Chapter 19
Reducing GHG Emissions from Traditional Livestock Systems to Mitigate Changing Climate and Biodiversity

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Abstract Climate change (CC) directly impacts the economy, ecosystems, water resources, weather events, health issues, desertification, sea level rise, and even political and social stability. The effects of CC affect different groups of societies differently. In Tanzania, the effects of CC have even acquired a gender dimension, whereby women are viewed as more vulnerable than men because of socioeconomic and historic barriers. CC is largely caused by anthropogenic activities, including those that increase the concentrations of greenhouse gases (GHGs) in the atmosphere. Recent findings indicate that the livestock sector is responsible for 18 % of GHG emissions measured in the CO_2 equivalent. Moreover, some gases emitted by livestock have higher potential to warm the atmosphere than CO_2 and have a very long atmospheric lifetime. Methane (CH_4) has 23 times the global warming potential (GWP) of CO_2, whereas nitrous oxide (N_2O) has 296 times the GWP of CO_2. It is now estimated that the atmospheric concentrations of CH_4 and N_2O are increasing at a rate of approximately 0.6 % and 0.25 % per year, respectively. Cattle may emit CH_4 from enteric fermentation equivalent to 2–12 % of the ingested energy, whereas produced manure can emit N_2O up to 1.25 % of its weight. The estimated total CH_4 and N_2O emissions from Tanzanian ruminants

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stand at 26.17 Gg and 0.57 Gg, respectively. In this paper, we first very briefly review emissions of GHGs from different livestock production systems in Tanzania with the view of identifying the main hot spots. Then, we concentrate on the available adaptation options and the limitations on the adoption of such adaptation options in Tanzania. Emission of these GHGs per unit product varies with the level of intensification, the types of livestock kept, and manure management. Intensification of livestock production reduces the size of the land required to sustain a livestock unit and frees up the land necessary for carbon sequestration. In Tanzania, such intensification could take the form of the early harvesting and storing forage for dry-season feeding. The advantage of this intervention is twofold: young harvests have higher digestibility and emit less CH_4 when fed to ruminants than mature lignified forage; use of stored roughage in the dry season will reduce the desertification of rangeland and deforestation that occur when livestock search for pastureland. Dry-season supplementation of ruminants with energy and protein-rich diets will reduce CH_4 emission. The chemical treatment of crops byproducts will increase the crops' digestibility and reduce CH_4 emission from ruminants. Crossbreds of indigenous and exotic breeds are more efficient converters of feed into products like meat and milk, with less GHG emitted per unit product. The use of manure for biogas production will reduce the emission of both CH_4 and N_2O into the atmosphere. Shifting from liquid to solid manure management has the potential to reduce CH_4 emissions. Most of these interventions, however, are not cost neutral – enhancing awareness alone will not lead to their widespread adoption. In the absence of subsidies, the adoption of these interventions will depend on the relative cost of other options. Although some traditional livestock systems in Tanzania are already coping with the impact of CC, such efforts are handicapped by inadequate resources, poor coordination, and implementation of competing measures.

Keywords Livestock production • Global warming • Climate change • Adaptation strategies

19.1 Introduction

Tanzania has a large land resource base (88.6 M ha), most (60 M ha) of which is rangeland suitable for livestock production. The country also has a large livestock population currently estimated at 22.8 million cattle, 15.6 million goats, 7.0 million sheep, 2 million pigs, and 60 million poultry (MLDF 2013). This livestock population is an important resource that, if used efficiently, can contribute significantly to economic development and poverty alleviation. This resource, however, has the potential to contribute significantly to global warming through greenhouse emissions if not utilized properly. For instance, livestock manure can emit N_2O up to 1.25 % of the weight of manure produced (Flessa et al. 2002), and cattle may emit CH_4 from enteric fermentation equivalent to 2–12 % of the ingested energy (Johnson and Johnson 1995). Currently, the contribution of the livestock sector to the Tanzanian gross domestic product is only 4.6 %, with beef cattle contributing

40 %, dairy cattle 30 %, and other livestock 30 % to this share (MLDF 2013). The largest proportion (95 %) of cattle in Tanzania is indigenous and in the hands of pastoral and agro-pastoral societies. These cattle are used mainly for beef production based on the free grazing on natural pasture. It is now known that beef production is the most inefficient production in terms of greenhouse gas (GHG) emissions produced per unit of product, especially compared to those of dairy cattle and monogastrics animals. Moreover, beef cattle production under extensive production systems leads to higher CH_4 emissions per animal, because these systems are characterized by lower feed quality and higher feed intake (FAO 2006; Pitesky et al. 2009). Given the large population of cattle in Tanzania and the extensive nature of production, the contribution of this sector to the GHG emissions is likely to be much larger than what is currently known.

The increase in the concentrations of GHG in the atmosphere results in global warming and ensuing CC. In Tanzania, the effects of CC have included the deterioration of water quality and quantity, the loss of biodiversity, a decline in agricultural productivity, and the loss of some means of livelihood (Shemsanga et al. 2010). The livelihood of pastoral communities has been among the worst hit by CC because of diminishing grazing and water resources, and the outbreak of climate-dependent livestock diseases. CC in the country has also been linked to the increasing problem of plants toxic to livestock and, potentially, to human beings (Shemsanga et al. 2010). Significant losses of livestock to drought in the recent past were linked to plant toxicity. The influx of young men from pastoral societies in Tanzania (Maasai, Nyaturu, and Barbaig) to urban areas is a manifestation of a failing means of making a living. Unfortunately, most efforts to mitigate the emission of GHGs have been directed toward the energy sector, because it accounts for about 75 % of the CO_2 emissions from human activities. Recent findings indicate that the global contribution of the livestock sector to the GHG emissions, measured in CO_2 equivalents, is estimated to be 18 % (FAO 2006; Pitesky et al. 2009; Rotz et al. 2010). There is, however, limited documentation on GHG emissions from livestock production in Africa. Current estimates of GHG emissions from Africa's agricultural sector rely on data collected in developed countries (Herrero et al. 2011). These estimates may not be applicable to Africa, given the different climatic conditions and production settings. Preliminary findings on GHG emissions and sinks in Tanzania, using default emissions factors, were reported by Mwandosya et al. (1996) and Mwandosya and Meena (1999). These reports show that CO_2 emissions from Tanzania amounted to 55,208 Gg. From these estimates, the contribution of CO_2, CH_4, and N_2O emissions from Tanzania to the global warming potential was 55 %, 45 %, and 1 %, respectively. However, there is a need to establish country-specific emission factors, since emissions of GHG differ with production systems used, which is determined by climatic conditions, socioeconomics, traditions, and available resources. It is argued, notwithstanding, that developed countries are responsible for two-thirds of anthropogenic emissions (Mwandosya et al. 1996). At the same time, CC causes more casualties in developing countries than in developed countries because of the lack of resources to cope with its effects and the overdependence on natural resources that are already affected by CC. The limited ability of developing countries to adapt to CC necessitates effective collaboration with developed countries to forge concerted efforts to mitigate GHG emissions and to build the capacity to adapt to the consequences of the emissions. Developing countries should, therefore, explore policy options and strategies that enhance the achievement of developmental objectives and of poverty alleviation while contributing to climate stabilization. In this paper, we briefly review: the impact of CC on traditional livestock systems; emissions of GHGs from different livestock production systems with the view of identifying the main GHGs emissions hot spots; the available mitigation and adaptation options; and the limitations on the adoption of such options in Tanzania.

