

Greenhouse gas emissions from Uganda's cattle corridor farming systems

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ABSTRACT

The objective of this study was to estimate the greenhouse gas (GHG) emissions from practised cattle farming systems (Stall, Semi-Intensive, Grazing, Tethering and Scavenging) and identify potential areas for GHG mitigation. Using the Global Livestock Environmental Assessment Model (GLEAM-i), GHG emissions in 2016 were 2009 Gg CO₂-eq/yr of which the Grazing system contributed 88.5%. Enteric fermentation produced about 75.8% of the total GHG emissions. At an annual growth rate of 3%, the projected GHG for 2020 and 2025 would increase by 12.6% and 30.7% respectively. The milk and meat emission intensities were far higher than the global averages. A reduction in grazing by 10% and a 10% increase in use of anaerobic digesters to handle manure resulted in a 4.4% reduction in annual GHG emission.

1. Introduction

Livestock sector is a key sector to Uganda's growing economy contributing an average of 4.2% to the national Gross Domestic Product (GDP) in recent years (Uganda Bureau of Statistics (UBOS, 2017)). The 4.2% of Uganda's GDP is an equivalent of US \$1.1 billion representing a substantial increase from a contribution of about 1.7% to the GDP in the year 2009. However, the Intergovernmental Authority on Development (IGAD) argues that the livestock contribution to the GDP in the year 2009 nearly doubles the UBOS estimate at 3.2%, an equivalent of US \$ 526 million (Behnke and Nakirya, 2012). Cattle's milk and meat cumulatively contributed up to 73% of the gross livestock value, with milk and meat contributing US \$ 172.5 million and US \$ 309.1 million respectively. The current per capita consumption of beef in Uganda is low averaging 9 kg/yr (FAO, 2018) as compared to the global average of 42 kg/yr (OECD/FAO, 2017). Similarly, the per capita milk consumption estimated at 58 L/yr is far lower than the recommended 200 L/yr by the World Health Organization (FAO, 2014). While the per capita consumption of animal products is expected to decrease in developed countries due to increased health benefits and potential reductions in greenhouse gas (GHG) emissions (Farchi et al., 2017), meat consumption in Sub-Saharan Africa is projected to increase by 54–69% when the GDP doubles.

Methane (CH₄), nitrous oxide (N₂O) and Carbon dioxide (CO₂)

constitute the three major GHG emissions from ruminant livestock produced mainly through enteric fermentation, feed production and manure production and management processes (Gerber et al., 2010; Li et al., 2004). The process of anaerobic fermentation in the rumen and large intestines is responsible for the release of enteric methane to the atmosphere as the ruminant animals respire methane gas from the mouth and nostrils (Henry and Eckard, 2009). This process referred to as methanogenesis or biomethanation has been associated with loss of energy from the feed (Wood and Knipmeyer, 1998; Grobler et al., 2014) and some researchers (Pinares-Patino et al., 2003) have suggested that use of feed combinations such as tanniferous legumes with grasses have the potential to reduce methane emission per unit of dry matter intake. In addition, livestock excreta (manure and urine) and its subsequent handling and management practices contribute to on-farm GHG emissions. Manure management practices differ across livestock farming systems, manure form (solid or liquid) and quantities produced among other factors. A complex of microbial activities and chemical processes dictated by the prevailing anaerobic conditions result in a fluctuating production of nitrous oxide and methane from livestock excreta (Petersen and Miller, 2006; Amon et al., 2006). Urine deposited on pastures while animals graze produces a high flux of nitrous oxide immediately after urination with a sudden decline a day after (Luo et al., 2018).

The global anthropogenic GHG emissions from the agricultural

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sector show some variations across time and regions. Measured in CO₂ equivalent, Steinfeld et al. (2006) estimated that livestock generated 18% of the global anthropogenic GHGs and of which 9%, 37% and 65% are CO₂, CH₄ and N₂O respectively. In a later study, Gerber et al. (2010) reported a livestock contribution of 14.5% to the global anthropogenic GHG pool, 3.5% less than the estimate of Steinfeld et al. (2006). In developed countries, ruminant livestock GHG emission intensities are < 100 kg CO₂ eq/kg protein while in Sub-Saharan Africa (SSA), it ranges between 250 and 1,000 kg CO₂ eq/ kg protein (Herrero et al., 2016). The high emission intensity in SSA has been mainly attributed to low animal productivities where most of the local cattle breeds weigh less than a tropical livestock unit (1 Tropical Livestock Unit (TLU) = an adult animal of 250 kg live weight) and poor quality of feeds. Consequently, SSA is a hotspot for livestock GHG emissions and a region where an intervention could potentially benefit the efforts of reducing GHG emissions. Such interventions are in line with the 2015 Paris climate agreement that aimed at holding the global warming temperature below 2 °C (Rogelj et al., 2016).

Various techniques have been employed in quantifying GHG emissions such as; modelling techniques (Klimont and Brink, 2004; Olesen et al., 2006; Schils et al., 2007), direct-field measurements (Harper et al., 1999; Leytem et al., 2011; Allen et al., 2013) SF₆ tracer techniques and chamber techniques for methane measurement (Storm et al., 2012). Modelling techniques are superior to other methods of estimating GHG emissions when used to estimate emissions from large herds of cattle at country (Casey and Holden, 2005; Paul et al., 2018), regional (Mottet et al., 2017) and global scales (Herrero et al., 2016).

Cattle production in Uganda is highly concentrated in the rangeland ecosystem, commonly referred to as the cattle corridor which covers a land area of about 84,000 km² (about 35%) of Uganda's total land area. The cattle corridor is characterized by; periodic droughts, profound rainfall variability and for these reasons, the pastoralists occasionally move their livestock in search of water and pasture. While this is a growing concern, the future growth and sustainability of Uganda's livestock sector largely depends on the concerted efforts towards adaptation, mitigation, coping up with the effects of climate change/variability and management of GHG emissions from livestock that contribute to climate change (Zervas and Tsiplakou, 2012). There is limited information on GHG emissions from cattle farming systems of Uganda's central cattle corridor. This information is critical in designing intervention measures and strategies to mitigate the adverse impacts of climate change on livestock production. Therefore, the purpose of this study was to estimate the GHG emissions from cattle farming systems of Uganda's central cattle corridor and quantify potential benefits of a package of mitigation strategies.

2. Methodology

2.1. Study area

The study was conducted between February 2016 and May 2017 in the central cattle corridor of Uganda covering six (6) Global Climate Change Alliance-European Union (GCCA-EU) Project districts namely; Nakasongola, Luwero, Kiboga, Nakaseke, Mubende and Sembabule (Fig. 1). The area receives a bimodal-seasonal type of rainfall where the first season rains occur from March to May and the second rain season occurs from August to November. The mean daily temperatures range from 18 to 35 °C while the annual rainfall ranges between 750 and 1200 mm. Due to the erratic nature of the rainfall and occasional droughts in this area, the cattle corridor can be described as a semi-arid area characterized by perennial grasses suited for grazing livestock production.

2.2. Baseline survey, data collection and analysis

A baseline survey was carried out using a semi-structured

questionnaire whose parameters are described in Table 1. The enumerators were drawn from extension officers working in the area who had the trust of the respondents. These enumerators could also validate the information from the respondents since they knew the study area well. The enumerators were trained and the survey tool was pre-tested prior to data collection.

To select the respondent farmers, a purposive random sampling technique (Tongco, 2007) was employed in every sub-county within the six districts. The sampling technique ensured that each of the five cattle farming systems (CFS) (Stall, Semi-Intensive, Grazing, Scavenging and Tethering) practiced in the central cattle corridor were represented. The description and distinction of these CFS is shown in Table 2. The key characteristics of the CFS include: the priority of keeping the cattle, mobility, the feed resources used and the level of input use.

The data were analysed using SPSS 16.0 (SPSS Inc., Chicago, Illinois, USA) to produce usable input into the GHG emission estimation tool-GLEAM-i (<http://www.fao.org/gleam/resources>). The analysis used cross tabulation to establish relationships among variables such as; age at first calving against CFS, herd composition (calves, heifers, pregnant, adult males, adult females, etc.) against CFS, production (milk yield and gross weight) against CFS etc.

