Understanding Variability in Carbon Foot Prints of Smallholder Dairy Farm, in the Central Highlands of Ethiopia.

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Abstract

Smallholder dairy farms face enormous challenges of increasing milk production while also mitigating associated GHG emission, thereby increasing climate resilience. Carbon foot prints (CF) of smallholder milk production is expected to increase with increasing demand for dairy products under business as usual scenario. This study estimate the carbon foot prints of smallholder milk production and examine variation across farms using data from 480 households in order to identify viable options for mitigating GHG emissions. We applied a cradle to farm-gate Life Cycle Assessment (LCA) approach to examine the effects of farming systems on GHG emissions intensifies across intensification gradients of smallholder farm (SHF) from four dairy potential districts in central highlands of Ethiopia. Our study findings revealed that enteric fermentation was the primary source of GHG emission and CH_4 emission from enteric fermentation and manure management comprised the bulk of total emission across farms. The estimated average CF varies depending on farm systems, Global Warming Potential (GWP), and allocation methods used. When GHG emissions were allocated to multiple products using economic allocation to milk, beef, finance and insurances, the overall average CF of milk production reported was 1.91 and 2.35 kg CO_2e/kg fat and protein corrected milk (FPCM), and on average 72% of total GHG emissions were allocated to milk. With regard to farm typology, rural SHF tended to have significantly higher CF per kg of milk than urban and peri-urban SHF system. Variation in milk yield explained more than 50% of the variation in GHG emission intensity at farm level. Feed digestibility and feed efficiency had a negative and significant ($P < 0.01$) association with CF of SHF. Our findings suggested that improved feeding by increasing the proportion of concentrate and improved forage, and chemically upgrading straw and crop residue could provide opportunity to both increase milk yield and reduce the CF of milk production of SHF in the study area. Supporting SHF to realize strategies that contribute to climate resilient dairy development will requires interventions at several level in dairy value chain.

1. Introduction

The global livestock sector in general and the Ethiopian dairy sector in particular lies at the crossroads of mitigating greenhouse gas (GHG) emissions as well as enhancing resilience to climate change, to meet the increasing demand for livestock products (FAO, 2010; Shapiro et al., 2015). Ethiopia is home to Africa's largest cattle population, currently estimated at about 65 million cattle, and endowed with a diversified breed and distinct production system (CSA, 2020). The sector has a potential to significantly contribute to national growth and development plan of the country, including poverty alleviation by improving the livelihoods of smallholder farmers (Gizaw et al., 2016; Tegegne et al., 2013). Smallholder farmers represent about 85% of the population and are accounts for 98% of milk production in the country. Smallholder dairy farm in the central highland of Ethiopia, is one of the most developed and the leading milk shed in the country. The milk shed is known for its high milk production potential and serve as the major milk supplier to the more affluent population in the capital, Addis Ababa (Brandsma et al. 2012; Zijlstra et al., 2015). However, despite the potential of the sector in stimulating growth, reducing poverty and achieving food security, the sector has not been able to produce adequate products to satisfy the growing demand of the country, mainly due to feed problems, poor health services and low genetic potential of indigenous breeds (Zijlstra et al., 2015).

On the other hand, cattle are the main contributor to GHG emission in Ethiopia. Methane emission from enteric fermentation and manure management accounts for 45% of the total national methane emission (CRGE, 2011; FAO & NZAGRC, 2017). The rural mixed crop-livestock system, and the pastoral/agro-pastoral system, contribute 96% of national milk production, but at the same time responsible for 56% and 43% of the total greenhouse gas (GHG) emissions associated with milk production respectively (de Vries et al., 2016; FAO & NZAGRC, 2017).

Given the expected increase in demand for dairy products, the Ethiopian dairy value chains are facing tremendous challenges of a substantial increase in milk production, while mitigating associated GHG emission (Shapiro et al., 2015; FAO & NZAGRC, 2017). More importantly, the Ethiopian green growth pathway has the ambition to foster economic development and growth, along with limiting GHG emission levels to 150 million tonnes (CO_2 eq-) by 2030 under business as usual (BAU) scenario. As part of the green growth strategy, the dairy sector has been identified and prioritized for fast track implementation to reduce GHG emissions while also improving milk production (CRGE 2011; Shapiro et al., 2015). Emission reduction through reduction in emission intensity while improving smallholder farmers' livelihoods have strong alignment with the Ethiopian livestock development strategy (CRGE, 2011; Shapiro et al., 2015). For this purpose, estimation of GHGs emission and identifying an emission hotspot from smallholder dairy farms helps to generate baseline information that could serve as an input to national emission inventory and designing subsequent national mitigation strategies. Moreover, studies at local level are very important to assess the effects of specific farm management practices to improve CF performances of SHF milk production, so that contribute knowledge of practices changes that can be promoted through Ethiopia's livestock maser plans.

So far, however, in spite of the large contribution of the sector to the national GHG emissions and large number of cattle population in Ethiopia, limited attempt has been made to examine carbon footprints of smallholder dairy farming system, and how variation in farming system affects CF of SHF milk production. Some of the CF studies so far have either focused on evaluating the GHG emission of milk production at regional and/or national level (FAO & NZAGRC, 2017) or assumed characteristics of typical farm and actual data from small samples of farm (Woldegebriel et al., 2017; de Vries et al., 2016). Accordingly, the findings of those studies are, highly aggregated and are of little help in addressing the local peculiarities of production characteristics and intervention measures. More important, in spite of the multiple functions of dairy cattle in the livelihoods of small holder farmer in the study area, the vast majority of CF solely based on the base of main products (Milk or meat) (De Varis et al., 2017; FAO & NZAGRC, 2017; Opio et al., 2013). The results of mono-dimensional analyses does not reflect the complexity of the dairy production characteristics appropriately, as a result, it leads to biased conclusions.

To our knowledge, this study is the first to use actual data from a large size of SHF and large number of dairy cow to estimate cradle to farm-gate GHG emission and to examine variation in CF of milk production across different farming system. We hypothesized that CF of smallholder milk production significantly varies across farms.

2. Materials And Methods

2.1 Description of the study area

The study was conducted in Salale milk shed the central highlands of Ethiopia. The study area is lies at 38°07’60”E longitude and 9°40’60”N latitude and having an elevation of 250 to greater than 3000 masl. The area receive average annual rainfall of 1200 mm with average minimum and maximum temperature of 6˚C and 21˚C respectively. According to Brandsma et al. (2012) the large proportion of the area (42%) falls under tropical highland similar to that of temperate regions climate and almost a quarter of the land in the zone which is typical tropical dry land. Livestock, especially dairy farming is the dominant agricultural enterprises and sources of income in the Salale highland.