19.2 The Effects of CC on the Performance of Traditional Livestock Systems and on Biodiversity in Tanzania

Ongoing CC has affected livestock productivity (draught power, milk and meat production), survival, and distribution, through the reduced quantity and quality of range resources, and through the prevalence of vector-born livestock diseases (IPCC 2001; URT 2003). Consequently, milk and meat production is likely to be reduced following the stress on the grazing lands. This is more likely to happen in Tanzania, considering that the number of livestock already overwhelms the carrying capacity of many grazing grounds in the central and northwest zones, where droughts are common. Studies indicate that increased carbon dioxide reduces the protein available from vegetation and increases the eruption of diseases and new pests, for example, ticks, snails, and other pests (IPCC 2001; URT 2003). There are indications that the distribution of tsetse flies is shifting into northeast Tanzania and, thus, reduces land for human settlements, grazing ranges, and other developments (IPCC 2001). As a result, pastoralists have been forced to relocate to places where pasture and water are available (Shayo 2006). This mobility has already caused conflicts between different pastoral societies, on one hand, and farmers and pastoralists, on the other hand. Moreover, there are reported conflicts between livestock and wildlife. High livestock mortality linked to the lack of water and pastures has been recurring in Tanzania in recent years, hence, threatening the livelihood of pastoralists in the country. Pastoral societies have started to learn alternative livelihood support activities. Nonetheless, such adaptations are useful only for the short-term effects of CC (Shemsanga et al. 2010).

Despite Tanzania being among the richest countries in terms of biodiversity (UNEP 1998; URT 2007), Tanzania's forests are in major continuing danger of deforestation from both anthropogenic activities and CC. In 2002, it was estimated that the deforestation rate in the country was about 91,276 ha per year. Among the main anthropogenic activities responsible for deforestation are overgrazing, wildfires, and clearing the land for agriculture and settlement. These anthropogenic activities have been contributing significant CO_2 emission while reducing carbon sinks (URT 2007). As in many other countries in Africa, the biodiversity of Tanzania is expected to change as different species try to adjust and cope with the impact of CC. CC may trigger the loss of some species and the migration of ecosystems. Because of increased ambient temperatures and decreasing precipitation, many important forests are likely to be replaced by grasslands and woodlands (Shemsanga et al. 2010). Because invasive species tend to adapt better to changing climates than the desirable pasture species (Malcolm et al. 2002), pasturelands also are likely to be rendered a no-go area for animal grazing.

19.3 Livestock Production Systems and GHG Emissions

Livestock production can be classified into three main systems, based on the spatial characteristics (area requirement) and the economic objective (commercial or subsistence) of livestock keeping: extensive, semi-intensive, and intensive. Extensive systems are grassland based and require a large area (>5 ha) of rangeland to sustain a livestock unit for 1 year. In this system, livestock are mainly sustained by the free grazing of natural pastures whose quality and quantity vary with the season. Extensive systems may involve keeping livestock only (solely livestock), like pastoralism and commercial ranching, or keeping livestock combined with crop cultivation (mixed farming), like agro-pastoralism. Extensive systems are usually present on land considered unfit for growing crops, primarily semiarid or arid areas (FAO 2006; Pitesky et al. 2009). In Tanzania, this system is predominantly found in the central zone (Dodoma and Singida), the lake zone (Mwanza and Shinyanga), and the northeastern zone (Manyara and Arusha). In semi-intensive systems, livestock are allowed to graze during the day and are supplemented with improved feed upon their return from grazing. A good example of this system is the smallholder dairy production system. Intensive systems are high input–high output, with animals spending their lifetime in stalls (landless systems) and receiving improved feed; or, the animals spend time partly in the pasture and finish their eating via stall feeding (feedlot systems). Livestock production systems (LPs) used in any particular area are determined by the socioeconomic environment, tradition, and available resources.

To estimate the GHG "footprint" of livestock, the type of LP needs to be identified and characterized. The type of production system utilized (i.e., landless vs. grassland based) has a direct (from the animal) and an indirect (emissions associated with livestock) effect on livestock-based emissions. Globally, extensive LPs produce more GHG (5,000 vs. 2,100 Tg CO_2-eq year^{-1}) than intensive systems (FAO 2006; Pitesky et al. 2009), as poor livestock holders with extensive systems often extract marginal livelihoods from dwindling resources and lack the funds to invest in change. Most of these GHG emissions come from ruminants that produce more GHG than monogastrics, because of their greater biomass and unique metabolic function (ruminal fermentation). The high level of emissions from extensive systems is attributed to a high intake of poor-quality feed with a high retention time in the gastrointestinal tract, giving rise to a higher enteric emission of CH_4 per animal compared to that of a landless production system. Under grassland-based livestock management, livestock production is considered a net zero emitter of CO_2. This occurs is because the CO_2 from the respiration of livestock that had previously been absorbed via plants (FAO 2006). Thus, livestock-based CO_2

emissions are components of a continuously cycling biological system, where plant matter that had once sequestered CO_2 is consumed by livestock and then released back into the atmosphere by respiration to be reabsorbed by plants (Kyoto Protocol 1997; FAO 2006). There is significant evidence from the literature that grassland more than offsets CO_2 emissions from livestock (Garnett 2009; Herrero et al. 2011). However, desertification caused by overgrazing of grassland during dry periods tends to make grassland-based livestock production a net emitter of CO_2 (Asner et al. 2003). In addition, extensive systems tend to contribute to deforestation, soil erosion, biodiversity loss, and water contamination caused by overgrazing (Eckard et al. 2010). Thus, the large population of ruminants in Tanzania in the hands of pastoral societies may be contributing more to global GHG emissions than the current estimates. For instance, with 22 million cattle, 15.6 million goats, and 7.0 million sheep, Tanzania may be a significant contributor to GHG emissions. However, as long as we do not have country-specific emission of GHG from livestock, we cannot demonize the ruminant population in the country as a causative agent of global warming. The current paucity of information on livestock-based emission levels from Tanzania and other African countries, in the face of increasing livestock population, calls for the commitment of research efforts and resources to generate badly needed emission indicators. The establishment of country-specific emission levels requires appropriate expertise and know-how, establishing networks for cooperation, sufficient funding for data collection, supportive policies, and the perceived application of information on emission levels (Brent et al. 2002; Udo de Haes 2004). In contrast to developed countries, developing countries may be facing challenges that need to be tackled before the environmental burdens of GHG emissions become a priority in their national policies (Arena 2001).

