# Estimation of greenhouse gas emissions from three livestock production systems in Ethiopia

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## Abstract

**Purpose** – Different livestock production systems contribute to globally Greenhouse gas emission (GHG) emission differently. The aim of this paper is to understand variation in emission in different production systems and it is also important for developing mitigation interventions that work for a specific production system.

**Design/methodology/approach** – In this study, the authors used the Global Livestock Environmental Assessment interactive model (GLEAM-i) to estimate the GHG emission and emission intensity and tested the effectiveness of mitigation strategies from 180 farms under three production systems in northern Ethiopia, namely, pastoral, mixed and urban production systems.

**Findings** – Production systems varied in terms of herd composition, livestock productivity, livestock reproductive parameters and manure management systems, which resulted in difference in total GHG emission. Methane (82.77%) was the largest contributor followed by carbon dioxide (13.40%) and nitrous oxide (3.83%). While both total carbon dioxide and methane were significantly higher ($p < 0.05$) in urban production system than the other systems emission intensities of cow's milk and goat and sheep's meat were lower in urban systems. Improvement in feed, manure management and herd parameters resulted in reduction of total GHG emission by 30, 29 and 21% in pastoral, mixed and urban production systems, respectively.

**Originality/value** – This study is a first time comparison of the GHG emission production by various production systems in northern Ethiopia. Moreover, it uses the GLEAM-i program for the first time in the ex ante settings for measuring and comparing emissions as well as for developing mitigation scenarios. By doing so, it provides information on the various livestock production system properties that contribute to the increase or decrease in GHG emission and helps in developing guidelines for low emission livestock production systems.

**Keywords** Livestock, Greenhouse gas, Emission intensity, GLEAM-i, Livestock production systems

**Paper type** Research paper



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## Background information and justification

Despite livestock production being an important source of livelihoods for many communities around the globe, especially in low- and middle-income countries, it is also an important contributor to global greenhouse gas (GHG) emissions. It is globally estimated that 7,516 million metric tons per year of $CO_2$ equivalents ($CO_2$eq), or 18% of annual worldwide GHG emissions, are attributable to cattle, buffalo, sheep, goats, pigs and poultry (Steinfeld *et al.*, 2006); more exhaustive estimation of food production is responsible for 26% of the total annuals global GHG emission (Hannah, 2019). With increase in demand for animal source food (ASF) and thus increase in number of animals (Delgado *et al.*, 2001) and intensification of livestock farming, the importance of the livestock sector in terms of its contribution to global GHG emission will continue to rise. Not only is the livestock sector implicated in climate change, but also that climate change negatively affect livestock either directly by rising temperature affecting metabolic activity and prevalence of new disease, or indirectly by limiting the feed and water resource availability for livestock.

Despite its significant contribution to global GHG emissions, livestock nonetheless will continue to be important source of incomes and livelihoods, especially for the global poor. Therefore, livestock production systems that offer reduced GHG emission potentials without significantly reducing livestock productivity need to be identified. This can be achieved by estimating and comparing the GHG emissions from different livestock production systems with various levels of intensification and comparing various intensification scenarios. The Global Livestock Environmental Assessment Model interactive (GLEAM-i) provides a flexible tool for undertaking GHG estimation from various livestock systems *ex ante* (FAO and New Zealand Agricultural Greenhouse Gas Research Centre, 2017a, 2017b).

Understanding the variation in GHG emissions among different production systems helps to identify production systems or system properties that help in sustainable intensification of livestock production that reduce GHG emissions (van de Steeg and Tibbo, 2012). This study was, therefore, undertaken to compare GHG emissions across three livestock production systems in Eastern and Northern Ethiopia through quantification of ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$), and emission per kilogram of different livestock products from dairy cattle, sheep and goat across the three different production systems.

## Materials and methods

### *Description of the study areas*

The study was conducted in three study sites in Ethiopia, namely, Aba'ala, Enderta and Mekelle, belonging to three production systems, namely, pastoral, mixed crop–livestock and urban production systems (Figure 1).

Aba'ala district is geographically located at $13^0$11'N and $13^0$17'N latitudes, and $39^0$48'E and $39^0$54'E longitudes. It is characterized by a semi-arid agro-ecology and receives a bi-modal rainfall ranging from 315–450 mm, with annual average of 422 mm. The annual average temperature varies between 25 and $30^0$C. The altitude varies from 1,000–1700 m above sea level with an average of 1,500 m above sea level (Tsegaye *et al.*, 2007). Livestock production in Aba'ala district and surrounding is characterized as pastoral and agro-pastoral production systems, where livestock, dominated by sheep and goat, are dependent on extensive grazing across vast rangelands.