2.2 Sampling and Data collection

A multi-stage stratified random sampling technique was employed to select SHF for this study. First four districts (Sululta, Wuchale, Girar Jarso and Degem) were purposively selected from Salale milk shed to represent different agro-ecology and farming system. Girar Jarso district was selected to represent urban SHF where dairy farming is practiced to support family income in addition to off-farm activities. Sululta and Wuchale districts represent mid-land agro-ecology and peri-urban dairy farming system where crop and livestock production are closely integrated. Degem district is characterized by typical highland agro-ecology where both crop and livestock (dairy) production are closely integrated. Four kebeles (the smallest administrative unit in Ethiopia) were purposively selected from each districts by considering dairy cattle potential, road accessibility and SHF registered under national dairy cattle data base. In each kebele, SHF were stratified to urban, peri-urban and rural dairy farming system based on scale of production, production resources, feeding system, breeds and genotypes kept, and contribution of dairy to livelihoods (Gizaw et al., 2016; Tegegne et al., 2013). A total of 480 (Urban = 120, peri-urban =180 and Rural = 180) SHF were randomly selected to represent all farming system (Arsham, 200). A survey questionnaire was designed to collect data on farm household characteristics, farm input-output, sources of feed, production and feeding practices, production and reproductive performance, manure management system. Three enumerators, experts in livestock production were selected from each district, were given orientation and refresher training on household survey. The survey was supervised by the firs author. The data collected through survey were triangulated by transect walk and group discussion. Additional data were extracted from national dairy cattle data base found Addis Ababa, Ethiopia. Data collection was held between July 2020 and February 2021. SHFs were visited three times in the period of July, 2020 to February 2021 to obtain seasonal variation of feed resources and for cross checking the data.

Field measurements: Body weight of different categories of animals were estimated by using heart girth (HG) measurements of individual animals by the standard description list developed by FAO, (2011). The HG measurements were converted to an estimate of live weight (LW) in kg by using the regression equation developed for Ethiopian Zebu and cross breed cattle and east African cattle by (Taylor and Galal,1980), ILRI, 1998; (Goopy et al., 2018).

https://agris.fao.org/agrissearch/search.do?recordID=ET2010000024

Milk yield and Chemical Composition: Milk yield data for SHF under the study was extracted from national dairy cattle data base. Milk yield data also obtained from milk collector (retailers) and dairy cooperative union and farmers to substantiate data obtained from national dairy data base. Milk yield data of 2019-2020 lactation period were used for the analysis. The standard 305-d milk yield for each animal was estimated from test date (TD) milk yield records by using test interval method described by Sargent (1968), cited in Meseret et al. (2015). Milk suckled by calf was not accounted for in rural SHF. For milk chemical compositions, milk samples were collected from a total 70 SHF (U= 27, PU = 21, Rural = 21) in the morning and afternoon time following standard procedure and analyzed for its chemical composition such as fat (%), using (Gerber method) and milk density (Kg/L at 20^{O}C; Van Marle-Koster et al., 200). Richmond's formula (Becter and Sharma, 1980) was used to calculate milk Solid Not-Fat (SNF) as follows:

$$\mathrm{SNF\%} = \left(\frac{\text{milk density (Kg/L)}}{4}\right) + \left(0.22 * \mathrm{BF}(\%)\right) + 0.72 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Milk energy content (ECM) was calculated following the equation developed by Tyrrel and Reid (1965):

$$\mathrm{ECM(MJ/kg)} = 0.0386\mathrm{BF}(\text{g/kg milk}) + 0.0205\ \mathrm{SNF}\ (\text{g/kg milk}) - 0.236 \ldots\ldots\ldots\ldots (2)$$

Secondary data collection: Secondary data was collected from various sources. Nutrient component and nutritional characteristics of common feed basket specific to the study area were taken from ILRI database and various scientific publications. The standard crop yields, fertilizer use, pesticide use and market price were based on central statistics agency (CSA). Secondary data was also collected from: IPCC guidelines (IPCC, 2014 refined, 2019; default values, coefficients, and emission factors for calculation of emissions from animals, feed, and manure). GLEAM*i* databases (Opio et al., 2013; FAO, 2016; IPCC, 2019), Feed Print (Vellinga et al., 2013) were used for feed emission.

2.3 Method of estimating carbon footprints

An attributional LCA approach was employed to assess GHG emission of 480 SHF over one year. Global warming potentials (GWP) of the IPCC assessment report (IPCC, 2007; IPCC, 2014) were used to calculate carbon dioxide equivalent (CO_2e) units for carbon dioxide, methane, and nitrous oxide. The Global Livestock Environmental Assessment Model-*interactive* (GLEAM-*i*) (https://gleami.apps.fao.org;

FAO, 2020) was used to estimate GHG emissions, and the CF is expressed in kg CO_2e per kg FPCM (fat and protein corrected milk).

2.3.1 System boundaries, functional units, and allocation

A cradle to farm gate system was determined following (Opio et al., 2013; FAO, 2016) which include all on farm and off-farm processes related to dairy production. On farm processes were mostly related to the farm activities such as management of dairy cattle, feed production and processing and manure management practices. The off-farm process included production, processing and transportation of feeds and energy production. As indicated in the schematic diagram below (Fig. 2) the system boundary included on farm processes (Feed production and processing, farm management practices and manure management) and off-farm processes.

2.3.2. Functional Units and Allocation

As recommended in global CF studies the functional unit used is kg CO_2e/kg FPCM (FAO, 2016). Milk yield (liter) was converted to kg using a standard density of 1.031 kg /L and corrected to kg CO_2e/kg FPCM, following equation described (Opio, 2013), assuming the overall average of 4.18% fat, 3.25% protein content of laboratory analysis of the study area (Table 1). As reported in previous studies in Tropics, dairy farming plays a multiple roles in SHF livelihoods, provide milk and meat, sources of income (sale of animal and animal products), draft power, insurance and security for future finance needs and other social and cultural services in Ethiopia (Moll et al., 2007; Behnke and Muthami, 2011; Woldegebriel et al., 2017). Hence, in this study the burden of GHG emissions were shared to a kg of row milk, a kg of beef, an hour of draught power, and a kg of manure used, finance and insurance. Emissions were attributed to milk production using three allocation methods: economic allocation based on the prices of products and co-products, mass allocation based on the protein content in milk and meat produced at farm level, and where all GHG emission were allocated to milk production at farm level. However, to compare the result with the existing literature and for consistency, the present study used economic allocation for each products and co-products.

In economic allocation approach, GHG emission generated in the process of milk production are allocated to product and co-products according to their economic values (FAO, 2010; Opio, et al., 2013). As also suggested previously, in the present study milk and meat have a direct market value, while the economic value of finance and cattle as a means of insurance and manure as fertilizer can only be assessed indirectly (Moll et al., 2007; Weiler et al., 2014). The current milk price per kg reported was 21.65, and 16.15 (Br). This price difference was caused by lack of appropriate and consistent market system in the area. The economic value of animals sold was based on the selling price of different categories of animals. The local rent value of an ox per year was used to determine the economic value of animal used for draught purpose. The quantities of manure produced (Refined IPCC, 2019), used as fertilizer for on farm crops, sold as fertilizer and used as fuel in the form of dung cakes was collected and observed during survey. According to Alary et al. (2011), the economic value of manure as fertilizer is valued based on synthetic nitrogen fertilizer equivalents. The economic value of nitrogen in manure used for fertilizing is 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 used by (Alary et al., 2011; Weiler et al., 2014). Similarly, as described in the study of Woldegebriel *et al.* (2017), the economic value of dung cake sold and used as source of fuel was valued based on the local market.

