kg fluid milk) (Vergé et al. 2013), and from USA (0.099 kg CO2-eq/kg refrigerated milk) (Thomas et al. 2013).The reason for the difference may be due to the variations in the standard emission conversion factor among different countries and power utilisation capacity of cooling machines. The emission conversion factor for Ethiopian electric power (0.13 kg CO2-eq/kWh) is far below that of the USA (0.547 kg CO2-eq/kWh) and Canada (0.179 kg CO2/kWh) (Brander et al. 2011).

In the present study, processors emitted 0.370 and 0.055 kg CO2-eq/kg processed milk from fuel and electricity, respectively. In the USA, emission from processing of products was 0.077 kg CO2-eq/kg packed milk (Thomas et al. 2013). Studies in Europe reported on average 0.086 (FAO 2010) and in Sweden 0.05 kg CO2-eq/kg processed milk (Flysjö 2012). All these reported values in the USA and Europe are lower than the overall average emission value contributed by milk processors in Ziway-Hawassa milk shed (0.160 kg CO2-eq/kg milk). The higher emission of the processing plants in the current study might be due to the high utilisation of fuel which has a higher emission conversion factor than electric-based emission. In practices, the frequency and duration of electric power interruptions in Ethiopia is high compared to developed countries such as USA and Europe. As a result, every processing plant has a generator as a power backup which consumes fuel and imposes higher emission. Dairy plants in Iran and China emitted on average 0.163 and 0.173 kg CO2-eq/kg pasteurised milk, respectively (Daneshi et al. 2014; Zhao et al. 2017), which is comparable to this study. In the present study, emission from fuel was much higher than from electricity. In Canada, similar findings were reported, 0.666 kg CO2-eq/kg processed fluid milk from fuel and 0.285 from electricity (Vergé et al. 2013). In fact, the average emission reported in Ziway-Hawassa milk was much lower compared to the findings reported in Canada but higher than the values reported for China (Table 7). In the present study, Almi fresh milk and milk products processing centre showed high emission level (0.398 kg CO2-eq/kg milk) from its fuel generators compared to the other three small-scale processors.

Similar studies on carbon footprint in downstream dairy value chains are mainly found in the context of developed countries. Since causes and effects of climate change in the African context are expected to be significant in the next decade, further studies contributing to climate smart practices and innovations are highly required.

**Table 7** Carbon footprint estimations in the lower dairy value chain in different countries

| Countries | Carbon footprint (kg $CO_2$/kg milk) | | | | References |
|---|---|---|---|---|---|
| | Transport 1 | Transport 2 | Cooling[a] | Processing | |
| Ethiopia small-scale collectors | 0.106 | | 0.0082 | | This study |
| Ethiopia large-scale collectors | 0.023 | 0.060 | 0.0081 | | This study |
| Ethiopia milk processors | | | | 0.160 | This study |
| USA | 0.050 | 0.072 | 0.0990 | 0.077 | Ulrich et al. (2012), Thomas et al. (2013) |
| Canada | | | 0.0190 | 0.285 | Vergé et al. (2013) |
| China | 0.030 | 0.007 | | 0.173 | Zhao et al. (2017) |
| Europe | 0.030 | | | 0.086 | FAO (2010) |
| Sweden | 0.070 | | | 0.050 | Flysjö (2012) |
| Iran | | | | 0.163 | Daneshi et al. (2014) |
| Italy | 0.115 | | | | Torquati et al. (2015) |

[a]At milk collection centre

## 5 Conclusions

The mean kg $CO_2$-eq/kg milk was significantly different between small- and large-scale milk collectors. On average, milk collectors contributed 0.056 kg $CO_2$-eq/kg milk during collection (transport 1), 0.060 kg $CO_2$-eq/kg milk during the distribution of products (transport 2) and 0.008 kg $CO_2$-eq/kg through cooling machines. In general, large-scale milk collectors showed lower emissions compared to small-scale collectors due to a better utilisation of loading capacity of vehicles. Processors in Ziway-Hawassa milk shed produced high levels of emissions mainly due to fuel consumption during interruption of electricity. A shift from small- to large-scale milk collection by forming a cooperative as well as increased use of electricity instead of fossil fuel would result in a lower carbon footprint of the Ethiopian dairy sector. In the transformation from informal to formal dairy value chains, quality control and waste management systems of milk collectors and processors need further study to reduce emissions from product spoilage and the development of a climate-smart milk supply chain in the milk shed.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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