Enderta district is located between latitudes 13–14° N and longitudes 39–40°30' E in the southern part of Tigray region (Gebrehiwot and Veen, 2014). Enderta lies in the midland agro-ecology, characterized by dry climatic conditions with annual minimum and maximum temperature of 11.3 and 24.3°C, respectively. It has an elevation ranging between 1,500 and

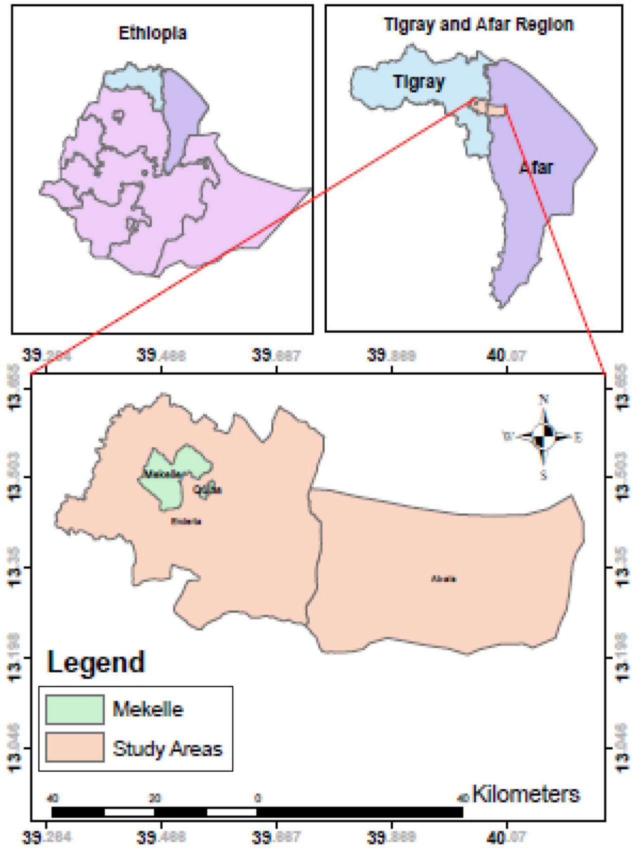


**Figure 1.** Map of the study areas

2,300 m and erratic mono-modal annual rainfall ranges from 450–600 mm. Mixed crop–livestock production is the main livelihood (Gebrehiwot and Veen, 2014, Gebre *et al.*, 2015).

Mekelle, the capital city of the Tigray National Regional State, is geographically located between 13°24'30" and 13° 36'52" latitude and 39°25'30" to 39° 38'33" longitude. It has at an average altitude of 2,000–2,200 m above sea level. The average annual rain fall ranges from 500–700 mm and mono-modal type of rainfall. The minimum and maximum annual temperature varies from 12–27°C (Kibrom, 2005). The livestock production in Mekelle city is characterized as urban (intensive) system. Table 1 provides a description of the three production systems.

*Data sources and collection methods*

Data used in the different modules of the GLEAM-i tool such as herd module, feed module, manure module, system module and allocation module were collected from interviewing 30 farming households in six kebels (villages). These data are used as inputs by each of the module to make estimations of GHG emission from the different components or processes of livestock production systems. These data were supplemented with secondary information from published and unpublished data sources such as livestock population, type of crops

Table 1.
Characterization of the different livestock production systems

| Characterization | Production systems<br>Pastoral production system | Mixed crop–livestock production system highlands | Urban production system |
|---|---|---|---|
| Agro-ecology | Arid | Semi-arid, humid and sub-humid | All agro-ecological conditions |
| Practice of crop production | Not suitable able for crop production. Example: Aba'ala | Practice of crop production with poor soils. Example: Enderta | Small land comparative to other systems. Example: Mekelle |
| Main livestock species | Camel, sheep and goat and cattle | Sheep and goat and cattle | Mostly pigs, chickens and dairy cow |
| Feed resources | Rangeland | Crop residue and natural pasture | Highly concentrate feed and other roughage feeds |
| Function of livestock | Subsistence | Agricultural input | Cash income |

grown and so on from the Tigray Region Bureau of Agriculture and Rural Development and Bureau of Agriculture and Pastoral Development (Table 2).

*Sampling procedures*
A multi-stage sampling technique was used to collect socio-economic data from respondents by using semi-structured questionnaire. At the beginning, three districts (one from Afar National Regional State and two from Tigray National Regional State) were selected. Two kebeles were then selected from each district based on the number of livestock available. A total of 180 households who own livestock (60 from each district) were selected using stratified random sampling techniques. Questionnaire was pre-tested in ten households in three kebeles before actual data collection process, after which adjustments were made based on problems encountered during the questionnaire testing stage.

*Model description and input parameters*
GLEAM-i is a freely available, Web-based Excel program developed by (FAO, 2017; Gerber *et al.*, 2013b). The GLEAM-i quantifies GHG emissions arising from production of the main livestock commodities such as meat and milk from cattle, sheep, goats and buffalo; meat

Table 2.
Parameter types collected from different sources

| Data type | Method of measurement | References |
|---|---|---|
| Feed type and their relative percentage | Interview | Birhan and Adugna (2014) |
| Intake percentage | Interview/estimation equivalent | FAO and New Zealand Agricultural Greenhouse Gas Research Centre (2017b) |
| Herd size per household | Interview/ direct counting | FAO (2010) |
| Reproductive parameters | Interview | FAO (2010) |
| Body weight of livestock | Literature review | Gerber *et al.* (2013b) |
| Milk production | Interview and farmer self-reported yield | FAO and NZAGRC (2017b) |
| Manure management system | Interview and observation | Gerber *et al.* (2013b) |

from pigs; and meat and eggs from chickens (Gerber *et al.*, 2013b). In this study, the authors considered three livestock types, including dairy cattle, sheep and goat, which were the common types of livestock in the three production systems. The GLEAM-i model was used to estimate $CO_2$, $CH_4$ and $N_2O$ emissions from each stage of production (FAO, 2017; Gerber *et al.*, 2013b).