Valuing the role of cattle as finance and insurance is well documented in the previous sudies (Moll et al., 2007; Behnke and Muthami, 2011). The financing value in the study area was estimated at 8%, based on commercial interest rates for short and medium term credit in Ethiopia. Similarly, the economic value of cattle as insurance was calculated as a product of economic value of herd and the insurance premium, i.e. the cost that farmers would need to pay to purchase insurance coverage equal to the capital value of their herd (Moll et al., 2007; Weiler et al., 2014). The insurance premium of 10% in the rural system was estimated based on national insurance rates. Economic allocation was also used to allocate the share of GHG emissions for crop residue production, where the proportion of economic importance of crop residues were computed (Woldegebriel et al., 2017).

Table 1.Chemical composition of milk in the study area

Milk composition (%)	Urban	Peri-urban	Rural
Fat	3.79 ± 0.09	3.79 ± 0.12	4.49 ± 0.43
Protein	3.05 ± 0.063	3.2 ± 0.034	3.5 ± 0.41
SNF	8.2 ± 0.15	8.2 ± 0.33	8.56 ±1.56
Density	29.9 ± 0.29	30.5 ± 0.29	31.15 ± 1.65
Lactose	4.36 ± 0.9	4.66 ± 0.1	4.34 ± 1.43

2.3.3 Inventory Analysis

Four hundred eighty (480) SHFs were selected to represent the three SHF system in the study area. GHG emissions were estimated for a total 1365 (515, 515, 350) cattle in urban, peri-urban and rural SHF system respectively, while about 235 dairy cattle were dropped from the analysis because of incomplete milk taste date and data inconsistency prior to data analysis (Table 2).

Methane emission from enteric fermentation: Enteric methane emission was estimated based on gross energy intake (GEI) and 6.5% conversion factors, using IPCC Tier 2 model (IPCC, 2006; Refined IPCC, 2019). Average daily feed intake expressed as gross energy intake was calculated from the diet for cattle (cow, replacement and male). Emission factor for each animal category was calculated following Marquardt et al. (2020), a protocol for a tier 2 approach to generate region -specific enteric methane EF.

Emission from manure management:

Direct and indirect N_2O and CH_4 emissions from manure management were calculated for each animal category using IPCC Tier 2 method. The New Refined IPCC (2019) spreadsheet was used to calculate methane emission factor from manure management. Methane conversion factors (MCF) were estimated considering average annual mean air temperature (^oC) in the study area. The basic step in N2O emission calculation using tier 2 is estimation of nitrogen excretion rate from managed manure. Nitrogen intake rates were calculated following Refined IPCC (2019) equation using input data on GE intake, CP content of major feeds. Nitrogen excretion was estimated by subtracting nitrogen retention from nitrogen intake IPCC (2019). IPCC default emissions factor (for direct N2O emissions from manure management system (EF3) for Africa farming system was adapted from IPCC due to lack of country specific data.

Emission from feed production and transportation: Data on-farm feed production and transportation include, draught power; application of synthetic fertilizers, manure, pesticide and seeds; and modes of transportation were gathered during survey. Framers used animal traction for crop production and harvesting, and no SHF reported to use farm machines in the study area. Following Feyissa *et al.* (2018), the amount of hay, crop residue and improved forage per hectare was estimated from farmers recall and data from CSA (2020). Emission related to off-farm feed production and transportation was estimated from the amount of feed produced off-farm. There were no country-specific emission factors available in Ethiopia. Feed emission factors (kg CO_2e kg DM^{-1}) for this study were taken from (FAO and LEAP, 2015; Wilkes et al., 2020), and feed print (Vellinga et al., 2013) Netherlands.

2.4 Data analysis

Both descriptive statistics and one way ANOVA was used to analyze quantitative data. One way ANOVA was employed to analyze variation of GHG emission per kg milk among the three farming system. Post-hoc test was used for means comparison. The association between GHG emission and milk yield, digestible energy, and feed efficiency was estimated using regression analysis. Analyses were made by using Statistical Package for Social Studies (SPSS) (2003) version 26 computer software and Microsoft Excel computer program. Uncertainty analysis was carried out using Monte Carlo simulation implemented in excel spread sheet. Uncertainty was estimated as the margin of error with a confidence interval of 95%. Calculation of margins of error used a z-score of 1.96 corresponding to α value of 0.05.

3. Results

3.1 Characteristics of smallholder Dairy Farming System

Table 2 depicts herd structure, breed composition and production performances in the study area. The average herd size and the number of breeding caw was 4.85, 5.91 6.45, and 3.02, 2.55 and 2.31 in urban, peri-urban and rural farming systems respectively. This results are in agreement with previous study (Gizaw et al., 2016; Tegegne et al., 2013) in the central high lands of Ethiopia. All cows in urban and peri-urban SHF were either pure exotic breed or cross breed of medium to high level exotic blood cattle (he cross of Holstein and *Bos -indicus*). Whereas dual purpose indigenous cattle were dominantly kept in rural SHF. All animals were stall fed in urban farm where farm land was a bottle neck. Stall feeding with limited grazing on restricted area and private pasture was the common feeding practices in per-urban farming system. Whereas, the rural SHF followed free grazing of natural pasture and crop aftermath throughout the year with a minimum supplementation for milking cow.

Table 2 Farm characteristics, herd structure, and production performances of SHF (mean ± SD)

Parameters	**Farming system**			**Overall**
	Urban	Peri-Urban	Rural	
	Mean ± SD	Mean ± SD	Mean ± SD	
Breed & genotype				
Cattle breed	High grade Holstein Friesians	High grade & Crossbred	Pure indigenous breeds	
Herd structure				
Livestock holding	5.85 ± 2.58	5.91 ± 2.97	6.43 ± 3.57	5.73 ± 3.1
Adult female	3.02 ± 1.39	2.55 ± 1.329	2.31 ± 1.112	2.63 ± 1.15
Adult male	NA	1.2 ± 0.56	1.57 ± 0.18	1.43 ± 0.34
Heifer	2.16 ± 1.38	1.76 ± 1.09	1.62 ± 0.781	1.85 ± 1.06
Young Female	1.95 ± 1.21	1.72 ± 1.14	1.36 ± 0.672	1.68 ± 1.05
Growing male	1.46± 0.61	1.46 ± 0.755	1.43 ± 0.693	1.44 ± 0.71
Herd Performance				
Age at 1st calving (year)	3.1±0.4	3.27 ± 0.551	3.79 ± 0.66	3.51 ± 0.49
Lactation length (month)	9.56±0.91	8.43 ±1.059	6.77 ± 0.948	8.12 ± 0.98
Calving interval (month)	13.3 ± 0.86	13.7 ± 0.78	24.5 ± 0.27	13.06 ±0.54
MY FPC kg/year	3750.7^{a} ± 511.4	3226.46^{b}± 452.67	785.74^{c} ± 98.57	2587.64 ± 354.2
Adult cow BW (kg)	429.12^{a} ± 43.72	423.26^{a} ± 42.02	284.16^{c} ± 34.46	374.02 ± 34.17
Average Agricultural Land holding (ha)				
Agricultural land (ha)	1.5 ± 0.59	2.87 ± 1.2	3.38 ± 0.9	2.58 ± 0.86
Crop land (ha)	0.93 ± 0.44	2.21 ± 0.862	2.14 ± 0.95	1.79 ± 0.75
Pasture land (ha)	0.65 ± 0.256	0.69 ± 0.620	1.23 ± 0.88	0.86 ± 0.58

Adult cows (≥3years), growing female (1-3 years), growing male (1-3 years), Calve (≤1), calve (≤ 6m), Adult male (≥3). Values in the brackets are number of animals; Means with different superscript letters in the same row indicate significant differences at p<0.05; MYFPC= fat and protein corrected milk yield per **y**ear; NA = not applicable.

