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Livestock and environment spotlight

ETHIOPIA

Cattle sector

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Livestock and Environment Spotlight

Cattle sector and the environment in Ethiopia

1. Introduction

There are more than 56 million heads of cattle in Ethiopia, providing over 3.8 billion litres of milk (FAO & NZGGRC, 2017) and roughly one million tonnes of beef (Shapiro *et al.*, 2015) per year. Available projections suggest that consumption of beef and milk will grow from 53 to 193 percent and from 115 to over 750 percent in the next 35 years, with any difference explained by the underlying models and datasets (GPS 2017, Acosta and Felis, 2016). It is crucial that the rapidly growing cattle sector develops in a climate smart manner: currently 84 percent of livestock emissions come from cattle (CRGE, 2011), the water footprint per ton of cattle is more than three times the one of small ruminants and poultry, and 40 percent of land is grasslands.

Livestock and the environment have a close yet complex relationship. Livestock depends on the availability of water and feed, and can generate solid, liquid and gaseous "by-products" that have a negative impact on the environment. They rely on land and water for the provision of feed, thereby determining land use with further environmental consequences. If not managed properly, livestock production can have negative impacts on the environment through:

(i) overgrazing and improper land conversion resulting in grassland degradation;
(ii) excessive application of manure from livestock production leading to nutrient overloading of cropland;
(iii) manure and waste water mismanagement resulting in water pollution (chemical and microbiological);
(iv) water withdrawals to produce animal feed, drinking, cleaning and processing causing water stress[1];
(v) greenhouse gas (GHG) emissions from enteric fermentation; manure management including manure left on pasture, range and paddock; and energy-use contributing to climate change;
(vi) airborne contaminants including gases, odour, dust, and microorganisms impairing air quality;
(vii) land use change and all the above leading to biodiversity loss and reduced eco-system services.

This brief assesses the current impact of cattle systems on the environment in Ethiopia using available literature and data such as the Global Livestock Environmental Assessment Model (GLEAM), AQUASTAT, and water footprints calculated by Mekonnen and Hoekestra (2012). The reviewed issues relate to four elements: land, water, biodiversity and air. These are closely interrelated, for example, biodiversity loss can cause exhaustion of ecosystem services, or changes in soils can alter hydrological patterns that result in water scarcity (Daley, 2015).

2. Land

Land degradation may be defined as the loss of productive and ecosystem services provided by land resources or the reduction or loss of the biological or economic productivity and complexity of pastoral, agricultural and wooded land due to soil erosion, soil impoverishment (such as nutrient depletion) and/or the loss of natural vegetation (Daley, 2015). Global livestock production uses about 80 percent of agricultural land – 3.4 billion ha for grazing including rangelands and pasturelands and 0.5 billion hectares of arable lands dedicated to feed production; the latter figure corresponds to one-third of total cropland (FAO, 2009). The production of global feed requires 2.5 billion ha of land, which is about half of the global agricultural area, of which 2 billion ha is grassland and about 1.3 billion ha cannot be converted to cropland (Mottet *et al.*, 2017). This means that 57 percent of the land used for feed production is not suitable for

[1] Water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use

food production. Livestock consume about 6 billion tonnes drymatter as feed per year; however, 86 percent of this amount is made of materials that are currently not eaten by humans (Mottet *et al.*, 2017).

Grazing animals influence the landscape in several ways including creating bare soil, weakening the vegetation cover by grazing and then by breaking this cover down by trampling (Evans, 1998). Animals have erosional impacts on the land surface in both direct and indirect ways. Directly, animals can create, maintain and expand areas of bare soil, upon which the weather forces such as rain and wind act, and indirectly, by facilitating the rapid runoff of rainfall which may only slightly erode the surface where it gathers but which can incise into the ground surface forming gullies down stream. Roughly 35 percent of the world's land degradation is attributed to grazing animals, especially in Africa, where they cause 49.2 percent of the continent's degradation (Evans, 1998). Trampling is crucial in providing "a ready source of easily removed material" and it is extremely effective at killing seedlings and stopping the recolonization of bare soil (Evans, 1998).