The GLEAM-i tool has five modules, namely, herd module, feed module, manure module, system module and allocation module, which are used for estimating the GHG emission from respective modules of the livestock production system (Table 2). Herd, feed and manure modules are used to estimate GHG from animals, feed (production and processing) and manure management, respectively. Furthermore, the system module is used to estimate the GHG from the overall system, while the allocation module is used to allocate emission for each module (Figure 2).

*Developing and testing mitigation scenarios*

To see the possible effects of different interventions (mitigation strategies), three scenarios of introduction of commonly implemented strategies, including manipulating feed production and processing, manure management and livestock herd characteristics (Table 3), were tested for their effect on GHG emission from the different production systems (FAO and New Zealand Agricultural Greenhouse Gas Research Centre, 2017a, 2017b). As $CH_4$ was the principal GHG emission from the three production systems, the mitigation strategies incorporated in this study focused on reducing $CH_4$, which mostly came from

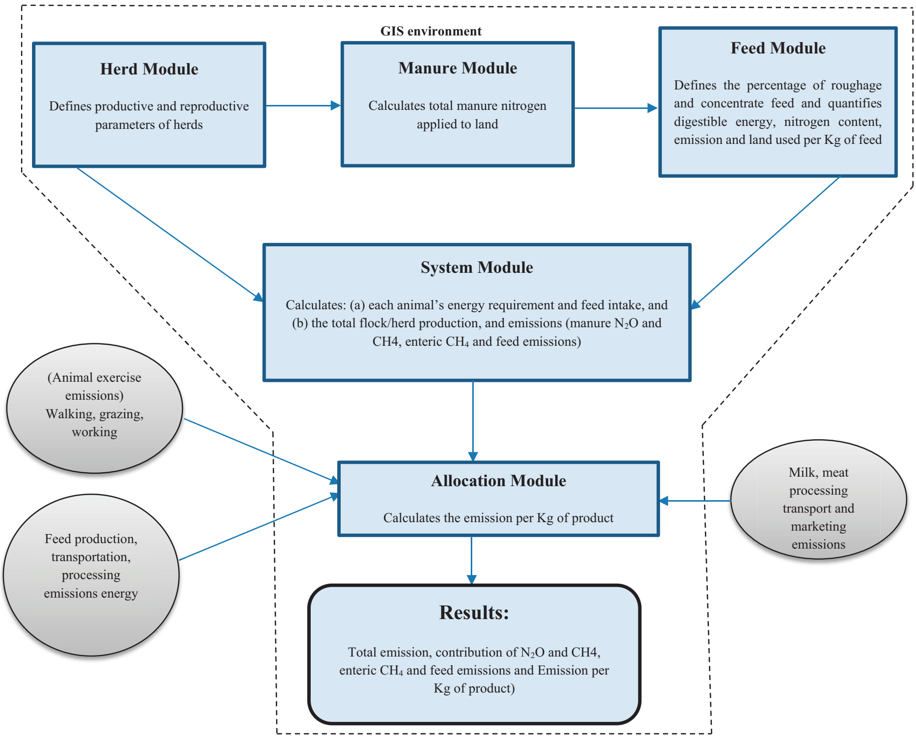


**Figure 2.**
Overview of GLEAM-i model and computation flows modified from Food and Agriculture Organization of the United Nations (2013a and 2017)

**Table 3.**
Description of the different mitigation scenarios

| | Production systems | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PPS | | | | | | MLPS | | | | | | UPS | | | | | |
| Feed type* | Cattle | | Sheep | | Goat | | Cattle | | Sheep | | Goat | | Cattle | | Sheep | | Goat | |
| Rangelands | 96.5 | 76.5 | 100 | 80 | 100 | 80 | – | – | 100 | 80 | 98.5 | 78.5 | – | – | 83 | 63 | 94 | 74 |
| Straw | – | – | – | – | – | – | 88.42 | 66.42 | – | – | – | – | 71.72 | 51.72 | – | – | – | – |
| Wheat bran | 3.5 | 3.5 | – | – | – | – | 13.58 | 13.58 | – | – | 1.5 | 1.5 | 26.72 | 26.72 | 17 | 17 | 6 | 6 |
| Grains | 0 | 20 | – | 20 | – | 20 | – | 20 | – | 20 | – | 20 | 1.56 | 21.56 | – | 20 | – | 20 |
| *Manure management system** | | | | | | | | | | | | | | | | | | |
| Range and paddock | 50 | 30 | 50 | 30 | 50 | 30 | 16.48 | 16.48 | 50 | 30 | 50 | 30 | – | – | 50 | 30 | 50 | 30 |
| Solid storage | 50 | 70 | 50 | 70 | 50 | 70 | 46.35 | 66.35 | 50 | 70 | 50 | 70 | 50.50 | 70.50 | 50 | 70 | 50 | 70 |
| Fuel | – | – | – | – | – | – | 37.17 | 17.17 | – | – | – | – | 36 | 16 | – | – | – | – |
| Slurry | – | – | – | – | – | – | – | – | – | – | – | – | 16.50 | 16.50 | – | – | – | – |
| *Herd parameter* | | | | | | | | | | | | | | | | | | |
| Age at first calving** | 46.5 | 39 | – | – | – | – | 39.95 | 36 | – | – | – | – | 31.33 | 30.1 | – | – | – | – |
| Milk production*** | 322.5 | 900 | – | – | – | – | 565.93 | 1200 | – | – | – | – | 1907.33 | 3150 | – | – | – | – |