Natural pasture hay, crop residues and pasture grazing constitute the dominant sources of basal feed resources in the study area. Crop residues dominantly cereal straws, are produced and used as animal feed in peri-urban and rural farming system, particularly during dry season when pasture is hay depleted (Table 3). The commonly used agro-industrial by-products supplementation were wheat bran, wheat middling, and noug (*Guizotia abyssinica*) seed cake, while, oats grain/hull and grass pea hull were also used as local supplements (Table 3). The share of these feed ingredients in animal diet varied considerably across farming system and season of the years. The average feed digestibility (DMD) in rural farming system was significantly (≤0.05) lower than in urban farming system (Table 3). The overall feed digestibility and the proportion of supplementary feed in daily feed ration reported in the present study is similar with the LCA study of smallholder dairy farming system in Ethiopia and Kenya (Woldegebriel et al., 2017; Wilkes et al., 2020), but much lower than dairy farming system in developed countries (IPCC, 2019).

A large variation was reported in average lactation milk yield and body weight across farming system. Milk production per cow per year was significantly higher (≤ 0.01) in urban than in per-urban and rural SHF. The significant variation in milk yield reported might be attributed to the difference in degree of intensification, production objectives, and type of breeds and genotypes kept by farmers. This finding is in agreement with the reports of the study conducted in central highlands of Ethiopia (Tegegne et al., 2013, Gizaw et al., 2017). The average milk production per cow per year in urban and peri-urban SHF is higher than the CF study in India, and the CF study in Kenya (Gerg et al., 2016; Wilkes et al., 2020). However, the average milk production per cow per year reported in rural SHF is below milk production levels in rural smallholder farms in India and Kenya (Gerg et al., 2016; Wilkes et al., 2020). Besides, low digestibility of feed, this could be attributed to the breed/genotype of cattle kept in rural SHF. Rural SHF in Kenya highland keep high-grade European dairy breed, whereas, almost all of the rural SHF farmers in the study area keep cows of low generic potential, local *bos -indicus* , and a very few cross-bred cattle. This is in agreement with the previous reports of the study conducted in central highlands of Ethiopia (Tegegne et al., 2013, Gizaw et al., 2017).

Selling of fluid milk to urban market was the main production objectives of urban and peri-urban SHF. Dairy farming was the sole dominant sources of livelihood and sources of income for majority of urban SHF. In agreement to this, Gizaw et al. (2016) indicated that, livestock production is the most important activity, and/or the sole sources of livelihoods for nearly 100% of urban dairy farmers in the central highlands of Ethiopia. Whereas, milk production and draught power were given high rank in rural smallholder farming system where, animals are also kept for manure (fertilize the soil and fuel production), and castrated male are used for fattening.

Table 3. Feed type, diet composition and dry matter digestibility (% mean ± DS) in the three farming system.

Feed type (%)	Farming system			% DMD	References
	Urban (N = 120)	Peri-urban (N = 180)	Rural (N =180)		
Natural pasture (Native)	NF	8.77	32.17	58.49	Feyissa et al., 2014; Derara et al., 2021
Grass hay	18.98	13.05	1.78	59.3	Bediye et al., 2019; Feyissa et al., 2015; Shiferaw et al., 2020
Commercial concentrate	2.11	2.11	NF	70.28	Feyissa et al., 2015
Wheat bran	7.83	6.76	1.42	71.15	Feyissa et al., 2015
Wheat middling	7.11	4.74	1.98	79.03	;;
Oats grain	2.28	1.52	1.90	76.03	;;
Noug cake	7.10	4.97	NF	70.99	;;
Cotton seed cake	0.85	0.85	NF	84.67	;;
Desho grass (*Pennisetum glaucifolium*)	0.75	1.32	1.09	52.68	Faji et al., 2019
Napier grass (*Pennisetum purpureum*)	NF	NF	0.51	50.5	Gezahegn et al., 2019
Vetch (Vicia species)	NF	1.00	1.00	66.47	Gezahegn et al., 2015
Alfalfa	NF	0.77	1.15	76.63	Diriba et al., 2014
Oats (*Avena sativa*) straw	0.47	0.46	0.70	46.89	Gezahegn et al., 2019
Wheat straw	3.08	3.69	3.28	41	Feyisa, 2015
Barley straw	3.53	2.69	2.48	41.32	Derara et al., 2021;

					Bediye et al., 2019
Teff straw	2.76	2.76	2.30	46.01	Feyissa et al., 2015
Grass pea hull	NF	0.61	1.54	61.42	Feyissa et al., 2015
Faba bean hull	0.92	0.31	0.92	61.42	;;
Brewer residue	3.18	3.18	1.04	69.46	;;
Atela (traditionally home-made liquor residue))	0.74	0.74	2.21	73.66	;;
Feed digestibility	62.28 ± 3.44[a]	60.29 ± 3.25 [b]	57.46 ±3.83[c]		

Means with different superscript letters in the same row indicate significant differences between seasons of the ear at (≤0.05); DMD = dry matter digestibility; SD = standard deviations; NF: not fed

Manure management system was similar across different farming systems in the study area (Table 4). Manure management system and the proportion of animal manure used as dung cake for fuel is similar with the earlier reports of (de Vries et al., 2016; Woldegebriel et al., 2017). About two thirds of manure was managed in solid storage of dung cake and dry lot system in urban and peri-urban SHF system. Farmers used manure for multiple purpose, such as fertilizer for crop and pasture land, sold as dung cake for fuel, and very few farmers (urban, per-urban) used for biogas. Use of dung cake for fuel was a common practices among smallholder farmers in central highlands of Ethiopia (de Vries et al., 2016; FAO & NZAGRC, 2017). About 40-50% of the total animal manure used as sources of domestic fuel, for home consumption and sold for income generation. In line to his report, the Earlier CF study indicated that about 40% of animal manure used as sources of fuel, which means a large amount of valuable nutrients is lost from farm and regional nutrient cycle (de Varis et al., 2016).