To enable estimation of the total GHG emission, the total number of cattle from the study was computed. Using 2008 as the baseline year, when the Uganda national Census on Agriculture (UCA) was carried out, the cattle number for the year 2016 was computed using the cattle growth rates reported in the UBOS abstracts (UBOS, 2012; UBOS, 2015; UBOS, 2017). To inform future planning and any improvement in cattle production, a projection of the cattle numbers by the year 2025 was made using the observed average cattle growth rate of 3%. Distribution of the total cattle number per CFS was obtained by multiplying the total number of cattle from the six districts by the ratio of animals under each CFS as obtained from the survey. The total GHG emissions under each CFS were determined using GLEAM-i.

2.3. The global livestock environmental assessment model

2.3.1. Model description

The cattle GHG emissions (CO₂, CH₄ and N₂O) were estimated using the Global Livestock Environmental Assessment Model (GLEAM-i) version 2.0 revision 1 September 2016. GLEAM-i is a modelling tool developed by the Food Agricultural Organization (FAO) to enable a livestock sector environmental impact assessment with the view of moving towards more sustainable practices, lessening environmental afflictions and ensuring livelihood of the producers. The choice to use GLEAM-i in this study was based on its capabilities and inherent advantages namely; runs in a Geographic Information System (GIS) environment and it (a) enables spatial estimation and disaggregation of the GHG emissions (b) estimates GHG by production/farming system and subsequently the product (milk or meat protein) emission intensities and (c) built with a wide range of animal feed rations that caters to the different feeds for different farming systems at global, regional, national or sub-national level (<http://www.fao.org/gleam/en/>). Because emission intensity in GLEAM-i is expressed as a ratio of quantity of greenhouse emitted (kg CO₂-eq) per unit product (kg protein), fresh milk yield in kg and the carcass weight in kg are converted into protein equivalent to enable comparison of emission intensities. GLEAM-i determines the milk protein and meat protein according to eqs. (1) and (2) respectively.

$$\text{MilkTot}_{\text{prot}} = AF \times \text{Milk}_{\text{yield}} \times \text{Milk}_{\text{prot}} \quad (1)$$

Where:

MilkTot_{prot} = total amount of milk protein, kg protein

AF = number of milking cows

Milk_{yield} = average milk production per cow, kg milk-head⁻¹.year⁻¹

Milk_{prot} = average protein fraction in milk, kg protein/kg milk⁻¹

Table 1
Questionnaire survey parameters.

Parameters
1. Demography: Gender of House Hold (HH) head, HH level of education, HH ability to read and write
2. Practiced Cattle farming system from five options (stall, Semi-Intensive, tethering, Grazing and Scavenging)
3. Land utilization: Land area for grazing (under natural grass), land area under planted pasture
4. Crop Production: Type of crop produced, Area under each crop planted
5. Cattle production: Purpose of Cattle (meat, milk, others), Breed of cattle, Number of cattle, Cattle composition (young, adult or fatteners), Age at first calving, Age to slaughter, Live weight, Lactation period, Milk yield, Fertility, Replacement rate
6. Cattle feeds and feeding: Source of feed, Type of feed (planted or natural, residues, concentrates, hay and silage)
7. Manure management: Percentage use of solid storage, daily spread, pasture/range/paddock, dry lot, liquid/slurry, Uncovered anaerobic lagoon, Burned for fuel, anaerobic digester, pit storage

$$\text{MeatTot}_{\text{prot}} = \text{BFM} \times \text{Meat}_{\text{prot}} \times \sum c(N_{\text{exit}} \times \text{LW} \times \text{DP}/100)_c \quad (2)$$

Where:

- MeatTot_{prot} = Total amount of meat protein, kg protein
- BFM = Bone-free-meat to carcass weight ratio, dimensionless. It is taken as 0.75 for large ruminants
- N_{exit} = Number of animals slaughtered
- Meat_{prot} = Average protein fraction in meat, kg protein/kg meat – 1
- LW = Live weight of slaughtered animals, kg LW animal⁻¹
- DP = Dressing percentage, %
- c = Species cohort

GLEAM-*i* is a Microsoft-Excel based tool founded on a Life Cycle Assessment (LCA) and has a global coverage of six livestock species and their edible products: meat and milk from cattle, sheep, goats and buffalo, meat from pigs; and meat and eggs from chicken. The LCA is a widely used and accepted approach for estimating livestock environmental impacts (Gerber et al., 2010) and in summary, it takes into account the various food supply chain activities and stages of production marked by inputs and outputs of a particular animal product. In this work, emissions related to cattle meat and milk were of interest due to the economic importance of these products in the Cattle corridor.

GLEAM-*i* is built on five modules: herd, manure, feed, system and allocation modules. The first three modules (herd, manure and feed) are input modules for the system and allocation modules to quantify production, total emissions and emission intensities. The herd module represents the structure of the cattle herd while the animal feed module represents the cattle feeding scheme such as grains, grasses, crop residues, industrial by-products etc. The inputs to the herd module include livestock numbers (adult reproductive males and females), age at first parturition, fertility of adult females, mortality rate, cattle weight, milk yield and the protein content. The feed module takes in proportions of the various cattle feedstock specific to a CFS while the manure module accounts for the proportions of the prevailing manure management practices or systems unique to each CFS.

The overall structure of GLEAM-*i* is shown in Fig. 2. A full description of GLEAM-*i* capabilities, the model equations employed to estimate the production and GHG emissions can be found in the GLEAM-*i* manual available for download from the FAO website (<http://www.fao.org/gleam/resources>).

2.3.2. Estimation of GHG emissions and production

To estimate the GHG emissions for the five CFS, they were configured to match the two GLEAM-*i* broad production categories (Dairy and Beef systems) based on the cattle system key priorities (Table 2) and its main feed resources. Based on this configuration criteria, Stall, Semi-Intensive and Tethering CFS were categorized and analysed under the

Table 2
Cattle farming systems in the central cattle corridor.

Cattle farming system		Stall	Semi-Intensive	Grazing	Scavenging	Tethering
Characteristics	Farmers priority	Milk production	Milk production	Primarily beef production and secondary products: milk, hides, manure	Although there is no clear priority here, income is raised by mainly selling mature animals for slaughter. For this reason, this study categorized Scavenging as a beef producing system.	Milk production
Mobility		Cattle are housed and fed in stalls which are structures normally built using timber and wood within an iron sheet roofing. Excreta (manure and urine) is easily collected.	Cattle housed and fed in stalls and when there is an abundance of grass, the cattle are moved to graze and later moved to the housing area. Excreta collected while the cattle are in the housing units.	Cattle moved to grasslands for grazing all year round. Open kraals are used for confining activities such as night sleeping, manure management, spraying, dehorning, vaccinations etc. Excreta is collected at night and while carrying animal operations. The availability of grass and water determine cattle movement	Cattle are left to roam about towns, centers, markets and roadsides to meet their feed requirements. Later in the night, cattle are confined in kraals or tethered within a homestead compound. Excreta deposited during night periods when cattle have been confined	Cattle tied to graze or feed on sourced feeds. Excreta deposited where the cattle are tethered.
Feed resources and input use		Planted grasses such as Napier grass, Maize bran, Hay, and some crop residues	Planted grasses such as Napier grass, Maize bran, Hay, some crop residues and natural pastures	Natural grassland pastures	Mixed feeds that range from Banana peels, crop residues, natural pastures	Natural grass, crop planted grass, crop residues
		High investment in Pest and disease control	Moderate investment in pest and disease control	Low investment in pest and disease control	Low investment in pest and disease control	