**Notes:** *Feed resources and manure management systems are expressed in percentages; **Age at first calving and ***milk production are expressed in months and liters, respectively. PPS: pastoral production system, MLPS: mixed crop–livestock production system and UPS: urban production system enteric fermentation of ruminant livestock. The first scenario was improving low-quality feed by high-quality grains. In this scenario, low-quality roughage feed was replaced by maize grains. In the second scenario, manure management system was improved by replacement of range and paddock/manure and fuel manure by solid manure management interventions such as pilling, stacking and compaction. In the third scenario, changes that indicate improvement in livestock herd management such as lowering age at first calving and increasing cow milk production were tested.

### *System boundary*

The system boundary, as stipulated by the GLEAM-i model, covered all emissions during the process of livestock production up to the retail point from farm gate to retail of processed livestock products, excluding emissions from other stages beyond the retail of processed livestock products (excluded from retail to grave). It also does not consider the $CO_2$ from respiration of livestock. This is because $CO_2$ from respiration of livestock can be approximated to be equal to the $CO_2$ uptake or sequestration by plants for the photosynthesis process (FAO and New Zealand Agricultural Greenhouse Gas Research Centre, 2017a, 2017b; Pitesky *et al.*, 2009). Figure 3 provides a schematic presentation of the system boundary used in the estimation of GHG emission from the different production systems in this study.

### *Data analysis*

Data collected through questionnaire survey and focus group discussion were analyzed and presented using descriptive statistics such as average, percentage and frequency. Data relating to five modules of livestock production were entered in to GLEAM-i model to quantify the GHG emission across the three production systems (FAO, 2017; Gerber *et al.*, 2013b). Feed intake and manure production were converted into feed intake percentage and manure management type by percentage. The resulting values of GHG emission from each

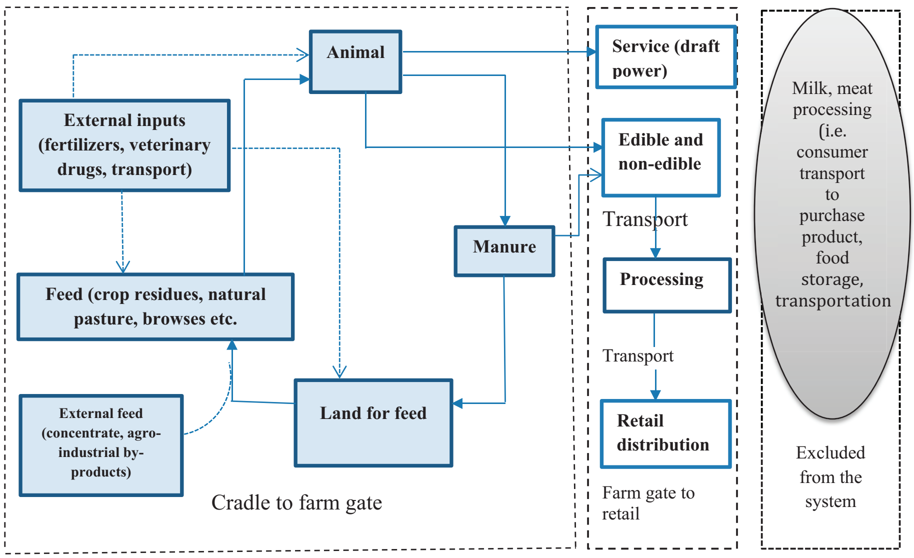


**Figure 3.**
System boundary of GLEAM-i modified from Food and Agriculture Organization of the United Nations (2013b)

of the production systems were analyzed using analysis of variance (ANOVA) procedure using Statistical Software for Social Science (SPSS) version 20 (SPSS, 2011).

## Results

### *Contribution of production systems toward greenhouse gas emission*

$CH_4$, $CO_2$ and $N_2O$ contributed 83.42, 4.18, 12.40% of the total GHG emissions, respectively. Urban production system was responsible for the highest GHG emission, i.e. 58.44% of the total GHG, while the pastoral and mixed production systems were responsible for 22.96 and 18.60% of the total emission, respectively (Table 4).