Table 4. Manure management systems

Manure management systems (%)	Farming systems		
	Urban	Peri-urban	Rural
Pasture/Range	0	10.76 ±1.79	41.5 ± 7.05
Daily spread	1.69 ± 0.50	4.60 ± 1.21	4.54 ± 1.21
Solid storage	37.57 ± 8.07	30.71 ± 3.56	17.23 ± 1.75
Dry lot	31.35 ± 5.91	26.00 ± 1.62	14.23 ± 1.74
Liquid/Slurry	1.77 ± 0.70	1.29 ± 0.64	0
Burned for fuel	25.29 ± 3.88	23.18 ± 1.6	12.40 ± 0.82
Composting	1.58 ± 0.87	2.96 ± 0.76	10.10 ± 1.38
Anaerobic digester	0.75 ± 0.44	0.5 ± 0.5	
Total	100	100	100

3.2 Greenhouse gas emissions and emissions hotspot

Enteric fermentation (CH_4) was the major source of GHG emissions, accounted about 67% of the total GHG emissions in all farming system. Greenhouse gas emissions from enteric fermentation was significantly ($p\leq 0.05$) higher in rural than in urban and peri-urban SHF. But, no significance ($p\leq 0.05$) variation observed between urban and peri-urban farming system. The proportion of GHG emissions associated with manure management (CH_4 and N_2O), and emission from feed production and transportation (CO_2, CH_4 and N_2O) contributed about 16% and 15% to the total emissions respectively. Greenhouse gas emissions related to feed production and processing were significantly higher ($p\leq 0.05$) in urban SHF than in rural SHF. Similarly, emission from manure management was significantly lower ($p\leq 0.05$) in rural SHF than in urban and per-urban SHF. Methane (CH_4) emissions from enteric fermentation (73.16) and N_2O emission (22.88) from manure management, and feed production and transportation were the two major hotspots of SHF. Carbon dioxide (CO_2) from feed production, processing and transportation contributed the least, about 3.96% to the total emissions. Adult and replacement females contributed most to the total farm GHG in urban and peri-urban SHF, however, in rural SHF about 31% of total GHG emission was caused by male stock.

Table 5. Sources of GHGs emissions and emission hotspot across farming systems

Sources of GHG emission (%)	Urban	Peri-urban	Rural	Total
Enteric fermentation (%)	66.2[a]	67.59[a]	69.77[b]	67.85
Manure management (%)	16.89[a]	16.67[b]	15.78[c]	16.45
Feed production & processing (%)	16.91[a]	15.74[ab]	14.45[b]	15.7
Contribution of GHG emissions				
CH_4 (%)	74.53[a]	72.07[a]	72.86[a]	73.16
N_2O (%)	20.58[a]	23.55[b]	24.52[c]	22.88
CO_2 (%)	4.89[a]	4.38[a]	2.62[b]	3.96

Means with different superscript letters in the same row indicate significant differences between farming systems at (≤0.05).

3.3 Carbon footprint of milk production

3.3. 1 Carbon footprint of milk production and it association

The CF of milk production (kg CO_2/kg FPCM) was estimated for each farm by using different allocation methods and global warming potential (GWPs) (Table 6). Carbon Foot prints of milk production varies among allocation methods and between GWPs. Using GWPs from (IPCC, 2007, 201 4), and when all GHG emissions were allocated to a single product, i.e. 100% allocated to milk, the overall weighted mean of CF was 3.54 and 3.65 kg CO_2e/kg FPCM respectively. Similarly, when GHG emissions were allocated to multiple products with economic allocation to kg milk, kg beef, kg manure, finance and insurances, the weighted mean of CF of milk production was 1.91 and 2.35 CO_2e/kg FPCM respectively, and on average 72% (Urban = 88%, Per-urban = 82%, Rural = 45%) of total GHG emissions were allocated to milk. A significant ($P \leq 0.01$) variation of CF between the three smallholder farming system were reported. Rural SHF reported to have significantly ($P \leq 0.05$) higher CF per kg of milk than urban and per-urban SHF system (Table, 6). When estimated using economic allocation, the CF was significantly lower ($P < 0.01$) in urban than per-urban and rural SHF. For consistency and to compare with the existing knowledge of CF of milk production, the remaining analysis uses the IPCC (2014) GWPs and economic allocation approach.

Table 6: Carbon footprints (kg CO_2e/kg FPC) of milk production (± SD) using different GWPs and allocation approaches

Allocation	IPPC (2014) GWPs			IPCC (2007) GWPs		
	Urban	Per-urban	Rural	Urban	Per-urban	Rural
100% to milk	2.6^{a} ± 0.35	2.8^{b} ± 0.39	5.56^{c} ± 0.89	2.1^{a} ± 0.3	2.26^{a} ± 0.32	5.36^{b} ±0.73
Mass allocation	2.10 ± 0.32	2.36 ± 0.33	3.68 ± 0.42	1.92 ± 0.26	1.91 ± 0.27	2.97 ± 0.34
Economic allocation	2.14^{a} ± 0.29	2.30^{b} ± 0.32	2.62^{c} ± 0.3	1.73 ± 0.26	1.86 ± 0.26	2.15 ± 0.25
All farming system	IPPC (2014) GWPs			IPCC (2007) GWPs		
100% allocated to milk	3.65 ± 0.56			3.54 ± 0.45		
Mass allocation	2.69 ± 0.29			2.27 ± 0.29		
Economic allocation	2.35 ± 0.26			1.91 ± 0.27		

Means with different superscript letters in the same row indicate significant differences between farming systems at (≤0.05).

3.3.2 Carbon footprint and its association with milk production and feed dry matter digestibility

A significant and a negative relation was reported between milk yield per farm and GHG emission per kg of milk, and milk yield explained more than half of the variability at farm level (64%) (Figure 3). Similarly, the magnitude of CF was also significantly influenced by feed dry matter digestibility (Fig. 4). Feed digestibility had negative and significant (P<0.01) association with emission intensity at animal level. It was observed that GHG emissions were consistently decrease with increasing feed digestibility across all farming system.

4. Discussions

4.1 GHG Emission Hotspot

The most important sources of GHG emissions were rumen enteric fermentation followed by manure management and feed production and transportation. This might be associated with the feed digestibility and feed conversion efficiency of the animals, and physical and chemical characteristics of feed and feeding level of the low quality (roughage) feed in the total feed basket. Emission from manure management (CO_2, CH_4 and N_2O) contributes about 16.45% to the total GHG emissions in peri-urban and rural SHF. This might be due to the fact that, a considerable amount of N_2O emission from direct deposition of manure by grazing animals (FAO, 2013). In addition a significant proportion of manure was collected and stored in an open heap for 3–4 months during rainy season, which may has been responsible for the production of potential CH_4 emission from an aerobic fermentation. In contrast to this findings, emission from feed production and transportation was the second largest sources of GHG emission.(Garg et al., 2016; Woldegebriel et al., 2017; Wilkes et al., 2020). In urban SHF, emissions from feed production and processing were the second largest GHG emission. The differences in GHG emission from feed production observed across farming systems were due to the type and the quality of feed used in daily ration. In urban SHF, for instance, the large GHG emissions from feed production were mainly attributed to relatively feeding large proportion of concentrate/processed feed in daily ration.

Enteric fermentation was significantly (< 0.05) higher in rural SHF than urban and peri-urban smallholder farming system. This might be due to low average feed digestibility and crude protein content reported in rural SHF than in peri-urban and urban SHF. The DMD and crude protein contents in the daily ration fed in rural SHF was below the crude protein (CP) requirements of productive dairy cows, which ranges 12–18% CP (Moran, 2005) in the diet. Low digestible feeds associated with high enteric CH_4 emission, and there by high GHG emission of milk was reported (Gebriel et al., 2011; Opio et al., 2013). The GHG emissions related to feed production in urban SHF was significantly ($p \leq 0.05$) higher than rural SHF. This might be due to the fact that, most of emission related to feed production emitted off-farm in urban SHF than in per-urban and rural SHF, as a significant amount of supplementary feed in urban SHF were produced off-farm. Similar result was reported in CF study by Garg et al. (2016) in India, and Wilkes et al.(2020) in Kenya. On the other hand, the low proportion of total GHG emission from feed production and transportation in rural and per-urban SHF indicated that, the large proportion of animal feed (pasture hay, crop residue) in daily ration was produced on-farm.