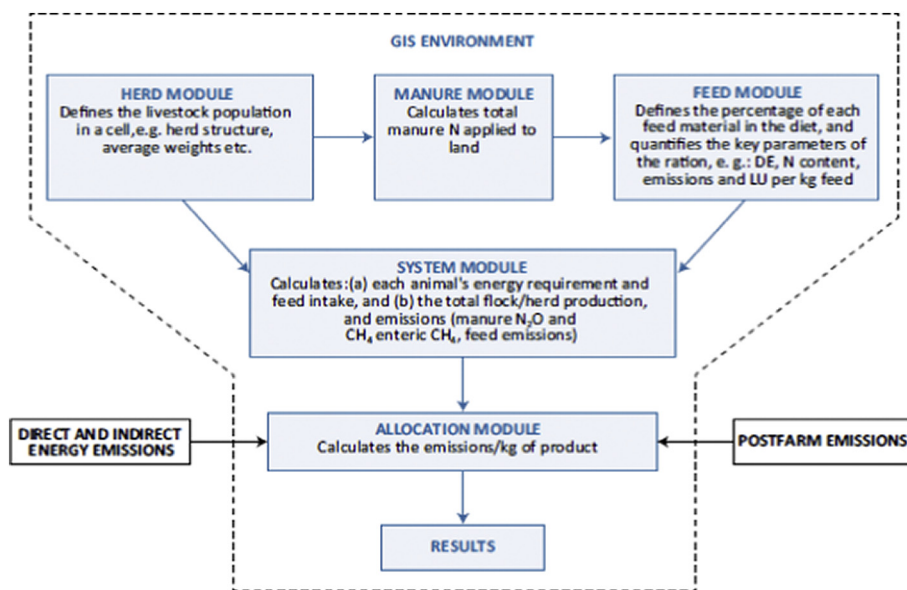


Fig. 2. Overview of the GLEAM-i modules and computation flows (Source: GLEAM- I manual version 2.0 revision 1 September 2016).

dairy systems while Grazing and Scavenging CFS were analysed as beef systems. Following this configuration, the observed data (Herd, Feed and manure) for the year 2016 was entered into the baseline cells in GLEAM-i to obtain the baseline production and the corresponding GHG emissions.

“For Scenario GHG emissions, this study considered interventions in literature such as: an improvement in the feed ration by supplementing grasses with dry-products from industries such as grain and bran that are considered energy dense feeds and improving manure handling and management through use of anaerobic (Mottet et al., 2017; Aguirre-Villegas and Larson, 2017; Gill et al., 2010).

Considering their physical applicability, the scenario interventions in this study therefore were:

1. Feed: A reduction in use of grass as feed by 10% and increase in use of industrial-by products by 10% across all the CFS.
2. Manure: Reduction in solid storage use by 10% and increased use of anaerobic digesters by 10% across all the CFS.

3. Results

3.1. Demography

Through the survey, data were collected from 1135 Household head (HH) respondents in the six study districts: 192 from Kiboga, 193 from Luwero, 207 from Mubenda, 144 from Nakaseke, 231 from Nakasongola and 168 from Sembabule. Of these respondents, 74.8% were male and 25.2% were female, most of them, in the age bracket of 30 to 55 years. The majority (52%) practiced Grazing CFS followed by 25.4% in Tethering, 10.2% under Stall, 9.5% in Semi-Intensive and the least (2.5%) practiced Scavenging. Across the five CFS, all the HHs had spent between 7 and 10 years at school, an equivalent of attaining primary and secondary level education. With this education level, over 89% of the HHs could read and write and this greatly benefited the data collection process in terms of providing useful, interpretable and analysable data.

3.2. Cattle farming systems

The Grazing CFS was the most dominant and accounted for 91.3% of the cattle numbers (Table 3 and Table 5). Stall CFS registered the highest milk yield (2062 kg/yr/head) while Grazing, Tethering and

Scavenging CFS registered about half of the milk yield in the Stall CFS. Although Stall had the highest milk yield, the mortality rate of the young males was highest here. About one in five young males die before becoming adult animals where survival rate increases to over 99%. Generally, the mortality of young animals was higher than for adult animals across the five CFS.

The total cattle in the study area represent about 16.4% of the total national cattle herd estimated at 14.4 million (UBOS, 2017). In Table 4, it can be observed that one third of the cattle in the central cattle corridor is in Kiboga district, one fifth is in Nakasongola district while Nakaseke, Mubenda and Sembabule districts had one eighth, one sixth and one seventh respectively. By using the ratios of the cattle numbers for the CFS in Table 3, the total numbers of cattle in the six study districts were split into the five CFS (Table 5). On average, the reproductive females formed 26.5% of the total cattle while the reproductive males were 9.9%.

3.3. Cattle breeds and feeding

Grazing and Scavenging CFS whose main product is beef production were the predominant grazing systems. The main cattle breed in these CFS are local breeds with the long horned Ankole breed forming more than half of the total herd while the Zebu and their crosses locally referred as the Nganda form about one third of the cattle herd. Although the average body weight (150–220 kg) of adult local cattle was lower than that for exotic and cross breeds, these breeds were reported to be relatively more disease resistant and drought tolerant. In addition, local breeds have the advantage of depending largely (83%) (Table 6) on natural grasses and leguminous pastures and converting it into useful products. The common types of natural indigenous grasses include; *Hyparrhenia rufa*, *Brachiaria spp.*, *Themeda triandra*, *Panicum maximum* and *Chloris gayana*. The rest of the feed ration especially in the dry season was derived from hay and silage (5%) while the available crop residues which depend on the crop harvesting cycle provided about 9% of the feed. The dominantly grown crops that provide useful residues include; maize, banana, beans, sweet potatoes and cassava. Other sources of feed include; dry by-products from grain industries such as bran and hay and silage from grass-legume mixtures which accounted for < 10% of the feed ration.

In Stall, Semi-Intensive and Tethering CFS whose main product is milk, pure exotic and cross breeds were kept. Among the common exotic breeds were the Jersey, Ayrshire, brown Swiss and Guernsey.

Table 3
Herd characteristics per cattle farming system.

Parameter	Cattle farming system				
	Stall	Semi-intensive	Grazing	Tethering	Scavenging
Total Cattle	418	2101	41,750	1247	222
Adult Reproductive females (heads)	104	688	10,966	305	69
Adult reproductive males	30	190	3973	278	40
Age at first calving in weeks	132	124	134	136	131
Fertility of adult females	71.8	62.5	61.3	65.3	65.7
Mortality of young females	4.9	5.4	15.3	12.3	20
Mortality of young males	23.8	18.8	17.3	25.2	15
Mortality of adult	0.07	11.18	15.60	5.78	17.50
Adult female replacement	26.6	32.1	24.4	27.5	10.7
Weight at birth (kg)	30.8	39	38	30	33
Weight of adult females (kg)	223.9	220	195	200	157
Weight of adult males (kg)	–	235	215	219	190
Weight of fattening females (kg)	273	235	228	–	–
Weight of fattening males (kg)	300	250	291	–	–
Milk yield (kg/yr/head)	2062	1589	1030	1237	949

Table 4
Cattle Numbers in the study districts.

District	Cattle numbers (000 ^a)			
	UCA 2008 ^a	2016	2020 ^{**}	2025 ^{**}
Kiboga	365	453	510	591
Luwero	80	99	111	129
Nakasongola	222	275	310	359
Nakaseke	161	199	224	260
Mubende	209	259	291	337
Ssembabule	177	220	248	287
Total	1214	1505	1694	1964

^a 2008 Baseline cattle numbers from the UCA.

^{**} Projected Cattle numbers based on a growth rate of 3% per annum.

Table 5
Cattle numbers managed in each cattle system.

2016 Animal numbers	Cattle systems				
	Stall	Semi-intensive	Grazing	Tethering	Scavenging
Total Cattle	13,754	69,132	1,373,762	41,032	7305
Adult Reproductive females	3422	22,638	360,830	10,036	2270
Adult reproductive males	987	6252	130,729	9147	1316

Table 6
Sources of feed.