In terms of utility, the land in Ethiopia is classified into 12 percent arable land, 1 percent permanent crops, 40 percent permanent pastures, 25 percent forest and woodland, and 22 percent other purposes (Taddese, 2001). At present, there are about 56.3 million ruminants measured in Tropical Livestock Unit (TLU) in the country of which 39.70 million TLUs are cattle. Of the total cattle population, nearly 75 percent is concentrated and graze in the highlands; only 25 percent is found in the rangelands (lowlands). Feed sources for roughly 80–85 percent of livestock, largely ruminants and equine, come from natural grazing.

The country experiences one of the world's highest rates of soil erosion due to degradation in much of its farm and rangelands caused by overexploitation due to crop production and overgrazing; it loses two billion metric tons of soil to erosion each year (Taddese, 2001; MacDonald and Simon, 2011). About 80 percent of the annual soil loss occurs from croplands during the rainy season (El Wakeel and Astatke, 1996). Land degradation is the most common environmental problem in Ethiopia and is responsible for low and declining agricultural productivity, ongoing food insecurity and rural poverty (Gashaw *et al.*, 2014). Cultivation on steep slopes and clearing of vegetation has accelerated erosion in the highlands. Soil erosion and land degradation in Ethiopia – and their connections with agriculture – have become a prominent environmental concern, one of the most important causes of low and declining agricultural productivity, ongoing food insecurity and rural poverty in the country (Daley, 2015). Recent estimates made by Gebreselassie *et al.* (2016) using satellite imagery show that land degradation hotspots over the last three decades cover about 228,160 km² (or 23 percent of total land area of the country) between 1982 and 2006. They estimated the annual cost of land degradation associated with land use and cover change to be about USD 4.3 billion. Ethiopia experiences several types of land degradation ranging from water and wind erosion; salinization (and recently acidification); as well as physical and biological soil degradation. Several factors including poverty, land fragmentation and high human and livestock population pressure act more indirectly as driving forces causing land degradation. Pressure from human and livestock leads to huge removal of vegetation cover to meet increasing crops, grazing and fuel wood demand (Gebreselassie *et al.*, 2016). According to the authors, there has been dynamic land use and land cover changes in the country over the 2001–2009 period. For example, in 2001 there were about 8.5 million ha of cropland, 5.5 million ha of forest land and about 29 million ha of grassland. In 2009, however, cropland increased to 11.3 million while forests and grasslands decreased to 4.1 and 25.5 million ha, respectively.

Soil erosion and land degradation have been particularly severe in the Ethiopian highlands due to the combined effects of rapid population increase, intensive agricultural and pastoral use, cultivation of marginal land, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production, precarious environmental conditions and inadequate soil conservation practices (Holden and Shiferaw, 2004; Kimball, 2011; Gashaw *et al.*, 2014; Daley, 2015; Gebreselassie *et al.*, 2016). Gashaw *et al.* (2014) acknowledge that land degradation in Ethiopia is also affected by topography, soil types and agro-ecological factors. There is no slope limit for crop production, therefore the land at upper slopes is almost barren and cannot guarantee sustainable crop production. Traditionally cropland on steep slopes is ploughed several times, which results in the breaking up of soil aggregates and causes soil erosion (Taddese, 2001).

As explained above, the direct causes of land degradation in Ethiopia are apparent and generally agreed upon. The causes include production on steep slopes and fragile soils with inadequate investments in soil conservation or vegetative cover, erratic and erosive rainfall patterns, declining use of fallow, limited recycling of dung and crop residues to the soil, limited application of external sources of plant nutrients, deforestation and overgrazing (Gashaw *et al.*, 2014; Daley, 2015; Gebreselassie *et al.*, 2016). Many factors underlie these proximate or direct causes including population pressure, poverty, high costs of and limited access to agricultural inputs and credit, low profitability of agricultural production and many conservation practices, high risks facing farmers, fragmented land holdings and insecure land tenure, short time horizons of farmers, and farmers' lack of information about appropriate alternative technologies (Desta *et al.*, 2000). Many of these factors are affected by government policies relating to infrastructure development, market development, input and credit supplies, land tenure, agricultural research and extension, conservation programmes, land use regulation, local governance and collective action, and non-governmental programmes (Desta *et al.*, 2000; Taddese, 2001; FAO, 2009). Land is state property in Ethiopia and the land tenure policy guarantees farmers and pastoralists only land use rights which, coupled with lack of adequate governance of the agricultural sectors (i.e. both crop and livestock), can contribute to the depletion and degradation of land, water and biodiversity. Nyssen *et al.* (2015) attribute the high soil erosion rates in the Ethiopian highlands to a combination of erosive rains, steep slopes due to the rapid tectonic uplift during the Pliocene and Pleistocene, and human impact by deforestation, overgrazing, agricultural systems where the open field dominates, impoverishment of the farmers, and stagnation of agricultural techniques. The livestock sector itself is affected by the degradation of ecosystems and faces increasing competition for these same resources from other sectors (FAO, 2009).