4.2 Carbon Foot prints and its uncertainties

Using economic allocation, the overall average CF of milk production estimated in this study (2.35 ± 0.27 kg CO_2e/kg FPCM) was much lower than the CF value reported by FAO & NZAGRC, (2017) in Ethiopia, and the explorative global study in SSA (FAO, 2010; Gerber, et al., 2013). But, a bit higher than CF reported in India and South Africa respectively (Garg et al., 2016; Reinecke and Casey 2017). The lower CF in urban than in peri-urban and rural farming system is largely due to the differences in degree of intensification and production objectives. In agreement to the present study, the variation in CF across farming systems were attributed to degree of intensification (Garg et al., 2016; Woldegebriel et al., 2017). In contrast, Wilkes et al. (2020) attributed the CF differences solely to feeding system (stall feeding, semi grazing and grazing). Feed conversion efficiency had strong and negative relationship with CF as also reported in (Thoma et al., 2013; Wilkes et al., 2020).

Emission intensifies increases with increasing milk yield, but decreased per kg of output (FPCM) per lactation. Similar trends was observed in CF study in India and Kenya (Gerber et al., 2011; Garg et al., 2016; Wilkes et al., 2020). Previous study by Gerber et al. (2011) stated that, GHG emission increases with higher yield, but emissions per kg FPCM decline substantially as animal productivity increases. Furthermore, Gerber et al. (2011) concluded that increasing productivity could be a viable mitigation option, especially in areas where milk yields are currently below 2000 kg per year per cow. Feed digestibility had strong but inverse relationship with milk yield per lactation. Low feed digestibility was mainly attributed due to large proportion of crop residue and pasture hay in the study area. As suggested in Gerber et al. (2011), low quality feed takes long time in the rumen, which leads to high enteric methane emission, and high emission intensity, and therefore, result low animal productivity (FAO, 2010; Gerber et al., 2011; Opio et al., 2013). The value obtained in this study is similar to the value reported in CF study in India and Kenya (Garg et al., 2016; Wilkes et al., 2020). Therefore, the significant association of emission intensity and feed digestibility reported in the present study will have an important contribution in designing effective GHG emission mitigations strategies.

The standard deviations of mean of CFs reported in our study had a margin of error of about ± 20 at a 95 percent of Confidence Interval (CI) (Table 7). This value is larger than the margin of error reported in CF study in Kenya and India (Garg et al., 2016; Wilkes et al., 2020). Similarly, a wide range of estimate from secondary data was reported in Ethiopia (Wilkes et al., 2020). The uncertainty range of (+ 26, + 18.75) was reported for weighted mean of farms. Monte Carlo simulation of uncertainty in in-put parameter value found that feed digestibility and feed EF were important sources of uncertainties in all feeding system. Hence, this are the key potential areas to reduce uncertainty and improve the accuracy.

Table 7
Milk yield, dry matter (DM) intake, feed efficiency (FE) and carbon footprint (CF) of milk produced per farm in different farming systems (mean values with S.D.)

Parameter	All farms N = 480	Urban N = 120	Peri-urban N = 180	Rural N = 180	P value
FPCM (kg/year)	2587.64 ± 354.2	3750.7[a]	3226.46[b]	785.74[c]	
Total DM intake (kg/year)	7130.41 ± 47.41	8427.65[a]	7808.34 [b]	4969 [c]	≤ 0.05
Feed efficiency (FE)	0.367 ± 0.13	0.44[a]	0.41[b]	0.14[c]	≤ 0.05
CF (Economic allocation)	2.35 ± 0.26	2.14[a]	2.30[b]	2.62[c]	≤ 0.05

Means with different superscript letters in the same row indicate significant differences between farming systems.

4.3 Mitigation of GHG emission and implication for policy makers

The CF in the present study varied with methodological choices, dry matter digestibility, feed conversion efficiency and increasing animal productivity. GHGs emission from enteric fermentation reported in this study pinpoints the importance of enteric fermentation as a hotspot to identify mitigation options in the study area. By considering the main drivers of emission intensity, the following mitigation options are identified as having the potential to reduce on-farm GHG emission, improve productivity while taking in to account the feasibility of implementation and their potential economic benefit at the farm level.

Improved feeding by increasing the proportion of concentrate in the daily ration at the expense of straw and crop residue will be an important area of intervention in all farm. Supplementation with leguminous shrubs, silage making and urea treatments of crop residue are expected to address feed scarcity and quality constraints, improve the quality of diet and increase intake and digestibility. Manure management system is another potential mitigation intervention prioritized next to improved feeding. Shifting the manure in to fertilizer, the amount of organic manure on farm land will increase, which reduce the need for synthetic N-fertilizers. In urban and per-urban SHF use of biogas/anaerobic digestion is very help-full to replace dung cake used for fuel.

Improving the genetic potential of indigenous breeds by cross breeding or/and by introducing crossbred heifers which can withstand feed and disease problem in the herd will improve production and reproductive performance, this in turn increases average milk production per animal and maximize the overall herd productivity reduce GHG emission intensity. Culling unproductive and retire dairy animal from the herd increase herd productivity and reduce GHG emissions at farm level.

5. Conclusion

Urban, Peri-urban and Rural smallholder farming system in Salale milk shed differ in degree of intensification, productions objectives and production inputs-output. Enteric fermentation and CH_4 from enteric fermentation and manure management was the primary sources of GHG emissions and emissions hotspot. Farming system, allocation approach and GWP used were the main sources of variability of CF of milk production. Average CF ranged between 2.14 and 2.62 kg CO2-eq/kg FPCM, using economic allocation, and significantly higher in rural smallholder farmers than peri-urban and urban farming system. There were a significant and inverse relationship was reported between CF and milk yield (FPCM) per kg output. Feed digestibility and feed conversion efficiency had strong and negative relationship with emission intensity. Improve feeding by increasing the proportion of concentrate and improved forage crops, and chemically treating crop residue and pasture hay could help to reduce enteric CH_4 emission, improve animal productivity and, thus, lower CF of milk. Shifting manure to fertilizer at the expense of manure used for fuel, so that, the amount of organic manure on farm land will increase, and improve nutrient use efficiency for sustainable dairy farming in the long run. The study recommends supporting SHF to realize strategies that contribute to climate resilient dairy development, which requires interventions at several level in dairy value chain.

Declarations

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Conflict of interest

We wish to declare that there are no known conflicts of interest.

Ethics approval

This study was based on physical and animal performance data, therefore, no ethics statements is needed.

Consent to participate:Farmers were asked for **t**heir willingness to participate before the commencement of the survey.

Consent to publish: Not applicable

Author's contribution

The first author (AA) generated the research idea, design the study, design and carry out data collection, analysis, interpret the result and draft the manuscript. The second author (FS) participate in the study design, data collection, analysis, and manuscript write-up. The third (DD) participate in the whole process of research design and analysis. AT also participated drafting the work, analyses, write up and drafting he manuscript. All authors read and approved the final manuscript.

Data and model availability statement

Data and model will be available upon request, the software used is available online to reviewers.