### *Comparison of greenhouse gas across production systems*

The total $CH_4$ emission was significantly higher ($p < 0.05$) in urban production system than mixed crop–livestock and pastoral production system (Table 5). $CH_4$ emission from enteric

**Table 4.** Contribution of the different modules of GHG from the three production systems (%)

| GHG emission | PPS | MLPS | UPS | (%) of total |
|---|---|---|---|---|
| $CO_2$ | 0.79 | 2.94 | 5.75 | 4.18 |
| $CH_4$ | 74.77 | 83.93 | 85.97 | 83.42 |
| $N_2O$ | 24.44 | 13.13 | 8.28 | 12.40 |
| % of total | 18.59% | 22.14% | 58.44 | 100.00 |

**Notes:** PPS: pastoral production system, MLPS: mixed crop–livestock production system and UPS: urban production system

**Table 5.** Comparison of GHG across production systems (mean ± SE) (kg of $CO_2$-eq per year)

| GHG emission | PPS | MLPS | UPS | Total |
|---|---|---|---|---|
| Total $CH_4$ | 7152.37 ± 702.75 | 9914.34 ± 1067.92 | 25852.04 ± 2469.13[a] | 13008.21 ± 939.58 |
| $CH_4$ from enteric fermentation | 6860.80 ± 670.47 | 8877.18 ± 939.75 | 21928.77 ± 2055.06[a] | 11506.62 ± 793.21 |
| $CH_4$ from manure management | 291.51 ± 33.13[a] | 1037.11 ± 141.58[a] | 3923.44 ± 469.43[a] | 1501.56 ± 164.00 |
| Total $CO_2$ | 75.13 ± 17.65 | 347.11 ± 42.62 | 1728.93 ± 162.96[a] | 602.65 ± 63.72 |
| $CO_2$ from feed production | 48.19 ± 17.14 | 316.75 ± 40.47 | 1524.34 ± 141.14[a] | 528.01 ± 56.25 |
| $CO_2$ from direct energy use | 21.30 ± 2.47 | 22.37 ± 3.19 | 187.72 ± 23.17[a] | 65.24 ± 7.83 |
| $CO_2$ from indirect energy use | 5.56 ± 0.54 | 7.92 ± 0.93 | 16.90 ± 2.11[a] | 9.35 ± 0.73 |
| Total $N_2O$ | 2338.85 ± 249.67 | 1551.69 ± 170.41[a] | 2491.45 ± 323.72 | 2105.15 ± 144.01 |
| $N_2O$ from crop residue and fertilization | 337.75 ± 31.52 | 379.01 ± 44.49 | 1274.68 ± 121.79[a] | 597.40 ± 45.76 |
| $N_2O$ from manure application | 1662.03 ± 187.30[a] | 759.74 ± 105.79 | 287.54 ± 165.20 | 988.51 ± 99.50 |
| $N_2O$ manure management | 339.10 ± 39.95 | 412.93 ± 46.15 | 929.36 ± 89.40[a] | 519.30 ± 36.05 |

**Notes:** PPS: Pastoral production system, MLPS: Mixed crop–livestock production system and UPS: Urban production system; [a] = indicates significant different ($p < 0.05$)

fermentation and manure management were higher in urban production system than mixed crop–livestock and pastoral production systems (Table 5).

The total $CO_2$ emission was significantly higher ($p < 0.05$) in urban production system than mixed crop–livestock and pastoral production systems (Table 5). $CO_2$ from feed production and from direct and indirect energy use were significantly higher ($p < 0.05$) in urban production system than mixed crop–livestock and pastoral production systems (Table 5).

Total $N_2O$ emission was significantly lower ($p < 0.05$) in mixed crop–livestock production system than pastoral and urban production system (Table 5). $N_2O$ from crop residue and fertilization and $N_2O$ from manure management was significantly higher ($p < 0.05$) in urban production system than mixed crop–livestock and pastoral production systems (Table 5). However, $N_2O$ from manure application was significantly higher ($p < 0.05$) in pastoral production system than mixed crop–livestock and urban production systems (Table 5).

*Emission intensity*

Emission intensity of cow's milk (i.e. GHG emission per unit of milk produced) was significantly lower ($p < 0.05$) in urban production system than mixed crop–livestock and production pastoral systems (Table 6). However, emission intensity of cow's meat, sheep and goats meat and milk were not significantly different ($p > 0.05$) among the three production systems (Table 6).

*Testing mitigation strategies for reducing greenhouse gas emission*

*Scenario I: impact of improving feed on greenhouse gas emission.* The first scenario, which is replacement of roughages by maize grain, improved the digestibility of feed, producing higher energy, better livestock performance and reduced manure production (Table 7). This in turn, reduced total GHG by 17.37, 24.18 and 26.81% in pastoral, mixed and urban production systems, respectively. Comparable reductions have also been observed for the total $CH_4$ and total $N_2O$ emission. Improving the feed resulted in reduction enteric $CH_4$ emission by 14.96, 25.40 and 28% in pastoral production system, mixed crop–livestock production system and urban production system, respectively (Table 7).

*Scenario II: improving manure management system.* Improved manure handling and management system reduced $CH_4$ and $N_2O$ emission from manure by 23.68 and 21.49% in pastoral, 36.30 and 18.10% mixed crop–livestock and 37.87 and 17.02% urban production systems, respectively (Table 7).