Livestock have been blamed for land degradation in Ethiopia. Overgrazing and over-utilization of woody plants reduces the species composition of important fodder plants, reducing the grazing/browsing capacities of the rangelands (Kassahun *et al.*, 2008). Heavy grazing leads to excessive defoliation of herbaceous vegetation, reducing standing biomass, basal cover and plant species diversity, and decrease in soil nutrient concentrations often triggered by a decline in net primary productivity as the intensity of grazing increases (Bilotta *et al.*, 2007; Tessema *et al.*, 2011; Mekuria and Aynekulu, 2011). Research has generally shown that as vegetation cover declines under heavy stocking rates, the water infiltration rate decreases and sediment production increases (Taddese, 2001). Comparisons between ungrazed and grazed pastures and less grazed compared to more grazed ranges using global data, bulk density of topsoils was higher in more grazed pastures in 88 percent of 43 instances; infiltration was less in 90 percent of 70 instances; runoff greater in 95 percent of 19 instances and erosion more in 81 percent of 32 instances (Evans, 1998). Similarly, Mwendere and Mohamed Saleem (1997) in their studies in Debre Zeit area found that heavy to very heavy grazing pressure significantly reduced biomass amounts, ground vegetative cover, increased surface runoff and soil loss, and reduced infiltrability of the soil. Reduction in infiltration rates was greater on soils which had been ploughed and exposed to very heavy trampling. They observed that, for the same percentage of vegetative cover, more soil loss occurred from plots on steep than gentle slopes, and that gentle slopes could withstand more grazing pressure without seriously affecting the ground biomass regeneration compared to steeper slopes.

Taddese (2001) argues the action of animal hooves, especially the small cloven hooves of sheep and goats, is extremely damaging to the surface soil as it destroys vegetation cover. The mechanical pulverization often greatly increases erodibility. In addition, heavy grazing denudes the land of vegetation or vegetative residue, which causes serious wind or water erosion.

The footpaths used by humans and cattle develop into rills and then into gullies over time. Even with limited or controlled grazing, the concentration of animal traffic in watering areas or through gates or lanes often becomes the site of initial wind erosion that may spread to other parts of the field. The author, however, concludes that dry land cropping has been a greater contributor to degradation in Ethiopia than livestock and wildlife grazing. The problem is aggravated when land is prepared for cultivation in dry years exposing topsoil to wind erosion and making it difficult for native plants to re-establish.

Desta *et al.* (2000) reporting on the state of soil erosion in the Amhara region based on site-specific test plots and experiments in 1987 and 1988 at Soil Conservation Research Project stations in the region, recorded soil loss rates between 0.04 and 212 tonnes/ha per year. About 29 percent of the total area of the region experienced high erosion rates (51–200 tonnes/ha per year); 31 percent experienced moderate erosion rates (16–50 tonnes/ha per year); 10 percent experienced very high erosion rates (>200 tonnes/ha per year); and the remaining 30 percent experienced low erosion rates (<16 tonnes/ha per year). The region's soil loss rate is estimated to be about 58 percent of the national rate. The spatial coverage of the region is only about one-sixth of the nation, hence compared with other regions, the soil loss rate per unit area is very high in Amhara. Land redistribution, which in recent years has been the only means of formally acquiring access to land to accommodate new households, has led to severe fragmentation of plots, a reduction of crop fields and insecurity. Reduction of cropland per capita and insecurity have led to reduction in activities such as fallowing, planting trees and investing in conservation structures, it has also caused cropping and grazing activities to be shifted to hillsides and ecologically fragile areas. Shortage of land has its repercussions on livestock stocking rates. Most of the fertile land is reserved for crop production, while grazing of cattle and other livestock is limited to hydromorphic valley bottomlands and marginal deforested hillsides. Hillsides that are supposed to be closed off for regeneration are kept under intensive grazing until they are completely bare and then abandoned. The crop–livestock farming system of the highlands shows the interdependence between crop production and animal husbandry. As an adaptation to the expansion of cropland and shortage of grazing land, hillside grazing is practised. Forests have come under severe encroachment not only for direct browsing and grazing, but also for cutting of trees for fuel and construction (Desta *et al.*, 2000).