Intensification may be seen as a panacea for the problem of GHG emissions from livestock. However, caution should be exercised about this generalization. Intensive systems involving the heavy use of machinery for feed production and processing will contribute to the net emission of CO_2. Cultivation of land for feed crop production will also contribute to the loss of soil organic carbon (SOC). The use of chemical nitrogen fertilizers to increase feed crop yield also contributes to increased N_2O emission. Developed countries are the primary users of this system, with 54.6 % of total meat production produced in landless systems (FAO 2006). Globally, landless systems are used mainly for poultry and pig production (FAO 2006; Pitesky et al. 2009). Developing countries hardly use these systems for ruminant production, because these countries are still struggling with producing enough food for the human population.

19.4 Livestock-Based GHG Emission Hot Spots

Compared to other countries, the estimated contribution of Tanzania to the causes of CC is low, and it is mainly through large animal herds, overgrazing, deforestation, land use changes, and waste management (Shemsanga et al. 2010). In terms of contribution by sector, land-use change in the country may contribute more to the GHG emission problem than fossil fuel emission, primarily because of the low level of industrialization.

The net emission of GHG from livestock production is best determined through a life cycle assessment (LCA) that includes all important emission sources and sinks within the production system as well as those associated with the production of resources used in the system (Weiske and Petersen 2006; Schils et al. 2007; Rotz et al. 2010; Gerber et al. 2013). The global contribution of livestock production to anthropogenic GHG emission varies a great deal, with the estimated contributions ranging from 8 to 18 % (Steinfeld et al. 2006; Weiske and Petersen 2006; Eckard et al. 2010; Herrero et al. 2011). This variation in estimates may reflect, *inter alia*, different methodological approaches used to measure the contribution of livestock to GHG emissions. Some of the methodologies used to estimate GHG emission per livestock product consider only edible outputs (FAO 2006; Weiske and Petersen 2006; Pitesky et al. 2009). When other non-food outputs of livestock production are considered, GHG emissions attributable to meat and dairy products will be much lower (Garnett 2009). For example, based on the economic value of leather, up to 7.7 % of GHG emission from livestock production is attributable to leather itself (Garnett 2009). This consideration would reduce GHG emissions per livestock product by 7.7 %, although overall livestock emissions will remain the same.

Despite efforts toward standardization, LCA methodology presents certain limitations and unresolved problems (Reap et al. 2008b; Finnveden et al. 2009), especially when applied to or adopted by developing countries (Arena 2001; Brent et al. 2002; Udo de Haes 2004). From the methodological point of view, several questions remain unsolved. The first methodological challenge deals with uncertainty, i.e., data gaps and uncertainties, methodological choices, and descriptions of the studied systems. First, data availability and quality in developing countries are common problems (Brent et al. 2002). To overcome this lack of data, databases included in commercial software packages are usually used. Hence, errors can occur because these databases rely on data from different countries or from regions with different practices, technologies, and regulations (Finnveden 2000; Brent et al. 2002). LCA is very data intensive, and the lack of data can restrict the conclusions that can be drawn from a specific study (Finnveden 2000). Second, regarding methodological choices, uncertainties arise in each of the LCA's four phases: (1) goal and scope definition; (2) life cycle inventory analysis; (3) life cycle impact assessment; and (4) life cycle interpretation. Such uncertainties can reduce the accuracy of the tool (Reap et al. 2008a, b). Generally, environmental impact categories have been performed in and for developed countries, without adjusting them for African conditions (Brent and Hietkamp 2003). Therefore, it may occur that impacts not considered important in developed countries are of major importance in developing ones (Brent et al. 2002). Furthermore, regional conditions should be well taken into account, clarifying the differences in conditions between industrialized and developing countries (Udo de Haes 2004). In general, livestock farming systems in developed countries are better defined, more homogeneous, and product oriented, and aim at optimizing animal performances. However, livestock farming systems in developing countries are less studied, more heterogeneous, multifunctional, and aim at optimizing the farming system as a whole. This phenomenon is especially true for most livestock farming systems in developing countries, but this may also apply to pasture-based livestock systems in developed countries, mostly located in marginal land (Ripoll-Bosch et al. 2013). Moreover, in developing countries, enormous spatial variation applies, which refers to differences in geology, topography, land cover (both natural and anthropogenic), and meteorological conditions (Reap et al. 2008a).

The LCA "cradle-to-grave" approach, combined with its focus on products, results in environmental burdens allocated to such products. Therefore, the productivity of the system (especially commodities) becomes a key issue. This is a handicap for livestock farming systems in developing countries and in marginal lands in developed countries, since they are inherently associated with lower breeding efficiency and lower animal productivity (Gill et al. 2010). However, such livestock farming systems provide other functions that are generally omitted in LCA, i.e., the delivery of most non-food ecosystem services, the settlement of populations in remote areas, or capital assets. In this sense, other relevant issues are not tackled in the debate: Higher emissions are associated with meat from ruminant livestock than monogastrics (Williams et al. 2006; De Vries and De Boer 2010). However, it is worth considering the type of animal feed, as most diets for monogastrics are edible for humans, whereas the diets of pasture-based ruminant production are not (Gill et al. 2010; Wilkinson 2011). Pasture-based farming systems have the ability to valorize "natural and renewable resources" that do not compete with human nutrition and cannot be used for alternative purposes, such as human-edible products. However, this ability becomes a handicap from an LCA point of view, also because the emission of CH_4 decreases as feed quality (digestibility) increases (Beauchemin et al. 2008). Therefore, since intensive systems generally rely more on highly digestible concentrates, a decrease in CH_4 emissions with an increase in the intensification level should be expected (Gerber et al. 2011). Although monogastrics are more efficient in terms of total food resource use, accounting for the proportions of human-edible and inedible feeds would render a more realistic estimate of efficiency to compare with that of other systems (Wilkinson 2011).