*Scenario III: improving the herd management.* In this scenario, the proposed improvement in herd management that would result in shortening age at first calving and increasing milk production, have increased the emission of total GHG by 102.1, 105.94 and

**Table 6.** Emission intensity for livestock products from the three livestock production systems (mean ± SE) (kg of $CO_2$-eq)

| Emission intensity | PPS | MLPS | UPS |
|---|---|---|---|
| Emission intensity of cow milk | 18.64 ± 3.93 | 13.02 ± 1.54 | 4.62 ± 0.33[a] |
| Emission intensity of sheep and goat milk | 17.50 ± 1.05 | 8.78 ± 2.20 | – |
| Emission intensity of cow meat | 28.33 ± 16.34 | 41.40 ± 9.93 | 17.69 ± 1.27 |
| Emission intensity of sheep and goat meat | 29.18 ± 16.28 | 39.32 ± 7.76 | 37.24 ± 6.12 |

**Notes:** PPS: Pastoral production system, MLPS: Mixed crop–livestock production system and UPS: Urban production system; [a] = indicates significant different ($p < 0.05$)

**Table 7.** Developing different scenarios in the three different production systems

| PS | Total GHG emission | Baseline (kg $CO_2$-eq/ year) | Feed module improvement: Replacement* scenario (kg $CO_2$-eq/year) | Feed module improvement: (%) reduction in GHG emission | Manure improvement: Replacement** scenario (kg $CO_2$-eq/year) | Manure improvement: (%) reduction in GHG emission | Herd module improvement: Replacement*** scenario (kg $CO_2$-eq/year | Herd module improvement: (%) Reduction in GHG emission | Combined effect of the three scenarios: Combined effect**** (kg $CO_2$-eq/year | Combined effect of the three scenarios: (%) Reduction in GHG emission |
|---|---|---|---|---|---|---|---|---|---|---|
| PPS | Total GHG | 15,807 | 13,062 | – 17.37 | 13007 | –17.71 | 16,139 | 102.10 | 11,012 | –30.33 |
| | $CO_2$ | 111 | | 145.95 | 106 | –4.50 | 125 | 112.61 | 167 | 150.45 |
| | $CH_4$ | 10,346 | 8,768 | –15.25 | 8378 | –19.02 | 10,534 | 101.81 | 7,259 | –29.83 |
| | $N_2O$ | 5,350 | 4,132 | –22.76 | 4523 | –15.45 | 5,480 | 102.42 | 3,587 | –32.95 |
| | Emission intensity of cow's milk | 18.64 | 7.59 | –40.71 | 9.01 | –51.66 | 3.95 | –78.80 | 3.12 | –83.26 |
| MLPS | Total GHG | 33782 | 25613 | –24.18 | 30045 | –11.06 | 35791 | 105.94 | 24007 | –28.93 |
| | $CO_2$ | 1007 | 879 | –12.71 | 1003 | –0.39 | 1171 | 116.28 | 1014 | 100.69 |
| | $CH_4$ | 26381 | 19554 | –25.87 | 23693 | –10.18 | 28132 | 106.63 | 18526 | –29.77 |
| | $N_2O$ | –0394 | 5180 | –18.98 | 5350 | –16.32 | 6488 | 101.47 | 4468 | –30.12 |
| | Emission intensity of cow's milk | 13.02 | 5.12 | –60.67 | 7.21 | –1.90 | 4.02 | –69.12 | 2.76 | –78.80 |
| UPS | Total GHG | 31763 | 23245 | –26.81 | 30696 | –3.35 | 35452 | 111.61 | 25181 | –20.72 |
| | $CO_2$ | 2062 | 1747 | –15.27 | 2060 | –0.09 | 2427 | 117.70 | 2072 | 100.48 |
| | $CH_4$ | 26756 | 18873 | –29.46 | 25896 | –3.21 | 29907 | 111.77 | 20447 | –23.57 |
| | $N_2O$ | 2945 | 2625 | –10.86 | 2739 | –6.99 | 3118 | 105.87 | 2661 | –21.11 |
| | Emission intensity of cow's milk | 4.62 | 2.42 | –47.61 | 3.36 | –27.27 | 2.43 | –47.40 | 1.74 | –62.33 |

**Notes:** PPS: Pastoral production system, MLPS: mixed crop–livestock production system; UPS: Urban production system. *Scenario developed by replacement of 20% roughage is by 20% maize grains, **Scenario developed by replacement of 20% range/paddock manure or burn for fuel and slurry by 20% solid manure management in pastoral, mixed crop–livestock and urban production system respectively, ***Scenario developed by shortening age at first calving and increasing milk production of dairy cattle, ****Scenario developed by the combined effect of the above three scenarios i.e. combination of improvement in feed, manure and herd parameter, Negative value indicated that there was a reduction and positive value indicated that there was increase in GHG emission

111.67% in pastoral, mixed crop–livestock and urban production systems, respectively (Table 7). This is also accompanied with a reduction in emission intensity in cow's milk by 78.80, 69.12 and 47.40% from pastoral, mixed crop–livestock and urban production systems (Table **7**).

*Combined effect of three scenarios*

The three interventions, namely, feed, herd and manure applied simultaneously have resulted in the reduction in total GHG emission by a range of 20.72–30.33% and reduction of $CH_4$ (23.57–29.83%) and $N_2O$ (21.11–32.95%) in the three production systems (Table 7). As a result, the emission intensity of cow's milk is reduced by 83.26, 78.80 and 62.33% in pastoral, mixed crop–livestock and urban production systems, respectively (Table7).