Sonneveld *et al.* (2010) studied rainfall use efficiency trends in the Afar region and found that most areas of the region show stable trends with a supply-demand ratio near one, i.e., forage production meets grazing demand. In the northern part, however, they found a significant degradation, most likely caused by the encroachment of cultivated areas into prime rangelands, which might have resulted in extended fallow periods without vegetative coverage. The authors concluded there is a declining trend of the rainfall use efficiency in the north-eastern corner near the border with Eritrea, gradually becoming less pronounced towards the south-west direction and turning into positive values in the southern cone of the region. The results may support the argument that if mobility of pastoralists continues unhampered, it results in sustainable land management, whereas restricted accessibility leads to overgrazing and land degradation (Sonneveld *et al.*, 2010). Evans (1998), on the other hand, argues that while there may be enough vegetation in a locality to sustain animals and their offspring (i.e., the threshold carrying capacity of the land in terms of production and economics has not been exceeded), the erosional threshold can be crossed as empirical findings in several countries.

To summarize, in Ethiopia, approximately 27 million ha (50 percent of the highlands) are already heavily degraded and 2 million ha have reached a point of no return due to the various degrading or eroding forces. As a result, the country loses ~17 percent of its potential annual agricultural gross domestic product (GDP) because of physical and biological soil degradation. However, regarding the role of livestock in land degradation, it is difficult to discriminate it from the effects of other factors. Moreover, it is poor livestock management – mainly based on free grazing system – and overstocking which result in overgrazing. When managed efficiently, animal production in its many forms plays an integral role in the food system, making use of marginal lands, turning co-products into edible goods, contributing to crop productivity and turning edible crops into highly nutritious, protein-rich food (Mottet, *et al.*, 2017).

3. Water

Ethiopia is considered a water scarce area, with more than 75 percent of its surface being dryland (Deng, 2000 in Tulu, 2006). The increasing population and food demand in Africa is putting unprecedented pressure on available water resources. The average water consumption in Ethiopia varies between 10 and 20 litres per capita per day (Getachew, 2005 in Tulu, 2006), but depending upon seasonality and location it might be as low as 3–4 litres per capita per day, that is less than one fifth of an adequate water supply (Tulu *et al.*, 2006). Efficient water management is therefore crucial in every sector, including livestock. Ethiopian livestock water consumption amounts to 687 million m^3, 7 percent of the total water withdrawal in the country (AQUASTAT, 2016).

Tulu (2006) compared livestock water productivity with the domestic use[2] and crop and found value of production per m^3 of water to be 41, 213 and 8 Birr, respectively. The study highlights that livestock productivity is often undervalued, due to the difficulties in accounting services such as draft power or manure use. The three activities are closely related, and one cannot recommend a household to only concentrate water consumption on one or two of the activities: for example, domestic water use contributes to the health of the household members, which will enhance cropping activities that, in turn, can result in increased quantity and quality of crop residues fed to livestock.

Bruegel *et al.* (2010) assessed the differences of livestock water productivity (LWP) of production systems across the Nile Basin. They found that there are great differences between countries and production systems, the Ethiopian mixed systems are compared with the Kenyan mixed systems due to similar conditions. They find that Ethiopian farmers perform substantially worse than their Kenyan peers, the main driver being low productivity rather than specific water-related issues. They generally find low water productivity across the whole Basin, driven by low productivity, high mortality rates and diseases.

In the following part of this section, the differences in water usage of production systems using the water footprint are assessed. Water footprints measure the amount of water consumed and polluted by an individual, entity or product. Mekonnen and Hoekestra (2012) conducted a thorough global assessment of farm animal products' water footprint by production systems and source of water (blue, green and grey). A blue water footprint refers to the amount of water consumed from surface and groundwater along the value chain of a product that is evaporated after withdrawal. Green water refers to rainwater consumption, while the grey water footprint refers to the volume of freshwater needed to assimilate the load of pollutants emitted. The study period was between 1996 and 2005. The water footprint of live animals consists of direct consumption via drinking and service water and indirect consumption via feed (Chapaign and Hoekestra, 2003 in Mekonnen and Hoekestra, 2012). The most important component of livestock related water footprints is water used for feed, this has been calculated by production system based on feed conversion efficiencies (the amount of feed needed to produce one unit of output) and by species. Figure 1 shows that in all production systems, green water consumption is the dominant form of cattle water consumption. In the following, the composition of water consumption to the world average is compared.