Feed	Beef CFS	Dairy CFS
Grazed Grass	80 ^a	75 ^b
Hay or silage from grass	5	5.5
Fresh mixture of grass and legumes	5	3
Hay and silage from grass and legumes	3	2.5
Crop residues from maize	3.5	3.5
Crop residues from rice	1.5	1.5
Crop residues from other grains	2	3
Crop residues from sugarcane	3	1
Dry by-product from grain industries	1	5

^a Natural grass.

^b Planted grass.

Their average body weights ranged from 200 to 300 kg for the adult cattle and 30–40 kg at birth (Table 3). These breeds were fed a more intentional feed ration where feed wastage was minimal as compared to

the grazing systems. For the milk producing CFS, planted grasses represented up to 75% of their feed ration (Table 6). The main planted grass, elephant grass (*Pennisetum purpureum*), is usually cut from the field and transported to the feeding lots in the cattle house where it is further cut into pieces of approximately 10–15 cm to improve its eatability and reduce feed wastage. Like in the grazing CFS, crop residues also contributed a small portion (9%) of the total feed ration. But to improve residue eatability, the residue is cut using a feed chopper and an additive such as animal salt, or molasses is added. Maize bran, a residue from maize millers although relatively expensive than the other feed sources is an important part of the diet in the milk producing systems. Maize bran plus other dry by-products contributed up to 5% of the feed ration.

Due to high temperatures in tropical regions, the nutritional quality or value of tropical pastures is low as compared to temperate pastures. Generally, the Dry matter content, Gross energy content, Crude protein (CP) and Neutral detergent fibre (NDF) for natural pastures in Uganda are; 37.79%, 3.97 kcal/g, 6.71% and 71.3% respectively (Roschinsky, 2009). However, it should be noted that nutritional value of the pastures can vary across pasture species, region, soils, and stage of growth and level of management among others. Across species, the mean CP of common pasture species in the cattle corridor is; 11.28%, 10.95%, 9.54%, 4.14%, 12.54% and 11.08% for *Brachiaria spp.*, *Chloris gayana*, *Hyparrhenia rufa*, *Themeda triandra*, *Panicum maximum* and *Pennisetum purpureum* (Sabiiti and Mugerwa, 1990). Macro nutrients phosphorus and calcium are low- 0.18% and 0.085% respectively (Roschinsky, 2009).

3.4. Manure management

The study showed that cattle manure is handled using eight different manure management methods that include:

- i. Pasture/range/paddock. Manure from the pasture and range is allowed to lie as deposited and is not managed;
- ii. Spreading on a daily basis. Manure is routinely applied to cropland or pasture within 24 h of excretion;
- iii. Solid storage. Manure is typically stored for several months in unconfined piles or stacks;
- iv. Dry lot storage. Accumulated manure may be removed periodically from a paved or unpaved confinement area;
- v. Storage as liquid slurry. Water is added to the manure and stored in tanks or earthen ponds outside the animal housing for periods less than a year;
- vi. Uncovered anaerobic lagoons. Manure systems that combines waste stabilization and storage in uncovered anaerobic lagoons for

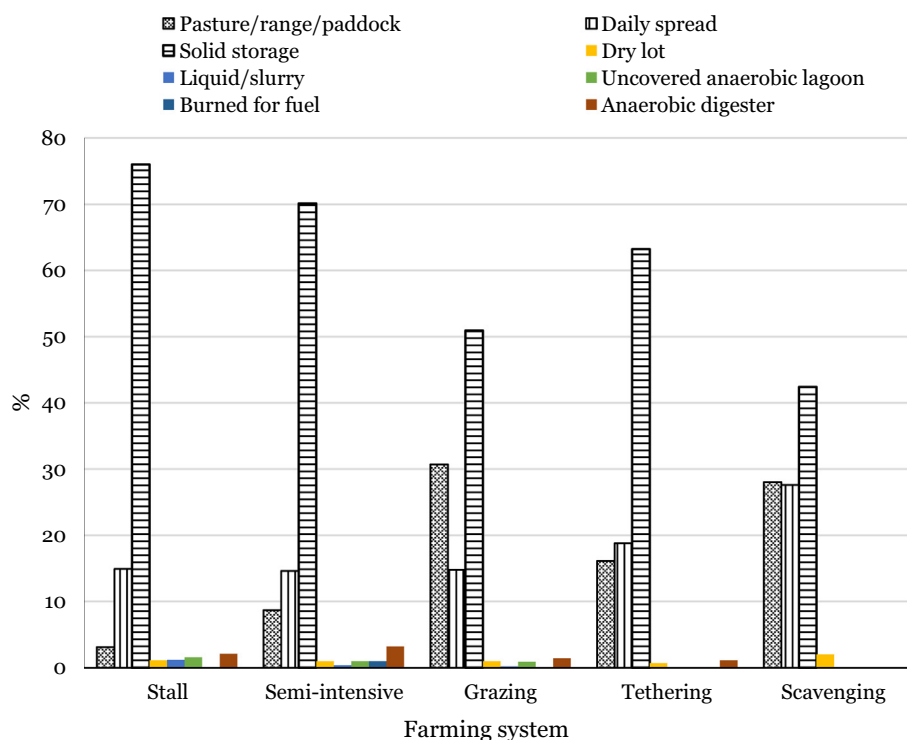


Fig. 3. Manure management methods used in each CFS.

- vi. periods up to a year or greater;
- vii. Burned for fuel. The sun dried dung cakes in the field are collected and burned for fuel and
- viii. Anaerobic digesters. The excreta which may be mixed with straw is collected and fed as substrate in to the anaerobic digesters to produce biogas fuel.

The proportions of the manure management methods in the CFS is shown in Fig. 3. Solid storage accounted for most of the manure handling in each of the farming systems and on average, its utilization was up to 60.5%. Spreading daily in the gardens and deposition at the paddock/range accounted on average for 18.1% and 17.4% respectively. Although the other management systems were individually insignificant, it can be noticed that the use of cattle manure as feedstock in the anaerobic digesters was practiced more in stall-based systems than in Grazing based systems.

3.5. Protein production

From the 1.505 million cattle equivalent to 1.379 million TLU in the baseline year (2016), the estimated milk protein production was 1996 Mt. protein/yr while the meat protein estimate was 2714 Mt. protein/yr. Of the total milk protein, Semi-Intensive CFS produced 64.9% while tethering and stall CFS each produced 22.4% and 12.7% respectively (Fig. 4). For beef protein production, Grazing CFS accounted for 89.1% and 6.4% in the Semi-Intensive system. The projected protein production (kg protein/yr) in 2020 and 2025 show a 12.6% and 30.7% increase respectively.

3.6. GHG emissions

For the total cattle protein production in 2016, the corresponding aggregated GHG emissions was 2009 Gg CO₂-eq/yr and the projections for 2020 and 2025 show a proportionate increase with protein production. Because Grazing CFS accounts for most of the cattle (91.3%) and most of the beef protein production, it was responsible for up to

88.5% of the total GHG emissions. Of the three GHGs (Carbon dioxide, Methane and Nitrous oxide), total methane represented 79.3% of the total emissions while total nitrous oxide and carbon dioxide estimates were 19.6% and 1.1% respectively (Fig. 5 and Fig. 6). Among the emission sources, enteric fermentation is of great importance as it accounted for 95.6% of the total methane production and 75.8% of the total GHG emissions. Second in importance to enteric methane was nitrous oxide emissions from manure applied in the crop and pasture fields for feed production and also that deposited while cattle graze. This source produced about 520 Gg CO₂-eq/yr which was 82.5% of the total nitrous oxide emission and about 25.9% of the total GHG emissions.

The emissions from milk producing CFS (Stall, Semi-Intensive and Tethering systems) primarily amounted to 222 Gg CO₂-eq/yr or 11.1% of the total emissions. The meat producing CFS (Grazing and Scavenging) were responsible for 1787Gg CO₂-eq/yr or 88.9% of the total emissions. While the emission intensity of milk production was 74.9 kg CO₂-eq/kg protein, the emission intensity of meat production was 8.5 times (639 kg CO₂-eq/kg protein) that of milk production. Considering the emission intensity per animal (TLU), the emission intensity in the baseline year was 1457.4 kg CO₂-eq/TLU.