In livestock production, particularly ruminants, the emission of GHG occurs during feed production, feed digestion, and the post-harvest handling of livestock product, with further emissions occurring during the handling of manure (FAO 2006; Rotz et al. 2010; Shortall and Barnes 2013). According to FAO (2006) and Pitesky et al. (2009), by disregarding post-harvest emissions, livestock account for 9 %, 37 %, and 65 % of the total global anthropogenic emission of CO_2, CH_4, and N_2O, respectively. However, FAO (2006) considered three sources as the main GHG emission hot spots in livestock production: enteric fermentation (the main source of CH_4); manure management (the main source of N_2O); and land-use changes for grazing and feed production (the main source of CO_2). Overall, beef production and cattle milk production account for most emissions, contributing, respectively, 41 % and 20 % of the sector's emissions (Gerber et al. 2013). Pig meat and poultry meat, and eggs contribute, respectively, 9 % and 8 % to the sector's emissions.

GHGs emissions from livestock can be divided into two types: direct and indirect emissions (FAO 2006; Pitesky et al. 2009; Rotz et al. 2010). Direct emissions are primarily produced by the livestock themselves, including CH_4 from enteric fermentation and manure, and N_2O from excreted urine and manure. Given the large population of ruminants in Africa, and in Tanzania, in particular, the extensive nature of livestock production, poor manure handling practices, and direct emissions from livestock may constitute significant contributions to global GHG emissions. Indirect emissions stem from livestock feed production and the handling of livestock products (transportation, cold storage, and processing) as well as land-use changes for livestock production (Mosier et al. 1998; Pitesky et al. 2009). These include: CO_2 emission from the combustion of fuel in machinery used to produce feed, and to process and to transport livestock products; land-use changes to support livestock production, namely, the conversion of forests to pastures and cropland for livestock purposes; the degradation of above-ground vegetation from livestock grazing; and the loss of soil organic carbon from cultivated soils associated with livestock (Fig. 19.1). The study done in Tanzania in 1990 produced similar findings on the sectorial contribution to GHG emission (Fig. 19.2). The limited use of machinery in Tanzania for feed crop production,

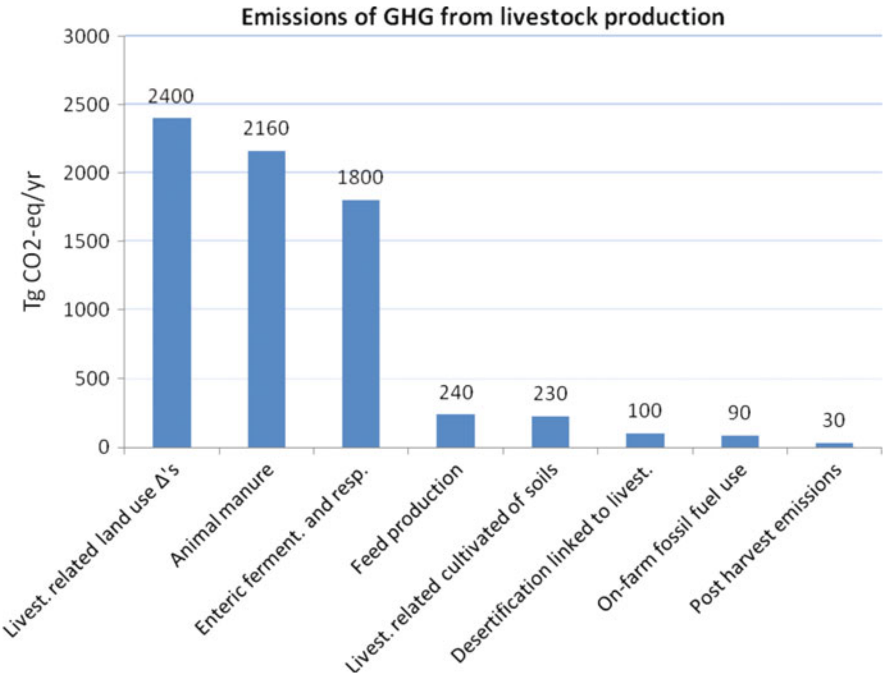


Fig. 19.1 Emission of GHG from livestock production (Derived from data provided by Pitesky et al. 2009)

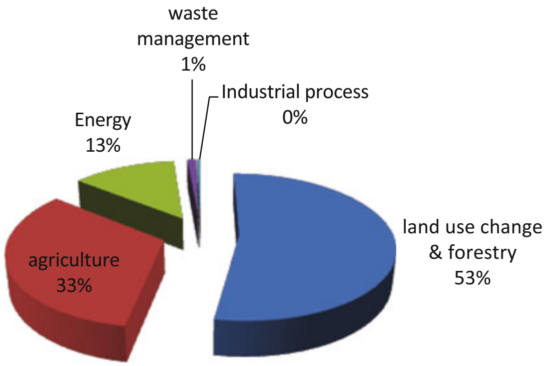


Fig. 19.2 Percentage contribution of different sectors to GHG emissions from Tanzania (Derived from data provided by Mwandosya and Meena 1999)

processing, and transportation of livestock may exempt the country from a significant contribution to CO_2 emission. However, the fast-growing population of livestock, which accelerates the rate of land-use changes to support livestock production, may imply that the livestock sector in Tanzania is still a significant contributor to global CO_2 emissions. Globally, feed production and processing, and enteric fermentation from ruminants are the two main sources of GHG (Fig. 19.1), representing, respectively, 45 % and 39 % of sector emissions (Gerber et al. 2013). The other main source is manure storage and processing, representing 10 %. The remainder is attributable to the processing and transportation of animal products. The consumption of fossil fuel along the sector supply chains accounts for about 20 % of sector emissions.

19.4.1 Emission of CH_4 from Livestock

Globally, livestock are the most important source of anthropogenic CH_4 emissions. Among domesticated livestock, ruminant animals (cattle, buffalo, sheep, goats, and camels) produce significant amounts of CH_4 as part of their normal digestive processes. Annual CH_4 emission (80 Tg) from ruminant livestock accounts for approximately 33 % of anthropogenic emissions globally (Beauchemin et al. 2008; Eckard et al. 2010). This emission stems from enteric fermentation in ruminant animals and manure disposals (Flessa et al. 2002; Mwandosya et al. 1996). Mwandosya and Meena (1999) estimated CH_4 emission from animals and manure in Tanzania to be 8 Gg.