## Discussion

*Contribution of production systems toward greenhouse gas emission*

The higher share of GHG emission from urban production system compared to mixed crop–livestock and pastoral production system (Table 4) was because, in the urban production system there was use of external inputs such as fossil fuel for feed production and processing, use of grain as feed resources, use of fertilization for feed production, transportation of inputs. Moreover, animals had larger body weight and produced more milk than cows in the other production systems. The smaller body weight of animals, low input such as processed feed and small milk production in the mixed and pastoral systems might have also contributed to lower reduction in GHG emission. Moreover, rangelands in the pastoral system and natural pastures in the mixed crop–livestock system serve as feed resources (without the need to clear and cultivate land for forage production), contributing to reduced estimate of carbon dioxide in these two systems (Derner and Schuman, 2007; Gerber *et al.*, 2013b). Lower levels of emission in pastoral areas as compared to other production systems have also been observed (Zhuang and Li, 2017).

*Contribution of individual gases*

$CH_4$ as the largest contributor to GHG emissions (83.42 in this study) (Table 4) has also been reported for other production systems (FAO and New Zealand Agricultural Greenhouse Gas Research Centre, 2017b, 2017a). This is because in many of the studied production systems, feed is dominated by low quality and quantity forages, which require longer retention time in the rumen, thus creating relatively larger amount of enteric $CH_4$ (Gerber *et al.*, 2013a). More $CH_4$ emission is caused by larger contribution of feeding roughages means that there is a potential for mitigation of $CH_4$ emission through better-quality feed that improve the digestibility and reduce rumen retention time of feeds (Opio *et al.*, 2013). The 4.18% $CO_2$ emission in the current study (Table 4) was higher than the value of 0.5% estimated for the Ethiopian dairy sector by FAO and New Zealand Agricultural Greenhouse Gas Research Centre (2017b). This lower estimate, according to FAO and New Zealand Agricultural Greenhouse Gas Research Centre (2017b), is said to be because the Ethiopian dairy sector was dominated by indigenous breeds, which are traditionally managed with low input of feed resources and almost no land or other resources devoted for forage production and no feed processing. This estimate was, therefore, inevitably smaller than the global $CO_2$, which was 27% of $CO_2$ from livestock sector (Gerber *et al.*, 2013b).

While the 12.40% total $N_2O$ estimate in the current study (Table 4) was higher than the 2.1% estimated by FAO and New Zealand Agricultural Greenhouse Gas Research Centre (2017b), it was by far lower than the 29% global estimate by Gerber *et al.* (2013a, 2013b). The lower proportion of $N_2O$ from the current estimation is probably because most of the surveyed communities are small scale and use limited or no fertilizer input for feed production. Moreover, solid manure management system, the commonest manure management system in the surveyed communities, results in lower amount of nitrous emission.

*Comparison of greenhouse gas across production systems*

Higher $CH_4$ and $CO_2$ emission in urban production system (85.97%) than mixed crop–livestock (83.93%) and pastoral production system (74.77%) (Table 4), is attributed to the variation in various characteristics of the livestock production system such as: livestock population, level of production, body weight, age, breed, type of digestive tract, type and quality of feed, amount of manure and manure management system and environmental temperature, all of which were different among the three production systems (Dong *et al.*, 2006; Yan *et al.*, 2010). Even though the total $CH_4$ emission is observed to be higher in the urban system, emission per output is lower for the urban systems, because the livestock produced higher mount of milk than those in the other two production systems. This implies that replacing the livestock in the pastoral and mixed crop–livestock systems, by better producing breeds and making adjustments to the production system would contribute to an overall reduction in $CH_4$, as also recommended by Homeier (2011) and Opio *et al.* (2013). However, it is also important to understand that the extreme ecologies, such as aridity, mainly in the pastoral areas may not allow for an overall replacement of indigenous breeds by exotic and better producing breeds. Gradual cross-breeding would, therefore, provide opportunities for improving productivity while keeping adaptive potential of local breeds.

Furthermore, $CH_4$ from manure management was also higher in urban production system (Table 5) because the liquid slurry form practiced in the urban systems allows for an aerobic fermentation that produces more $CH_4$ as compared to the open air range/paddock systems in the mixed and pastoral systems.

The total $N_2O$ emission was also higher in urban production systems than mixed crop–livestock and pastoral production system (Table 5). This could be probably due to the increased use of concentrate feed, which is used as the main livestock feed. By contrast, pastoral and mixed crop–livestock systems relay mainly on natural pasture and crop residue, respectively (Opio *et al.*, 2013; Jayne *et al.*, 2003). Generally, the tendency to increase total emission as livestock production becomes more intensified, as observed in this study, is an indication of the impact of increased inputs on the overall emission.

*Emission intensity*

While the more intensified urban production systems produced the highest emission, the emission intensity, which is amount of GHG emission per unit of animal produce (milk for this study) was lowest (Table 6). This is because improved and better management practices such as veterinary services, housing and feeding and nutrition in urban production system resulted in improved productivity, thereby reducing the emission per unit of product (Opio *et al.*, 2013; Gerber *et al.*, 2013b). The emission intensity value for urban production systems in this study (4.62 $CO_2$-eq./kg FPCM), however, was higher than the global emission intensity of industrialized dairy production systems (1.5 $CO_2$-eq./kg FPCM) conducted by Gerber *et al.* (2013a, 2013b), indicating that there is still potential for reducing the emission intensity through the improvement of productivity.