With the proposed interventions package (Section 2.3.2), a reduction of 4.4% (or 88.2 Gg CO₂-eq) from the 2016 baseline total GHG emissions could have been realised. Although the total non-CO₂ emissions: CH₄ and N₂O decrease by 2.1% and 13.6% respectively under the proposed interventions, total CO₂ emissions increased from the baseline by 177.7% (Fig. 5 and Fig. 6). For example, in 2016, the total baseline CO₂ emissions amounted to 14.5 Gg CO₂-eq/yr while the corresponding scenario emission was 40.1 Gg CO₂-eq/yr. If the proposed interventions were to be implemented from the study period, 2016 until 2025, about 1004 Gg CO₂-eq cumulatively could potentially be mitigated.

4. Discussion

Due to the abundance of natural and perennial grasses in the central corridor, Grazing CFS was the most practiced CFS. Moreover, the cattle

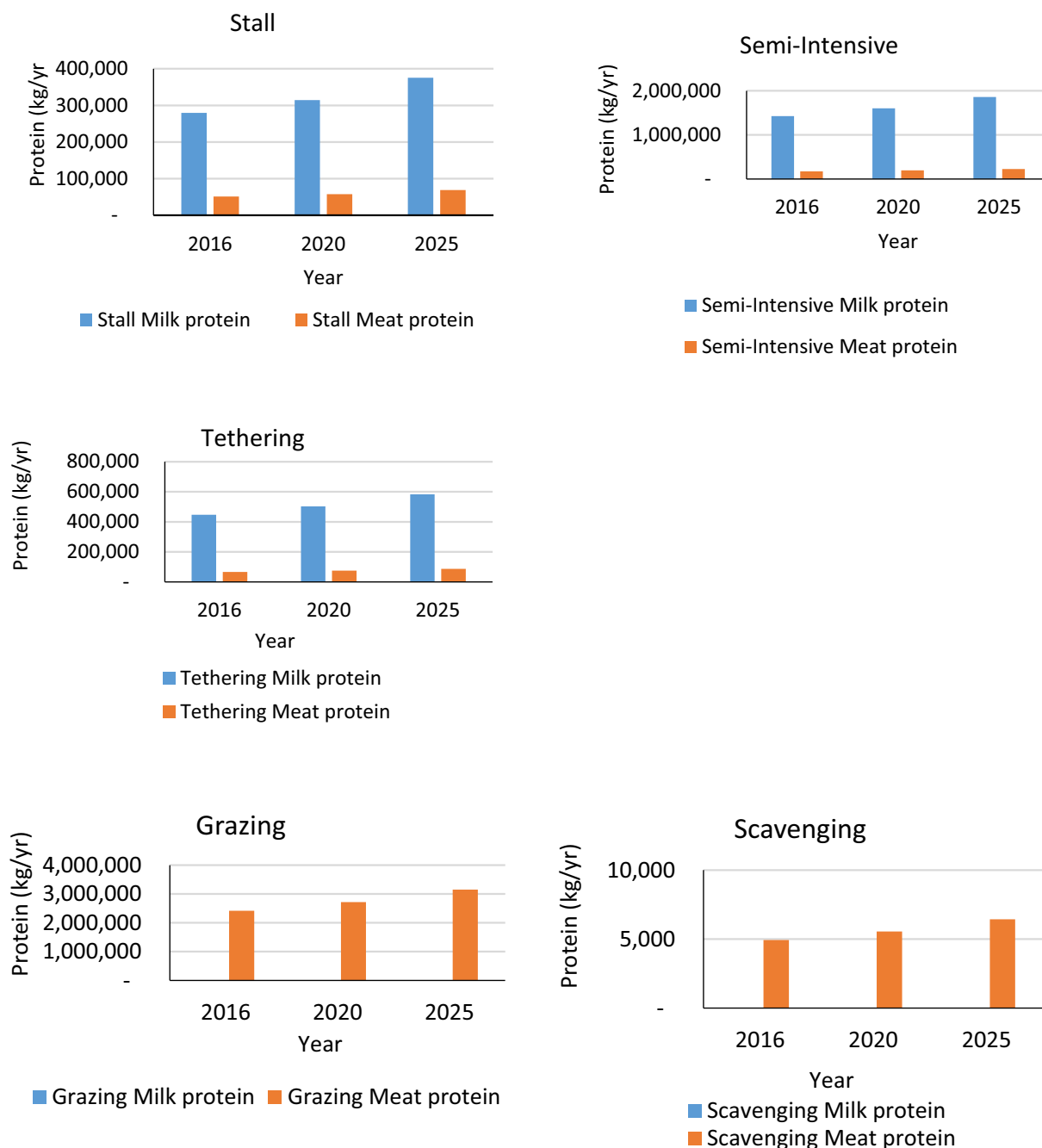


Fig. 4. Cattle Protein production in the different CFS.

breeds in the central cattle corridor were dominated by local breeds, which demand a relatively ‘lesser’ management plan and input use than the Stall-based systems. Across the five CFS, the young males had the highest mortality rate (Table 3). The factors for this male high mortality rate were attributed to killing males to control inbreeding, pests and diseases, and accidents among others. Other than killing the young calves, farmers should be encouraged to practice beneficial options such as castration of young calves and breeding the calves for beef.

From the FAOSTAT GHG emissions database for Uganda (<http://www.fao.org/faostat/en/>), the agricultural sector produced 26,570 Gg CO₂-eq in the year 2016. From the GHG model estimations of this study, the central cattle corridor in the same year-2016 produced 209 Gg CO₂-eq, which is 7.5% of the national agricultural sector emissions. Most of the GHG emissions were accounted for in the Grazing CFS given that it was largely practiced in the central cattle corridor. The main

sources of GHG emissions were CH₄ from enteric fermentation and N₂O from manure application and deposition and this finding agrees with the findings of studies done by Borhan et al. (2012) and Thoma et al. (2013). Although our study did not investigate feed digestibility, a study done by Mottet et al. (2017) indicated that the low feed digestibility of 54% on average versus the 59% global average combined with inferior animal growth rates and low milk yields in East Africa's dairy result in high (60% of total) enteric methane emissions. Concerning cattle feeding, Herrero et al. (2016) found that low feed quality, and feed scarcity which characterize grazing and meat producing cattle systems especially in sub-Saharan Africa (SSA) result in high GHG emission intensities. Their study suggested that emission intensities could be decreased with improvements in the diet composition and quality. Petersen et al. (2013) showed that an addition of fat supplements in the animal diet could reduce overall GHG by 8–14% and