19.4.1.1 CH_4 from Enteric Fermentation

Ruminants are capable of converting marginal land into useful land by utilizing plants on such lands to produce valuable animal protein. At the same time, ruminant livestock are important contributors to CH_4 in the atmosphere. Because of the unique digestive system of ruminants, CH_4 production is part of the normal

Table 19.1 Increasing emission of CH_4 with decreasing livestock productivity caused by increased stocking density

Stocking rate, ha/AUE	Grass used for maintenance, tones	Grass available for production, tones	Potential live weight gain, kg/year	Potential beef production, kg/year	Liter of CH_4 per kg beef produced
11.1	107	68	2,092	1,046	1,230
8.3	142	33	1,015	508	2,530
6.7	178	−3	−92	−46	∞
5.5	214	−39	−1,200	−600	∞

Source: Modified from Sundstøl (2007)

digestive process (Weiske and Petersen 2006; Rotz et al. 2010). The estimate of CH_4 emission from enteric fermentation is based on defining the type and the level of feeding, the number and the type of animal, animal size, livestock management systems, total energy intake, and production characteristics (Mwandosya et al. 1996; Jungbluth et al. 2001; Sun et al. 2008; Pitesky et al. 2009). Simplified relationships for the estimation of CH_4 emission are based on the estimation of the total energy intake by the animal and an estimate of the ratio of the feed energy converted to CH_4 (Mwandosya et al. 1996). Cattle may lose between 2 and 12 % of their ingested energy as eructated CH_4 (Johnson and Johnson 1995). Thus, the enteric emission of CH_4 in ruminants has two consequences: the loss of metabolizable energy and the contribution to GHG. Enteric CH_4 emissions per unit of production are highest when feed quality and level of production are low, see Table 19.1. Ruminants in the traditional sector in Tanzania and in many other African countries are mainly maintained on poor-quality feed and produce minimally. This natural combination of the type of feed available and the level of production may exacerbate the contribution of livestock in Tanzania to global GHG emissions. Holter and Young (1992) reported that CH_4 outputs range from 3.1 to 8.3 % of the gross energy intake for dry, non-lactating cows, and from 1.7 to 14.9 % of the gross energy intake for lactating cows. Overall, CH_4 emission from enteric fermentation accounts for 73 % of CH_4 from ruminants globally, making it the main source of this GHG from ruminants (Pitesky et al. 2009). The estimated level of enteric CH_4 emission amounts to approximately 1,800 Tg CO2-eq/yr. However, the definitive attribution of GHG emission to livestock production in developing countries awaits country-specific emission data.

19.4.1.2 CH_4 from Manure Management

Methanogens require an anaerobic environment to function. This means that the amount of CH_4 produced is less when manure is handled aerobically. The amount of CH_4 produced depends on the manure's characteristics, especially the amount of volatile solids present in the manure and manure management (Mwandosya et al. 1996). Typically, when livestock manure is stored or treated in lagoons, ponds, or tanks (anaerobic conditions), CH_4 emissions are produced in higher amounts than when manure is handled as a solid (stacks or drylot corrals) or deposited in a pasture where aerobic decomposition occurs, thereby reducing CH_4 emissions (Chadwick 2005; Pitesky et al. 2009). This understanding may indicate that intensive livestock systems produce more CH_4 than extensive systems, because liquid manure storage is common in intensive systems. In addition, semi-intensive livestock production systems may produce significant amounts of CH_4, as compacted manure heaps (with an anaerobic core environment) are common in these systems. The use of manure to fertilize rice fields may contribute to the significant emission of CH_4 on account of the primarily anaerobic conditions of irrigated rice fields. However, the free-grazing systems practiced in the traditional livestock sector may emit less CH_4, as free-grazing animals deposit manure directly onto the pasture, where manure fermentation proceeds aerobically. The use of straw as bedding material in a deep-litter system increases the aeration of manure and reduces CH_4 emission (Yamulki 2006). This method is one of the strategies that can easily be adopted in developing countries, given the abundance of such crop residues that otherwise would end up being burned in the field. Based on a number of assumptions, Mwandosya et al. (1996) estimated total CH_4 emission from ruminants in Tanzania at 26.17 Gg. This estimate, however, is based on default emission factors. There is a need, therefore, for researchers in Tanzania to establish emission factors specific to the country to give informed advice to the government for negotiating the implementation of various protocols and conventions related to CC.

19.4.2 Emission of N_2O from Livestock

Nitrous oxide is emitted in soils from applied manure and urine mainly through an anaerobic microbial process (denitrification) and, to a lesser extent, through an aerobic microbial process (nitrification) (Eckard et al. 2010). The denitrification process reduces nitrate to N_2, with N_2O as an obligatory intermediate, whereas the nitrification process oxidizes ammonium to nitrate, with N_2O as a byproduct. Quantitatively, the rate of N_2O emissions from soil is determined by the rate of fertilizer application (synthetic and manure), the presence of crop residues, the presence of N-fixing crops, the soil temperature, the soil anaerobicity, the soil pH, the soil nitrate content, and the tillage practices (Flessa et al. 2002; Eckard et al. 2010). A constant emission factor of 1.25 % for the amount of Nitrogen applied to agricultural land is currently recommended for calculating global and national emissions from fertilized soils (IPCC 1997; Flessa et al. 2002). The contribution of livestock production to anthropogenic N_2O emissions is between 65 and 75 % (Flessa et al. 2002; Eckard et al. 2010). This contribution makes livestock production the main source of this GHG emission, with 296 times more global warming potential than CO_2. The estimated N_2O emission from manure management and fertilizer use in Tanzania is 0.57 Gg (Mwandosya and Meena 1999).

19.4.3 Emission of CO_2 from Livestock

As indicated previously, CO_2 produced by livestock through respiration does not contribute to net GHG emission, because this is part of CO_2 that had previously been sequestered by plants, is released back to the atmosphere by the livestock, and will be sequestered by plants. Consequently, the emitted and absorbed quantities are considered the equivalent of making livestock a net zero source of CO_2 (Garnett 2009; Herrero et al. 2011). However, land-use changes, including the deforestation and desertification of pasturelands that lead to a combination of vegetative loss and soil trampling, cause the loss of soil carbon and a net release of CO_2 (Garnett 2009; Pitesky et al. 2009). The traditional livestock sector may cause deforestation through the expansion of the grazing area into the forested area. With the ever-increasing livestock population in the traditional sector, the deforestation and desertification of pastureland are likely to persist for the next few decades until deliberate measures are taken to arrest the situation (Geist and Lambin 2002; Asner et al. 2003; Smith et al. 2007). Desertification caused by excessive grazing by livestock in Tanzania primarily occurs in arid, semiarid, and dry sub-humid grazing areas (pastures and rangeland), and causes a net loss of Carbon to the atmosphere, ultimately leading to land with reduced biological productivity. Since biomass is about 45 % carbon by weight, clearing forested areas by burning leads to the instantaneous release of CO_2 (Mwandosya et al. 1996). Bushfires associated with keeping migratory livestock are not uncommon in the tropics, including Tanzania.