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Figures

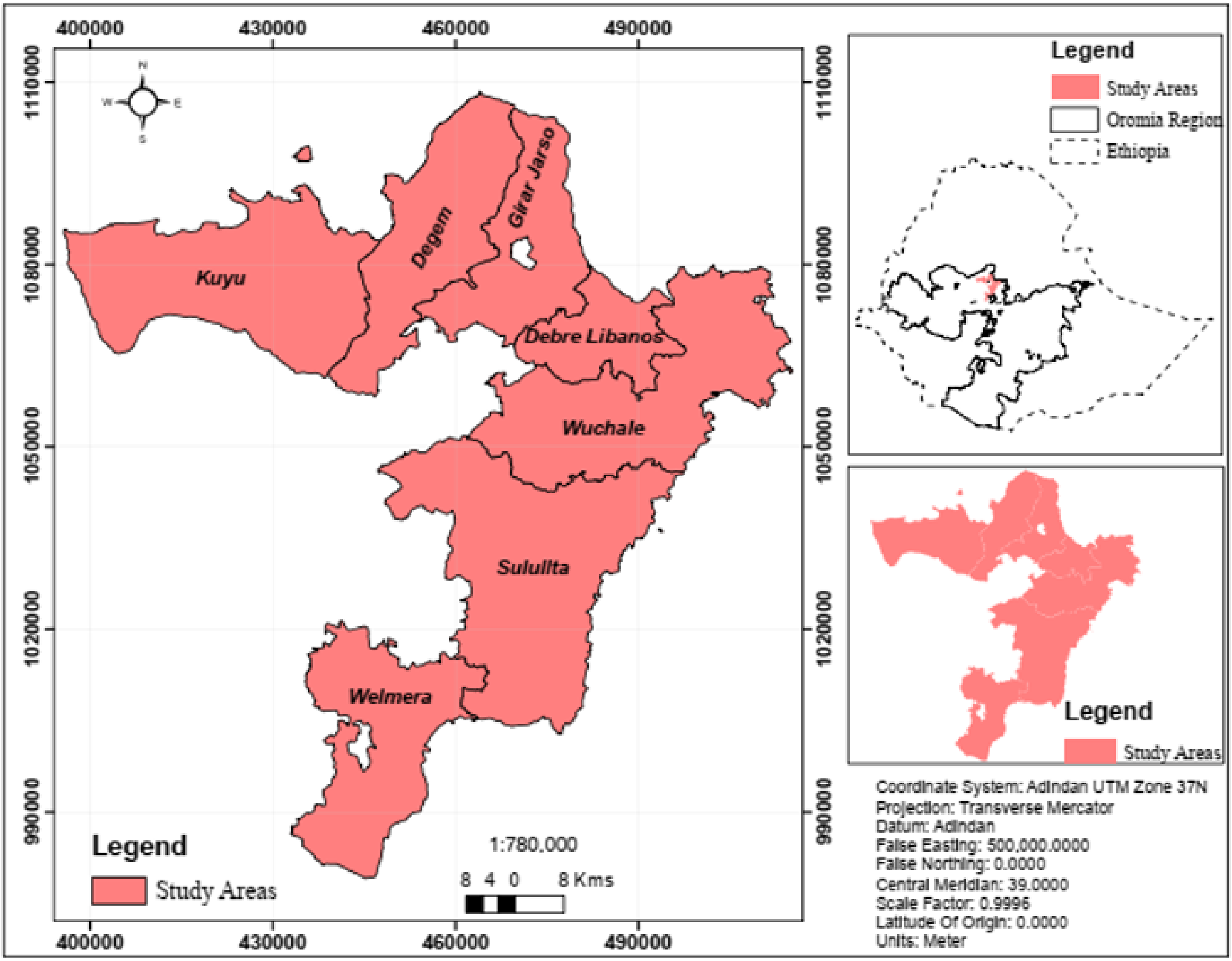

Figure 1

Location Map of the Study Area

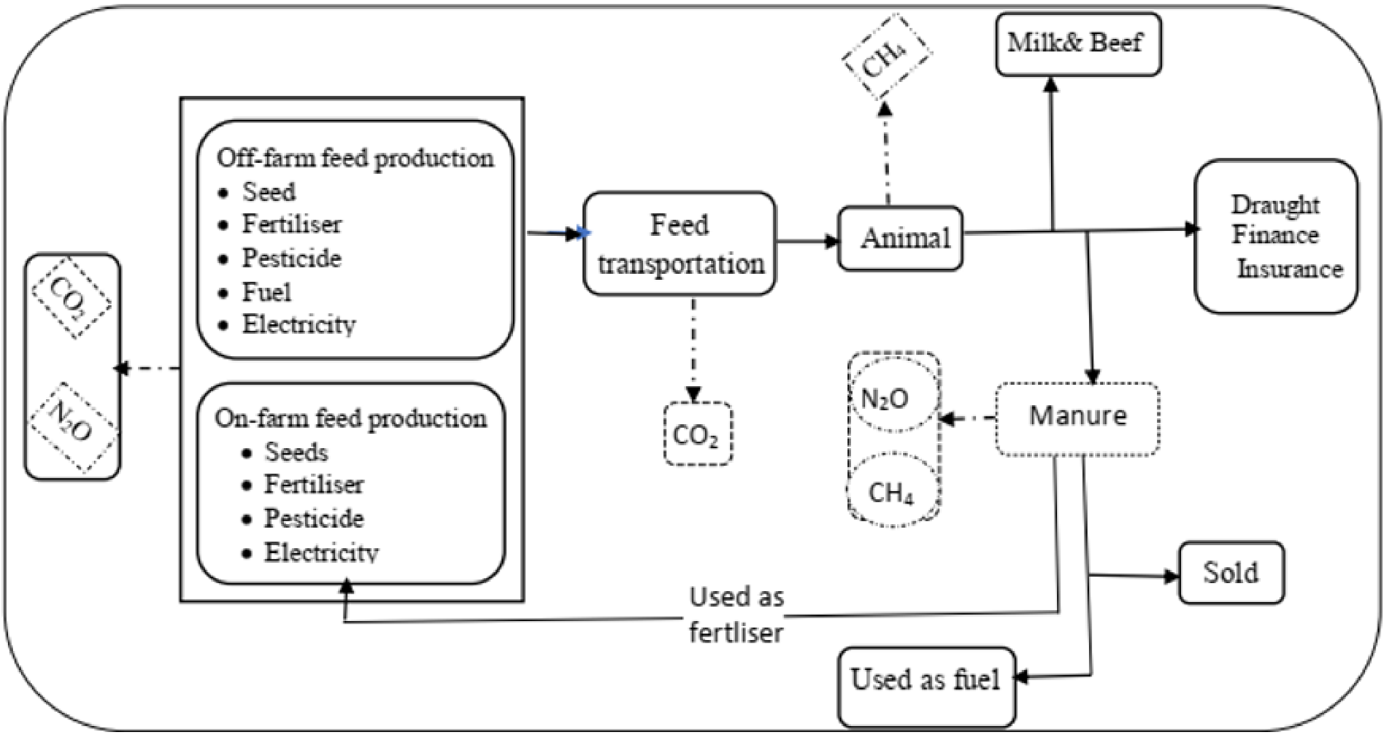

Fig. 2. Cradle to farm gate system boundary (—) indicating process (⟶) and emission (-·►) flows.