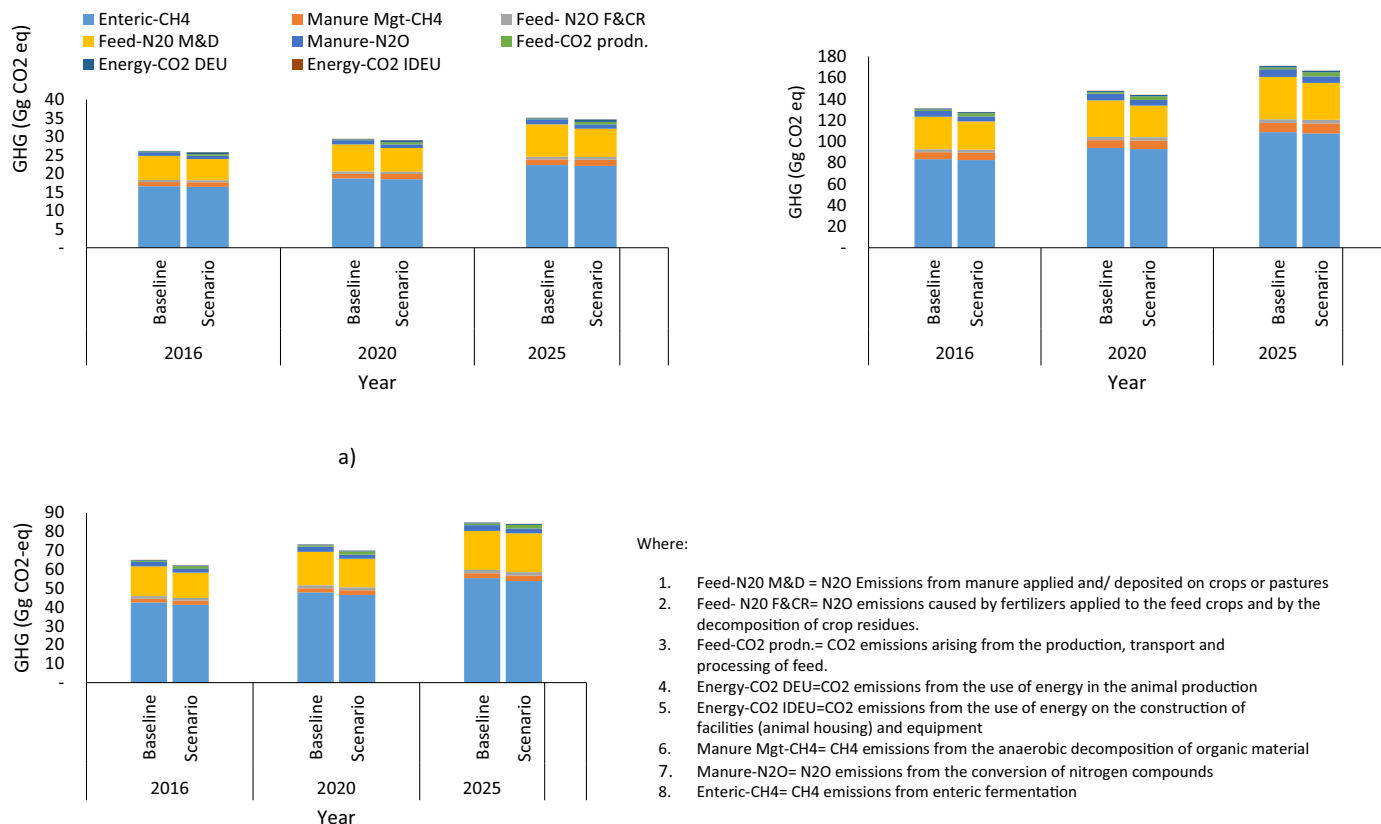


Fig. 5. GHG emissions from Meat producing systems: a) Grazing b) Scavenging (Baseline: Observed data (feed and manure) in the year 2016; Scenario: a 10% decrease in grass and a 10% increase in use of anaerobic digesters).

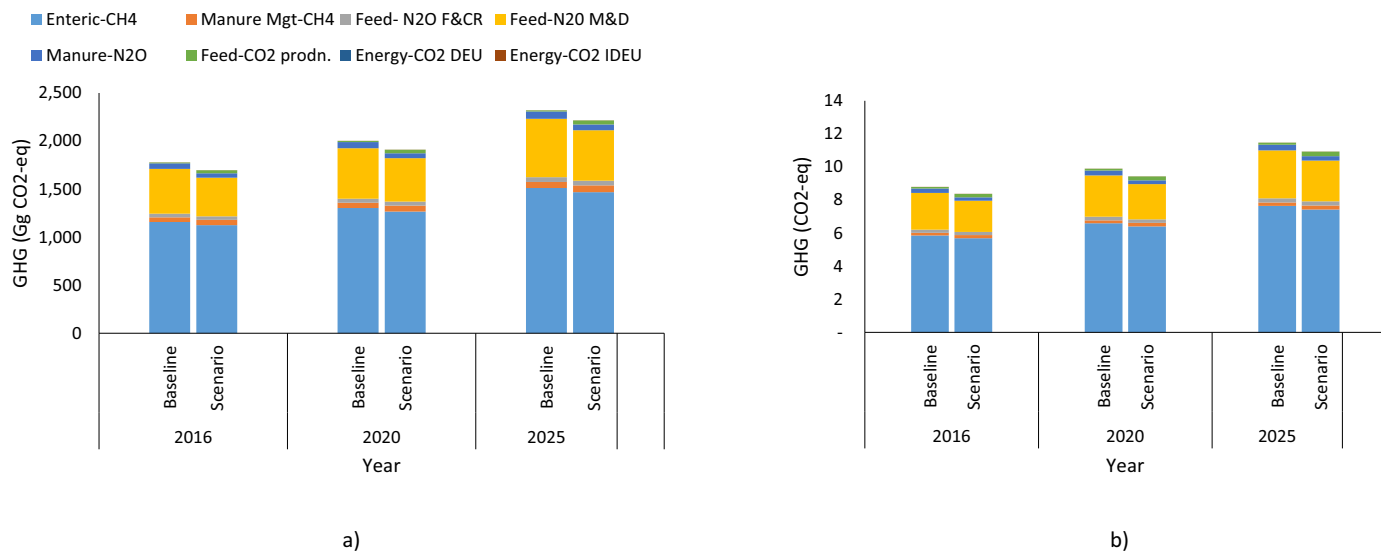


Fig. 6. GHG emissions from Meat producing systems: a) Grazing b) Scavenging (Baseline: Observed data (feed and manure) in the year 2016; Scenario: a 10% decrease in grass and a 10% increase in use of anaerobic digesters).

authors (Alvarez-Hess et al., 2019) suggest that use of 3-nitrooxypropional and nitrate as additives to forage feeds can reduce cattle greenhouse gas emissions by up to 23% depending on the additive feedrate and the age of the herd. Their study further suggested that increasing the rate of nitrate supplementation for both breeding and growing cattle achieved the most greenhouse gas reductions. The addition of supplements could be a viable greenhouse gas abatement intervention for the Stall, Semi-Intensive and Tethering CFS where there is ability to control feed sourcing and management. However, there are

potential challenges to implementing and achieving such an intervention. These challenges have been categorized to belong under the following: Practical limitations, knowledge limitations, cognitive limitations and interests (Kipling et al., 2019). All these limitations strongly identify with the central cattle corridor.

In this study, the emission intensities for milk and meat lie mid-range of the intensities reported in Havlík et al. (2014) where milk and meat emission intensities were: 12–140 kg CO₂-eq/kg protein and 58–1000 kg CO₂-eq/kg protein respectively. However, the emission

intensity for meat production (639 kg CO₂-eq/kg protein) could have been lower since the GLEAM-i, model only accounts for one product (either milk or beef) per CFS system. Yet in the study area each CFS has small inclusion of either beef or milk. For example, the milk yields in Grazing and Tethering CFS were 1030 kg/head/yr and 949 kg/head/yr respectively and these were not accounted for in the emission intensities for the protein from the beef CFS.

Results of emission intensities for the European livestock sectors reported by Lesschen et al. (2011) (22.6 kg CO₂-eq per kg for beef and only 1.3 kg CO₂-eq per kg for milk) are far lower than the intensities in our study. This variation in intensities could be explained by the major differences in the cattle feed rations, breed types, and productivity. While the EU livestock sector is characterized by high yielding cattle breeds with better management, results showed that local breeds and cross breeds with low productivity dominated the cattle herds in the central cattle corridor. A study (MacLeod et al., 2018) conducted in East Africa indicated that the high greenhouse gas emission intensity per unit of protein due to low productivity resulting from poor animal health could be reduced by up to 8%. Their study grounds this achievement to increased milk yields and cow fertility rates among trypanosomiasis free animals. The scope of this study did not include investigating animal health contribution to greenhouse gas emission.

In sub-Saharan Africa, livestock emission for Rwanda as expressed per TLU was reported to be on average 1360 kg CO₂-eq/TLU (Paul et al., 2018) and comparing this value with the finding of this study (1457.4 kg CO₂-eq/TLU), it suggests a much higher emission per TLU for Uganda. This disparity could be a result of Rwanda's deliberate efforts to promote and adopt zero grazing and improved livestock feeding due to their limited land resources (Paul et al., 2018). The benefits of such a farming system for livestock production include improved manure management with potential to limit greenhouse emission.