19.5 Available Mitigation Options for Livestock-Based GHG Emissions

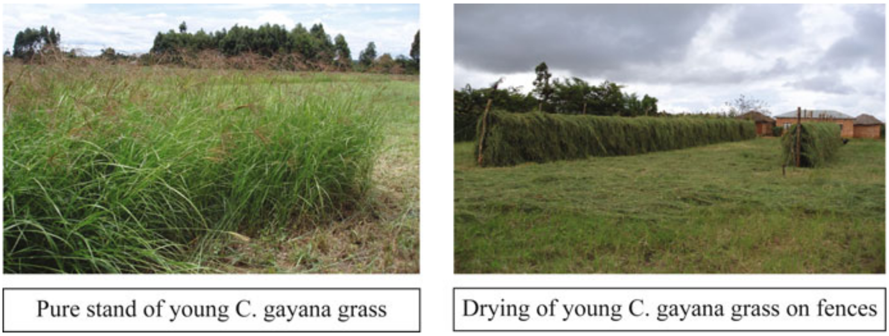
It is now estimated that atmospheric concentrations of the GHGs CO_2, CH_4, and N_2O are increasing at a rate of approximately 0.4 %, 0.6 %, and 0.25 % per year, respectively (IPCC 1997; Flessa et al. 2002). This phenomenon calls for mitigation strategies to keep down the levels of CH_4 and N_2O emissions. This effort may involve improved animal management, including feeding and housing, improved management of grazing land, genetic improvement of ruminants for improved efficiency and improved manure management (Monteny et al. 2006; Garnett 2009).

19.5.1 Mitigation of CH_4 Emission from Livestock Production

19.5.1.1 Improved Animal Feeding

It is now clear that enteric fermentation is the main source of CH_4 from ruminants and that emission per animal and per unit of product is higher when the animal diet is poor. The intensification of livestock production that accompanies improved feed quality has a potential to reduce CH_4 emissions from livestock production. Vlek et al. (2004) considered improved animal feed and feeding as important options to free up the land necessary for carbon sequestration. The increasing level of rapidly fermentable dietary carbohydrates (soluble carbohydrates and starch in concentrate feeds) promotes propionate production, subsequently reducing CH_4 formation (Monteny et al. 2006). In addition, improving dietary quality improves feed efficiency and economic benefits for producers (Pitesky et al. 2009). Supplementing ruminants on forage-based diets with high-energy concentrate feed increases starch and reduces fiber intake, reducing the rumen pH and favoring the production of propionate rather than acetate in the rumen (FAO 2006; McAllister and Newbold 2008; Eckard et al. 2010). This feeding intervention results in relatively higher animal productivity with less CH_4 emitted per unit of output (Johnson and Johnson 1995). Furthermore, concentrate supplementation reduces the time taken by meat-producing animals to attain market weight and, hence, reduces the total amount of GHG emitted by these livestock in their lifetime. This understanding should form the basis for promoting the feedlot finishing of beef cattle in the traditional sector in order to reduce the time taken to attain market weight from an average of 7 years to 2–3 years.

Feeding ruminants on less-mature pastures can reduce CH_4 production (Eckard et al. 2010; FAO 2006). This can be achieved through the early harvesting of forages before lignifications and storing them for dry-season feeding (Plate 19.1). To achieve this, harvesting should be done early in the rainy season to have good-quality hay (Sundstøl 2013). The CH_4 production per unit of cellulose digested is threefold higher than that of hemicelluloses; the fermentation of a unit of nonstructural carbohydrates yields far less CH_4 than that of cellulose and hemicellulose (FAO 2006; Eckard et al. 2010). Fewer fibrous forages promote higher voluntary intake and reduce the retention time in the rumen, energetically promoting more efficient post-ruminal digestion and reducing the proportion of dietary energy converted into CH_4. Mixing legumes in pure pasture stand will reduce CH_4 emission from livestock, partly because of the lower fiber content, the faster rate of passage, and in some cases, the presence of condensed tannins that suppress



Pure stand of young C. gayana grass

Drying of young C. gayana grass on fences

Plate 19.1 Young Chloris gayana grass before and after being harvested as hay (**a**) Pure stand of young C. gayana grass. (**b**) Drying of young C. gayana grass on fences methanogens. The chemical treatment of crop residues, like wheat straw, will improve their digestibility and reduce CH_4 emitted per unit of meat or milk. Overall, improving diet quality can both improve animal productivity and reduce CH_4 production, but it can also improve efficiency by reducing CH_4 emissions per unit of animal product. The increase in production efficiency also leads to a drop in CH_4 emissions from a reduction in the size of the herd required to produce a given level of product. Small-scale farmers in Tanzania can improve the diets of the ruminant animals by better managing their grazing lands through rotational grazing (this can take the form of traditional deferred grazing systems, known as "Ngitiri"), planting improved species of pasture grasses, strategic applications of manure, and developing "fodder banks" of planted legumes and other forages. Concerted efforts, however, have to be directed toward overcoming the challenges that hinder the adoption of these simple mitigation options.

19.5.1.2 Work with the Right Number and Breed of Livestock

Another option to mitigate CH_4 emission from livestock in the traditional sector is by instituting measures for destocking cattle in pastoral and agro-pastoral societies (Table 19.1). This can be done by establishing bylaws for controlling overgrazing. Reducing the number of unproductive animals on a farm can potentially both improve profitability and reduce CH_4. Better still, if a certain proportion of low-producing local breeds is replaced with higher-yielding, improved breeds, that method will contribute to the reduction in total emissions while maintaining or increasing livestock yields (Eckard et al. 2010). High-yielding beef breeds can be obtained from crossing local cows with genetically improved beef breeds to produce crossbred beef cattle that possess traits both for hardiness and higher meat yields, especially when combined with better fodder quality. However, caution should be exercised in implementing this option so as not to completely wipe out local breeds; some animals from the target breeds must be kept as a genetic resource base. Synchronizing breeding to have animals calving/kidding at the time of an ample feed supply will also reduce emission of CH_4 (Safari et al. 2012). Where possible, exchanging ruminant animals for monogastrics could also reduce total CH_4 emissions.