Emission intensity of meat and milk from sheep and goat is not significantly different among the production systems (Table 6). This is because the sheep and goat production systems generally had lower milk production and body weight gain compared to other livestock production systems specializing in other products. Similarly in many traditional production systems in Ethiopia, sheep and goats are considered as supplementary and secondary animals to cattle and camels, and thus, there are no pronounced input applied to these two animals, making many systems to have similar input and output characteristics (Yami and Merkel, 2008).

Overall, the intensification of livestock production through the use of improved breeds, feed and other improved management inputs would not only improve productivity, but would reduce the contribution of livestock to the global GHGs' emission.

*Greenhouse gas mitigation scenarios and their impacts*

Reductions in GHG emissions as a result of improved feed by up to 17–26%, observed in this study (Table 7) are very common (van de Steeg and Tibbo, 2012; Forabosco *et al.*, 2017; Yusuf *et al.*, 2012). In this study, the reduction in GHG emission could be because maize grains have lower fiber component, resulting in higher passage rate and post-ruminal digestion and less energy loss in the rumen in the form of $CH_4$ (Cabrera, 2008). Furthermore, replacement of roughages by maize could also reduce grazing pressure and degradation of rangelands/natural pasture, further contributing to reduced GHG emission due to range and pastureland degradation (Lal, 2003), though maize cultivation can also require larger input such as fossil fuel for traction, fertilization and soon as compared to grassland/roughages. Maize could also be consumed by people than by animals, which could create strong competition between human and animal.

There could also be other options for reducing enteric $CH_4$ emission such as improvement of low-quality fibrous feeds/forage with high-quality forages and feed treatment techniques such as urea treatment, which result in higher digestibility of feeds (FAO and New Zealand Agricultural Greenhouse Gas Research Centre, 2017b). As expected, there was also a resultant reduction in emission intensity of cow's milk 40.71, 60.67 and 47.61% from pastoral, mixed crop–livestock and urban production systems, respectively. The higher increase is observed in the mixed crop–livestock system, perhaps because low-quality feed, dominated by crop residue, is the most productivity-limiting factor in this system that a change in improvement of the quality of feed, as in this scenario, would result in a bigger change in the productivity and emission intensity. Improving manure management systems reduced the GHG emission by 3–17%, with the highest reduction observed in the pastoral production system, (Table 7), indicating that an uncontrolled open range/paddock system produces more emissions than controlled systems. A reduction in GHG emission due to change of manure management system is also observed for the mixed crop–livestock system (Table 7) probably because dung cake, the common manure management system in the mixed crop–livestock systems, unlike the new solid manure management, exposes the dung into the open air, making it release more $CH_4$ (Ericksen and Crane, 2018). Cattle in both in mixed crop–livestock and pastoral production systems spend substantial time in grazing pasture, depositing organic nitrogen in manure and urine and any collected manure is stored solid, reducing the release of $N_2O$ compared to the new solid management system. Though to a lesser extent (i.e. only 3%), the new liquid/slurry manure management system reduced GHG emission in the urban system (Table 7), because the new system of liquid manure facilitates decomposition process of organic matter in manure making for quicker GHG production (Vergé *et al.*, 2007).

The intervention in improving herd productive and reproductive parameters resulted in an increase in GHG emission (Table 7). An improvement in herd productive and reproductive parameters is accompanied with increase in GHG because an overall improvement in productive and reproductive performance of livestock is associated with increased inputs such as feed production and processing causing the GHG emission to increase (Pitesky *et al.*, 2009).

Simultaneous applications of all the three interventions have resulted in overall reduction of GHG emissions (Table 7). These reductions are because of the improvement in the overall livestock performance and management systems, which have a synergetic effect on the reduction of GHG emission (van de Steeg and Tibbo, 2012). Such an improvement, at the farm level could be applied through many interventions such as improving feed quality through the use improved forage plants, concentrate supplementation, urea molasses blocks, etc. (FAO and New Zealand Agricultural Greenhouse Gas Research Centre (2017b); better manure management such as converting of slurry in biogas and solid manure management (van de Steeg and Tibbo, 2012; Homeier, 2011); culling unproductive large number of livestock and replacement by small number productive livestock breeds (Forabosco *et al.*, 2017; Shapiro *et al.*, 2015; Ericksen and Crane, 2018).

## Conclusion

Urban production system had the highest GHG emission compared to mixed crop–livestock and pastoral production systems, indicating the effect of higher inputs in the urban systems in increasing GHG emission. However, emission intensity (i.e. emission per unit of animal product) of cow's milk was lowest in urban production system implying that there is a potential to reduce GHG emission from mixed crop–livestock and pastoral areas by improving animal productivity. Supplementary feeding of maize grain to livestock accompanied with improvement of manure management and improvement of herd productive and reproductive parameters (e.g. through breed improvement) applied either separately or in combination have resulted in the reduction of GHG emission, specifically enteric $CH_4$ emission. While livestock production systems vary in their contribution to GHG emission, all systems responded positively to improved management interventions, indicating a potential for synergetic improvement of livestock productivity and environmental sustainability of livestock production systems in similar production systems.

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