The three commonly managed manure systems (Fig. 3) are: solid storage, daily spread, and pasture/range/paddock system. Daily spread system is where manure is regularly (within 24 h of excretion) removed from the point of deposition and applied to crop or pasture land. Daily spread is quite laborious and demanding as compared to solid storage where fresh manure is first collected into unconfined piles or stacks for several months resulting in evaporative moisture loss and weight loss. Solid storage or composting results in microorganisms breaking down organic matter producing GHGs and aeration can potentially result in a reduction in CH₄ and an increase in N₂O (Petersen et al., 2013; Webb et al., 2012). Solid storage is commonly practiced where there is presence of bedding material. Because of the high use of grasses across the CFS and the need to improve handling and transportation of manure to the gardens, solid storage accounted for most of the manure handling. Petersen et al. (2013) discussed regional differences in manure management with regard to GHG mitigation. Among the six manure management systems (lagoon, liquid/slurry, solid storage, dry lot, pasture/range, and daily spread), only three were common in SSA. Pasture/range was used up to 48% while solid storage and dry lot were 32% and 21% respectively to handle the manure produced. In our study, dry lot use was far lower as compared to solid storage, daily spreading, and pasture/range use. According to (Aguirre-Villegas and Larson, 2017), a reduction in GHG emissions can be achieved through frequent (daily or weekly) application in fields, but, measures have to be put in place to avoid potential runoff and leaching into water sources. In our study, simulations done across the five CFS with an increased use (10% increase) of biogas digesters and a corresponding decrease in solid storage for manure management showed an annual decrease of 2.1% in CH₄ production. The basis for a 10% increase in anaerobic digester relied on: a) the increasing demand for clean energy for heating operations in the cattle corridor area; b) high potential for biogas production given that each of the CFS collects some quantities of manure (Table 2) and c) the need to move towards a livestock-energy-nexus which achieves nutrient and energy recovery from anaerobic digester sludge and biogas respectively. However, there is need to strengthen the linkage and

collaboration with successful biogas companies and technical institutions to bridge the knowledge and skills gap among the cattle farmers.

Other interventions for manure (liquid and solid) handling and the associated GHG emission and mitigation, Petersen et al. (2013) suggested that a saving in GHG emissions (CH₄ and N₂O) of up to 36% could be achieved by covering solid manure using a plastic sheet or straw. This proposed intervention could work well for central corridor producers where natural perennial grass that can be used as a straw covering is abundant most of the year.

Based on the findings of this study and the observations of (Aguirre-Villegas and Larson, 2017; Mottet et al., 2017; Berndt and Tomkins, 2013; Bell et al., 2012), the intervention areas in the central cattle corridor should target mainly farmers practicing the Grazing cattle CFS which accounts for 91.3% of the cattle and address areas related to feed resources, cattle breeds and manure management. Grobler et al. (2014) compared methane emissions from three breeds (Bonsmara, Nguni and Jersey breeds) in South Africa using the laser methane detector measurement technique under cattle natural feeding condition and their results suggested that the Jersey breed, an exotic breed, produced significantly less ($P < 0.05$) methane than the Nguni and Bonsmara breeds. In another study (Robertson and Waghorn, 2002), large North American Holstein breed and small New Zealand Holstein breed when fed on a mixed ration and pasture resulted in differences in methane emissions. The large American Holstein breed produced 8–11% (as a percentage of Gross energy intake) less methane than the small New Zealand Holstein breed. Due to the limitations of the modelling tool (GLEAM-i version 2 revision 1) used in this study, a comparison of GHG emission for exotic and local breeds was not possible.

With regard to animal feeding, an increase in feed intake results in a decrease (on average 1.6% per unit of intake) in the fraction of gross energy lost as methane due to the reduction in rumen retention time (Bell et al., 2012). While this could lower enteric methane emissions conceivably, it can elevate nitrogen excretion in the form of nitrous oxide. This classic example compares with the intervention package analysed as our scenario where a reduction in non-CO₂ emissions is achieved but, the CO₂ emissions are tremendously increased as illustrated in Fig. 5 and Fig. 6.

5. Conclusions

This study established that Grazing CFS accounted for 91.3% of the cattle and 88.5% of the total GHG emission, therefore, the most important and critical for GHG emission mitigation in the central cattle corridor. Because local breeds with a low body weight dominated the Grazing CFS, registered a low milk yield, of 1030 kg/yr/head as compared to stall-based systems where pure and cross breeds produced twice the milk yield. All CFS generally depended on grasses for over 75% of the feed ration. However, milk producing systems depend on planted grasses like elephant grass while the meat producing systems depend on natural perennial grasses. Given that the main feed resource is natural grass with a low milk yield, GHG emission intensities for milk and meat were high: 74.9 kg CO₂-eq/kg protein and 639 kg CO₂-eq/kg protein respectively as compared to global average values. The most important emission source, enteric fermentation produced > 75% of the total GHG emissions and therefore intervention in the area of animal feeding is most important. In addition to enteric fermentation, N₂O emissions from manure applied and deposited constituted 25% of the total emissions. Analysis of a scenario where there is an improvement in animal feeding and manure handling showed a 4.4% reduction in total GHG emission annually.