19.5.1.3 Improved Manure Management

Livestock manure is a mixed blessing. On one hand, manure contributes vital nutrients to the soil, but, on the other hand, manure emits N_2O and CH_4 as it breaks down in the soil. As it is produced on a farm, the use of manure as fertilizer helps avoid the need to produce, transport, and use energy-intensive synthetic fertilizers. Controlled storage offers possibilities for the utilization of CH_4 produced (biogas). Other manure management strategies for the reduction of CH_4 emission may include solid disposal of manure (as opposed to liquid disposal, which increases

CH_4 emission), minimal compaction of manure heaps, and regular and complete removal of manure from animal barns (Arthur and Baidoo 2011; Monteny et al. 2006; Yamulki 2006). The use of crop residues as bedding will increase the Carbon to Nitrogen ratio of manure. Manure with a high nitrogen content will emit greater levels of methane than manure with a lower nitrogen content. The use of manure to generate biogas converts the treatment of livestock waste from a liability into a profit (Arthur and Baidoo 2011). The use of CH_4 to provide energy produces CO_2 that is less harmful to the environment than direct methane emission. This happens because CH_4 has 23 times more GWP than CO_2 within a span of 100 years (FAO 2006; Pitesky et al. 2009). The digested slurry from biogas chambers is the best fertilizer for farms in rural areas. This phenomenon makes use of manure for biogas production a win-win approach that enables the harnessing of energy in manure and produces slurry that has a limited emission of CH_4 to the atmosphere. With few exceptions, however, the dissemination of biogas technology in Tanzania has been relatively unsuccessful. This lack of success is partly attributable to the relatively high initial cost of installation that the rural poor cannot afford. In addition, African governments have given limited support to biogas technology through a focused energy policy. To overcome the financial component of biogas technology dissemination, governmental and non-governmental organizations in support of poor rural communities should introduce financial incentives, such as soft loans and subsidies at the initial stage of biogas acquisition, and design follow-up strategies to build the capacity for the regular maintenance of the biogas systems (Arthur and Baidoo 2011).

Aerobic conditions favor the production of CO_2 at the expense of CH_4 production (De Gryze et al. 2008). Thus, increasing the dry matter content and aerating the manure heap through the addition of straw have the potential to reduce CH_4 emission (Monteny et al. 2006; Yamulki 2006). The use of crop residues, like wheat straw as bedding material, is a workable solution in the traditional livestock sector. Most of these residues are either used for animal feeding or burned on crop fields before the next planting season. Governments can play an active role in reducing methane emission from manure by instituting regulatory frameworks for the better management of fresh manure and slurry.

19.5.2 Mitigation of N_2O Emission from Livestock Production

A paradox exists on the impact of strategies used for to mitigate CH_4 and N_2O. Strategies found to be effective in mitigating CH_4 emission tend increase N_2O emission. For instance, the increased aeration of manure lowers CH_4 emissions but increases N_2O emissions. For N_2O emissions to occur, the waste must first be handled aerobically, allowing ammonia or organic nitrogen to be converted into nitrates and nitrites (nitrification). If manure is handled anaerobically, nitrates and nitrites are reduced to N_2, with the intermediate production of N_2O and nitric oxide

(NO) (denitrification). The use of manure for biogas production is the only strategy that mitigates both CH_4 and N_2O emissions. This calls for the deployment of mitigation measures that take into account all GHGs to avoid instituting action to mitigate GHG emissions at one point in the production chain that may lead to higher emissions at a subsequent point (Weiske and Petersen 2006).

19.5.2.1 Dietary Improvement

Balancing the protein-to-energy ratios in the diets of ruminants will minimize N_2O emission from excessive urinary nitrogen excretion. Eckard et al. (2010) reported that dairy cows fed diets with 14 % crude protein (CP) excreted 45 % less urinary nitrogen than dairy cows fed a 19 % CP diet. Optimizing proteins or amino acids in animal feed to match the exact requirements of individual animals or animal groups will reduce the nitrogen content of manure. Cows in the traditional sector have limited access to protein diets and may not excrete a significant amount of nitrogen in urine or in manure compared to what dairy cows excrete in intensive or semi-intensive systems. In addition, cattle in the traditional system graze or browse plants with a high content of condensed tannins (CT). CT form complexes with proteins in the rumen, protecting them from microbial digestion. This reaction results in the more efficient digestion of amino acids in the abomasum and lower intestine, causing less urinary nitrogen excretion (Eckard et al. 2010). Fecal nitrogen is mainly in an organic form and is, thus, less volatile, whereas urinary nitrogen is largely urea and is, therefore, more rapidly nitrified to NO_3-, with N_2O as an important intermediate (Monteny et al. 2006). Further research is required to identify suitable and cost-effective high-tannin forages to which grazing ruminants should be given access.

19.5.2.2 Grazing Management

Improving the soil's physical conditions by drainage to reduce soil wetness, especially in grassland systems, may significantly reduce N_2O emissions. Compacting soil by grazing livestock can increase the anaerobicity of the soil and enhance the conditions for denitrification. Denitrification is enhanced under conditions of low soil aeration. Oenema et al. (1997) reported that treading by cattle could increase emissions of N_2O by a factor of two. Grazing livestock in one area for long time is very likely to happen around watering points, especially when such points are not evenly distributed in rangelands. This unequal distribution of livestock watering points is a common feature in rangelands grazed by livestock in the traditional systems in Tanzania.

Wet soils can be compacted easily by grazing animals. Reducing the waterlogging of grazing areas and/or restricting grazing on seasonally wet soils will reduce the potential for N_2O emissions (Eckard et al. 2010). Waterlogging can be reduced by introducing surface or subsurface drains in seasonally waterlogged grazing areas. Dobbie and Smith (2003) demonstrated that water-filled pore space of more than 70 % results in significant N_2O emissions from applied manure.

19.5.2.3 Improved Manure Management

Slurry from manure stored in biodigesters for biogas emits less N_2O than fresh manure applied directly to grassland (Lekule and Sarwatt 1997; Amon et al. 2006). This occurs because during storage and anaerobic digestion, readily available carbon, which could be used to fuel denitrification, is incorporated into the microbial biomass or is lost as CO_2 or CH_4. As a result, there is less available carbon in the slurry to fuel denitrification when the slurry is applied to land (Eckard et al. 2010). Indeed, controlled anaerobic digestion is potentially a "win–win" management of animal manure, since CH_4 emitted during storage (as a biogas) is used to produce heat and electricity, whereas N_2O emissions after digested slurry is spread are also reduced. The rate, timing, and placement of animal effluent applied to soils all affect potential N_2O emissions. Emission of N_2O from manure is higher when manure is applied to wet soil than when it is applied to drier soil; emission peaks generally occur within 24 h of application (Saggar et al. 2004; Eckard et al. 2010).