Figure 2

See image above for figure legend

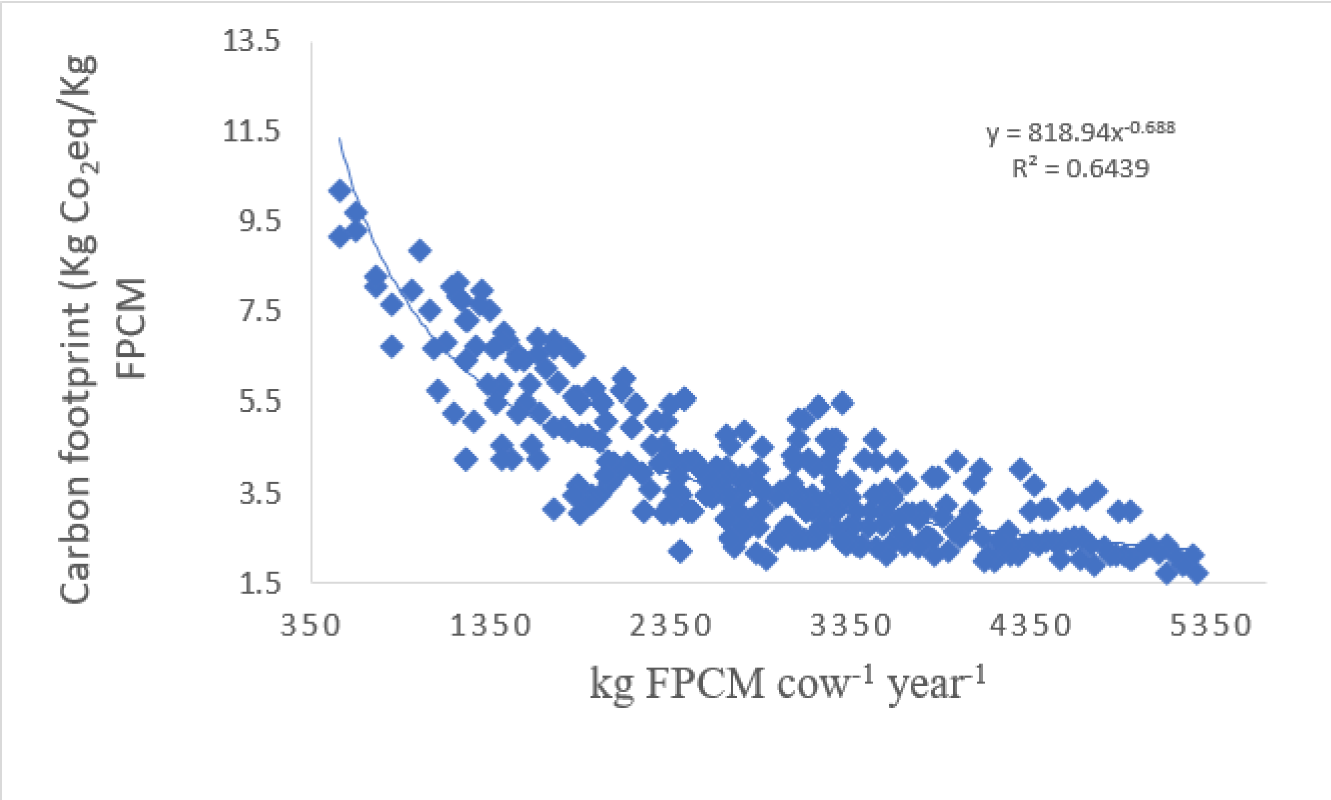

Figure 3

Relationship between milk yield and carbon footprint of milk of SHF

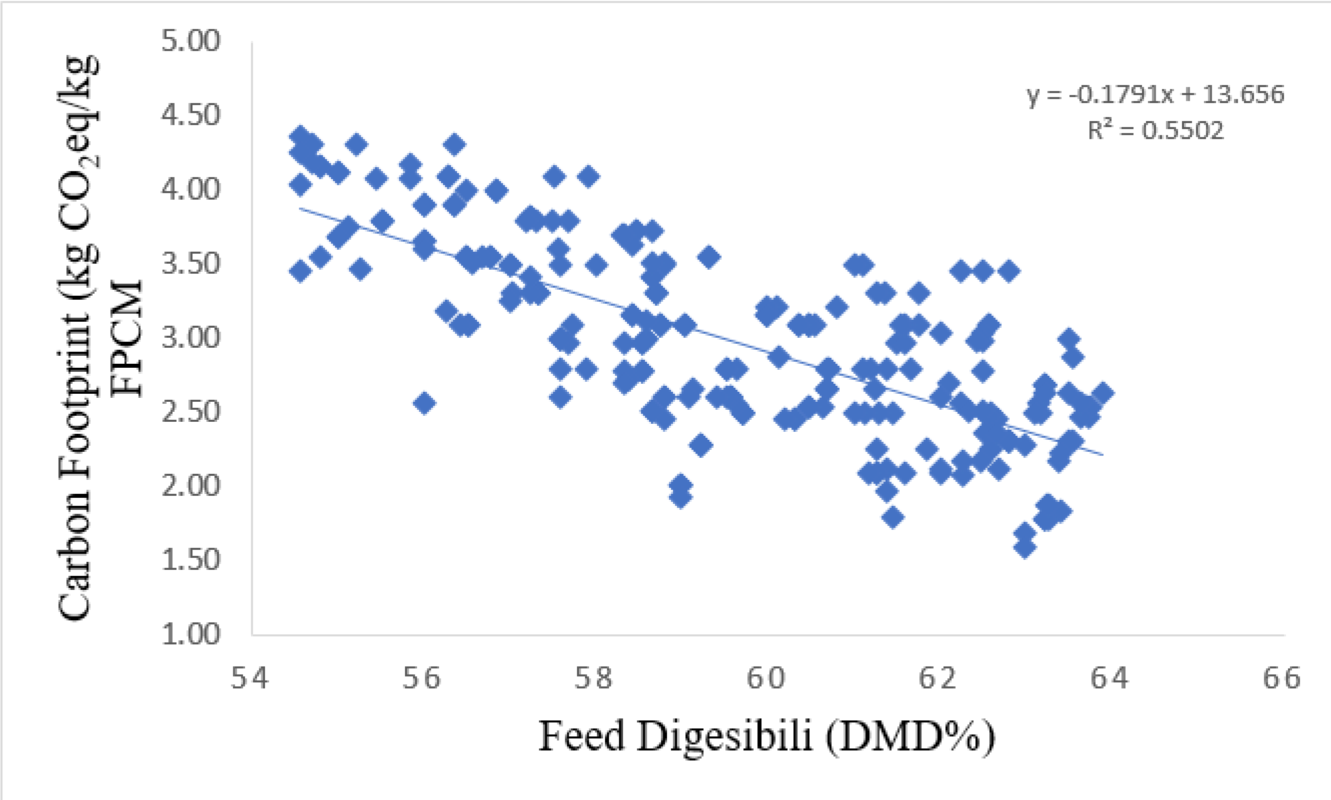

Figure 4

Relationship between milk yield and carbon footprint of milk of SHF