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References

- Aguirre-Villegas, H.A., Larson, R.A., 2017. Evaluating greenhouse gas emissions from dairy manure management practices using survey data and lifecycle tools. *J. Clean. Prod.* 143, 169–179.
- Allen, D.T., Torres, V.M., Thomas, J., Sullivan, D.W., Harrison, M., Hendler, A., Herndon, S.C., Kolb, C.E., Fraser, M.P., Hill, A.D., 2013. Measurements of methane emissions at natural gas production sites in the United States. *Proc. Natl. Acad. Sci.* 110, 17768–17773.
- Alvarez-Hess, P.S., Little, S.M., Moate, P.J., Jacobs, J.L., Beauchemin, K.A., Eckard, R.J., 2019. A partial life cycle assessment of the greenhouse gas mitigation potential of feeding 3-nitrooxypropanol and nitrate to cattle. *Agric. Syst.* 169, 14–23.
- Amon, B., Kryvoruchko, V., Amon, T., Zechmeister-Boltenstern, S., 2006. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. *Agric. Ecosyst. Environ.* 112, 153–162.
- Behnke, R., Nakiryia, M., 2012. The Contribution of Livestock to the Ugandan Economy. Bell, M., Eckard, R., Cullen, B., 2012. The effect of future climate scenarios on the balance between productivity and greenhouse gas emissions from sheep grazing systems. *Livest. Sci.* 147, 126–138.
- Berndt, A., Tomkins, N., 2013. Measurement and mitigation of methane emissions from beef cattle in tropical grazing systems: a perspective from Australia and Brazil. *Animal* 7, 363–372.
- Borhan, M.S., Mukhtar, S., Capareda, S., Rahman, S., 2012. Greenhouse gas emissions from housing and manure management systems at confined livestock operations. In: *Waste Management-an Integrated Vision*. InTech.
- Casey, J., Holden, N., 2005. Analysis of greenhouse gas emissions from the average Irish milk production system. *Agric. Syst.* 86, 97–114.
- FAO, 2014. *Technical note: Analysis of price incentives for milk in Uganda for the time period 2005–2013* [Online]. Available: http://www.fao.org/fileadmin/templates/mafap/documents/technical_notes/UGANDA/2005-2013/UGANDA_TN_dairy_web.pdf (Accessed 20th June 2018).
- FAO, 2018. *Africa Sustainable Livestock 2050- Livestock Production systems spotlight Uganda: Chicken, meat and beef* [online]. Available: <http://www.fao.org/3/i8713en/i8713EN.pdf> (Accessed 05th June 2018).
- Farchi, S., De Sario, M., Lapucci, E., Davoli, M., Michelozzi, P., 2017. Meat consumption reduction in Italian regions: health co-benefits and decreases in GHG emissions. *PLoS One* 12, e0182960.
- Gerber, P., Vellinga, T., Opio, C., Henderson, B., Steinfeld, H., 2010. Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment. Food and Agriculture of the United Nations, Rome, Italy.
- Gill, M., Smith, P., Wilkinson, J., 2010. Mitigating climate change: the role of domestic livestock. *Animal* 4, 323–333.
- Grobler, S., Scholtz, M., Van Rooyan, H., Mpapiphele, M., Neser, F., 2014. Methane production in different breeds, grazing different pastures or fed a total mixed ration, as measured by a laser methane detector. *South Afr. J. Anim. Sci.* 44, 12–16.
- Harper, L., Denmead, O., Freney, J., Byers, F., 1999. Direct measurements of methane emissions from grazing and feedlot cattle. *J. Anim. Sci.* 77, 1392–1401.
- Havlík, P., Valin, H., Herrero, M., Obersteiner, M., Schmid, E., Rufino, M.C., Mosnier, A., Thornton, P.K., Böttcher, H., Conant, R.T., 2014. Climate change mitigation through livestock system transitions. *Proc. Natl. Acad. Sci.* 111, 3709–3714 201308044.
- Henry, B., Eckard, R., 2009. Greenhouse gas emissions in livestock production systems. *TG: Tropical Grasslands* 43, 232.
- Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., Wierseni, S., Hristov, A.N., Gerber, P., Gill, M., 2016. Greenhouse gas mitigation potentials in the livestock sector. *Nat. Clim. Chang.* 6, 452.
- Kipling, R.P., Taft, H.E., Chadwick, D.R., Styles, D., Moorby, J., 2019. Challenges to implementing greenhouse gas mitigation measures in livestock agriculture: a conceptual framework for policymakers. *Environ. Sci. Pol.* 92, 107–115.
- Klimont, Z., Brink, C., 2004. Modeling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe.
- Lesschen, J., Van Den Berg, M., Westhoek, H., Witzke, H., Oenema, O., 2011. Greenhouse gas emission profiles of European livestock sectors. *Anim. Feed Sci. Technol.* 166, 16–28.
- Leytem, A.B., Dungan, R.S., Bjorneberg, D.L., Koehn, A.C., 2011. Emissions of ammonia, methane, carbon dioxide, and nitrous oxide from dairy cattle housing and manure management systems. *J. Environ. Qual.* 40, 1383–1394.
- Li, C., Mosier, A., Wassmann, R., Cai, Z., Zheng, X., Huang, Y., Tsuruta, H., Boonjawan, J., Lantin, R., 2004. Modeling greenhouse gas emissions from rice-based production systems: sensitivity and upscaling. *Glob. Biogeochem. Cycles* 18.
- Luo, J., Balvert, S., Wise, B., Welten, B., Ledgard, S., De Klein, C., Lindsey, S., Judge, A., 2018. Using alternative forage species to reduce emissions of the greenhouse gas nitrous oxide from cattle urine deposited onto soil. *Sci. Total Environ.* 610, 1271–1280.
- Macleod, M., Eory, V., Wint, W., Shaw, A., Cecchi, G., Mattioli, R., Sykes, A., Robinson, 2018. Assessing the greenhouse gas mitigation effect of removing bovine Trypanosomiasis in eastern Africa. *Sustainability* 10, 15.
- Mottet, A., Henderson, B., Opio, C., Falcucci, A., Tempio, G., Silvestri, S., Chesterman, S., Gerber, P.J., 2017. Climate change mitigation and productivity gains in livestock supply chains: insights from regional case studies. *Reg. Environ. Chang.* 17, 129–141.
- OECD/FAO, 2017. *OECD-FAO Agricultural Outlook 2017–2026* [Online]. OECD Publishing, Paris (Available: doi: 10.1787/agr_outlook-2017-en [Accessed 28th June 2018]).
- Olesen, J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A., Djurhuus, J., 2006. Modelling greenhouse gas emissions from European conventional and organic dairy farms. *Agric. Ecosyst. Environ.* 112, 207–220.
- Paul, B., Frelat, R., Birmholz, C., Ebong, C., Gahigi, A., Groot, J., Herrero, M., Kagabo, D., Notenbaert, A., Vanlauwe, B., 2018. Agricultural intensification scenarios, household food availability and greenhouse gas emissions in Rwanda: Ex-ante impacts and trade-offs. *Agric. Syst.* 163, 16–26.
- Petersen, S.O., Miller, D.N., 2006. Greenhouse gas mitigation by covers on livestock slurry tanks and lagoons? *J. Sci. Food Agric.* 86, 1407–1411.
- Petersen, S.O., Blanchard, M., Chadwick, D., Del Prado, A., Edouard, N., Mosquera, J., Sommer, S.G., 2013. Manure management for greenhouse gas mitigation. *Animal* 7, 266–282.
- Pinares-Patino, C., Ulyatt, M., Waghorn, G., Lassey, K., Barry, T., Holmes, C.W., Johnson, D., 2003. Methane emission by alpaca and sheep fed on lucerne hay or grazed on pastures of perennial ryegrass/white clover or birdsfoot trefoil. *J. Agric. Sci.* 140, 215–226.
- Robertson, L., Waghorn, G., 2002. Dairy industry perspectives on methane emissions and production from cattle fed pasture or total mixed rations in New Zealand. *Proc. New Zealand Soc. Anim. Product* 213–218 Wanfang Data Resource System.
- Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K., Meinshausen, M., 2016. Paris agreement climate proposals need a boost to keep warming well below 2 C. *Nature* 534, 631.
- Roschinsky, R.K., 2009. Analysis of pastures and pasture management on dairy cattle farms in South-Western Uganda, na.
- Sabiiti, E., Mugerwa, J., 1990. Forage research and developments for livestock production in Uganda. In: *Utilization of Research Results on Forage and Agricultural Byproduct Materials as Animal Feed Resources in Africa*. ILCA, Addis Ababa, pp. 186–206.
- Schils, R., Olesen, J.E., Del Prado, A., Soussana, J., 2007. A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. *Livest. Sci.* 112, 240–251.
- Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., Rosales, M., de Haan, C., 2006. *Livestock's Long Shadow: Environmental Issues and Options*. Food & Agriculture Org.
- Storm, I.M., Hellwing, A.L.F., Nielsen, N.I., Madsen, J., 2012. Methods for measuring and estimating methane emission from ruminants. *Animals* 2, 160–183.
- Thoma, G., Popp, J., Nutter, D., Shonnard, D., Ulrich, R., Matlock, M., Kim, D.S., Neiderman, Z., Kemper, N., East, C., 2013. Greenhouse gas emissions from milk production and consumption in the United States: a cradle-to-grave life cycle assessment circa 2008. *Int. Dairy J.* 31, S3–S14.
- Tongco, M.D.C., 2007. Purposive sampling as a tool for informant selection. *Ethnobot. Res. Appl.* 5, 147–158.
- UBOS, 2012. *Statistical abstract* [Online]. Available: <http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/2012StatisticalAbstract.pdf>, Accessed date: 15 January 2017.
- UBOS, 2015. *Statistical abstract* [Online]. Available: https://www.ubos.org/wp-content/uploads/publications/03_2018Statistical_Abstract_2015.pdf, Accessed date: 15 January 2017.
- UBOS, 2017. *Statistical abstract* [Online]. Available: https://www.ubos.org/wp-content/uploads/publications/03_20182017_Statistical_Abstract.pdf, Accessed date: 6 July 2018.
- Webb, J., Sommer, S.G., Kupper, T., Groenestein, K., Hutchings, N.J., Eurich-Menden, B., Rodhe, L., Misselbrook, T.H., Amon, B., 2012. Emissions of ammonia, nitrous oxide and methane during the management of solid manures. In: *Agroecology and Strategies for Climate Change*. Springer.
- Wood, C., Knipmeyer, C., 1998. *Global Climate Change and Environmental Stewardship by Ruminant Livestock Producers*. National Council for Agricultural Education, University of Missouri, USA.
- Zervas, G., Tsiplakou, E., 2012. An assessment of GHG emissions from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock. *Atmos. Environ.* 49, 13–23.