19.5.2.4 Breeding for Improved Feed Utilization

Breeding animals for higher protein utilization efficiency will lead to the lower excretion of nitrogen in urine, which is a substrate for emitted N_2O (Garnett 2009; Monteny et al. 2006). Crossbred animals are likely to have higher efficiency in utilizing dietary protein for large muscle tissue deposition than indigenous cattle. Eckard et al. (2010) reported that an improvement in the feed conversion efficiency of 0.01 could result in a 3.3 % reduction in nitrogen excretion. Therefore, breeding animals for more efficient feed conversion should produce animals that partition more of their intake into production and less into nitrogen excretion, thereby reducing potential N_2O loss.

19.6 Options for Adapting Traditional Livestock Systems to CC

CC adaptation measures in Tanzania will differ from community to community, depending on the geographical, sociological, and economical characteristics. There is evidence that some communities in the country are already coping with the effects of CC (Shayo 2006). These effects include rainwater harvesting for dry-season cattle use, the use of fuel-saving stoves, and the use of local skills to control livestock diseases. However, such adaptation mechanisms are handicapped by the severity and the speed of CC as well as the constraints on resources. Most local people find it hard to cope with CC by using modern technologies, such as high-input agriculture and biotechnology, and have, instead, relied on their indigenous skills. Some adaptation and mitigation options, however, are closely interrelated. The rehabilitation of pastureland through the use of leguminous species and species limiting denitrification (e.g., *Bracharia spp.*) is both a mitigation and an adaptation option. Destocking herds of ruminants to adhere to herd sizes in keeping with the carrying capacity of grazing land will reduce desertification and the loss of biodiversity. Destocking will also enhance feeding the remaining animals better to improve their productivity, including attaining market weight earlier to reduce amount of GHG produced in a lifetime. This adaptive strategy should be tied to strengthening extension services. The repeated occurrence of climate disasters has forced some pastoralist societies in Tanzania to reduce the numbers of their herds as a coping mechanism.

Supporting the development of agricultural markets is a crucial way for increasing farmers' income and capacity for intensification of livestock and crop production and for increasing resilience to shocks (adaptation). Market development potentially encourages destocking as livestock owners are likely to sell their animals when given an incentive-producing price. Market development should be conducive to reducing GHG emissions from farming and to regulating the harvest of nature (biodiversity). Such development should be supported so that farmers have a fair share in the added value of their products. Market development should include mechanisms for absorbing some surpluses and for facing shortages generated by adverse climatic conditions (adaptation). Market development should go hand in hand with the development of rural infrastructures. The objective is to facilitate marketing inputs and outputs; harness natural resources for development; empower people and drive social organization; and monitor and mitigate risks. This effort should target rural and feeder roads, water storage and distribution, and storage of agricultural commodities.

Facilitating farmers' access to credit systems and developing crop and livestock insurance systems are other means for adapting the traditional livestock sector to CC. Livestock keepers consider the maximization of the number of livestock owned as a hedge against losses caused by natural calamities. It is hypothesized that if given some form of insurance to cover the losses of livestock in natural calamities, livestock keepers will reduce herd size to the carrying capacity of the grazing lands. In addition, national financial systems should better subsidize rural credit than input systems do. A credit worth system should address agricultural inputs with contribution from the inputs industry and wherever possible from the production-to-consumption chains through contractual farming agreements. The development of social safety nets to alleviate vulnerability in rural areas will enhance the adaptation of rural communities to CC. This can be through public support for employment of and giving income to vulnerable people; job creation at the community level; water-harvesting investment; tree development (cropped areas and watersheds); and energy generation as a substitute for wood fuel and charcoal.

Promoting and facilitating the recycling of livestock waste into crop systems are adaptive strategies. Recycling raw or composted animal wastes, and post-harvest residues, and processing residues provide valuable input for crops and reduce the use of chemical fertilizers whose production and application contribute to GHG emission.

Adapting to some local ways of predicting short- to long-term climatic changes, such as drought, is equally helpful. When a drought is predicted locally, a pastoralist can distribute livestock and/or shift the herd to safer places to reduce risk (Shemsanga et al. 2010). Pastoral societies like Barabaig and Masaai have been particularly involved in transhumance. The Morogoro region has observed a huge influx of pastoralists with large herds of livestock (Paavola 2003). In addition, when a drought is likely, pastoralists in drought-prone regions should reserve pastureland for weak stocks, such as sick, young, and lactating animals. Such a method will enable them to survive during the drought season and reduce the deaths of weak individuals (Shayo 2006).

19.7 Conclusion

Introducing some form of intensification of livestock production in the traditional sector will provide opportunities for reducing GHG emissions and CC mitigation through improved feeding and feed utilization, manure management, and reduced deforestation. It is important to realize that with reasonable stocking intensity, ruminant production in the traditional sector can help tackle CC by making use of otherwise unproductive land. In addition, the ability of ruminant livestock to consume crop residues and byproducts that are inedible to humans is resource efficient and leads to GHG avoidance as long as there is controlled use of manure, such as biogas production. Some GHG emission abatement options have been identified in this review that can be implemented in animal production systems now and in the near future, many of which are likely to be cost effective in their own right. The adaptation option identified in this review should be closely tied to mitigation options to achieve greater impact. However, most of the options are not cost neutral and require economic incentives and institutional support for their adoption. A good example for this is the use of manure for biogas production in poor rural communities. Overall, livestock-related greenhouse gas reductions could be quickly achieved in the traditional sector by modifying production practices, such as keeping the right number and type of animals, switching to more nutritious pasture grasses, pasture harvesting and storage, supplementing diets with even small amounts of crop residues or grains, controlled manure disposal, restoring degraded grazing lands, and planting trees that both trap carbon and produce leaves that cows can eat. It is imperative to note that the current estimates of GHG emissions in livestock production in Africa rely heavily on data collected in developed countries that may not apply to Africa's climatic and environmental conditions. Obtaining country-specific GHG emission data from livestock production is critical to supporting "climate smart" agricultural practices that will help those in the traditional livestock sector protect their livelihood in face of CC. Although some traditional livestock systems in Tanzania are already coping with the impact of CC, such efforts are handicapped by inadequate resources, poor coordination, and implementation of competing measures.

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