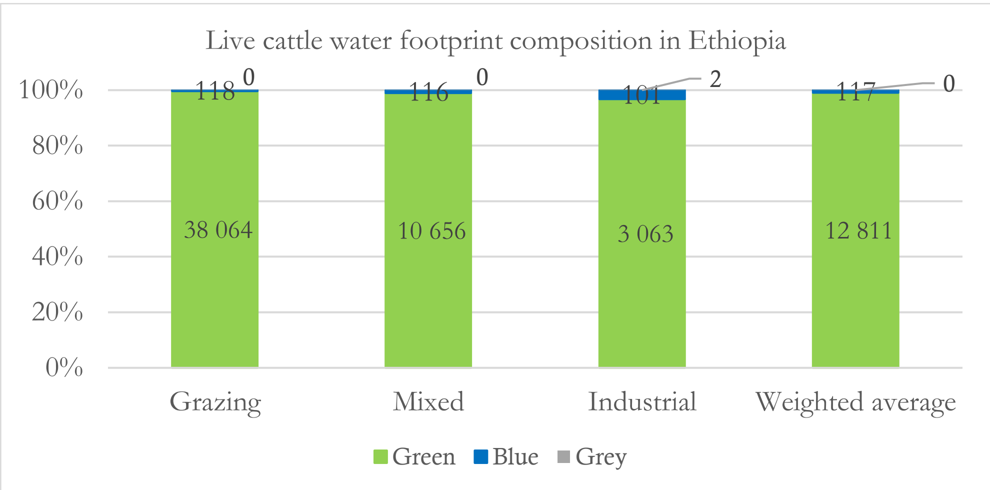

Figure 1. *Green, blue and grey water footprint of live cattle in Ethiopia, m3 per ton (Source: authors' compilation using data of Mekonnen and Hoekestra, 2012)*

[2] The value of production of domestic use is calculated as a sum of the value of improved health (cost of avoided sicknesses), water in food and local drinks, bricks and handcrafts.

The aggregate water consumption of live cattle is higher in Ethiopia than the world average; however, there are significant differences in the composition by water source. Gerbens-Leenes *et al.* (2013) reveal three main drivers of meat production's water footprint, all related to feed: feed conversion efficiencies, feed composition and feed origin. They show that the water footprint decreases from grazing to mixed crop-livestock to industrial systems, as animals in the latter systems get more concentrated feed, grow faster and are slaughtered earlier. That study focuses on the US, China and Brazil, but the trends hold for Ethiopia, as presented in Table 1.

Table 1. *Green, blue and grey water footprints of live cattle by production system, m3 per ton (Source: authors' compilation using data of Mekonnen and Hoekestra, 2012)*

Live cattle water footprints, m3 per ton

	Grazing		Mixed		Industrial		Weighted average	
	Ethiopia	World average	Ethiopia	World average	Ethiopia	World average	Ethiopia	World average
Green	38 064	9 197	10 656	7 348	3 063	4 174	12 811	7 002
Blue	118	192	116	241	101	311	117	256
Grey	0	106	0	199	2	336	0	219
Total	**38 183**	**9 495**	**10 773**	**7 787**	**3 166**	**4 821**	**12 928**	**7 477**

There are important differences in implications by different types of water footprints. Green water (rainfall) has a lower opportunity cost than blue water, since the latter could be used in a wider range for the society (SAB Miller and WWF, 2009). Green water consumption is highest in the Ethiopian grazing systems, it is four times the world average. Consumption of Ethiopian mixed systems is also above the world average, by 45 percent. The green water footprint of industrial systems is lower in Ethiopia than the world average.

Across all production systems, blue water consumption in Ethiopia is relatively low: the weighted average across all production systems is less than half of the global average. The biggest gap is found in the intensive systems: the Ethiopian consumption is one third of the world average.

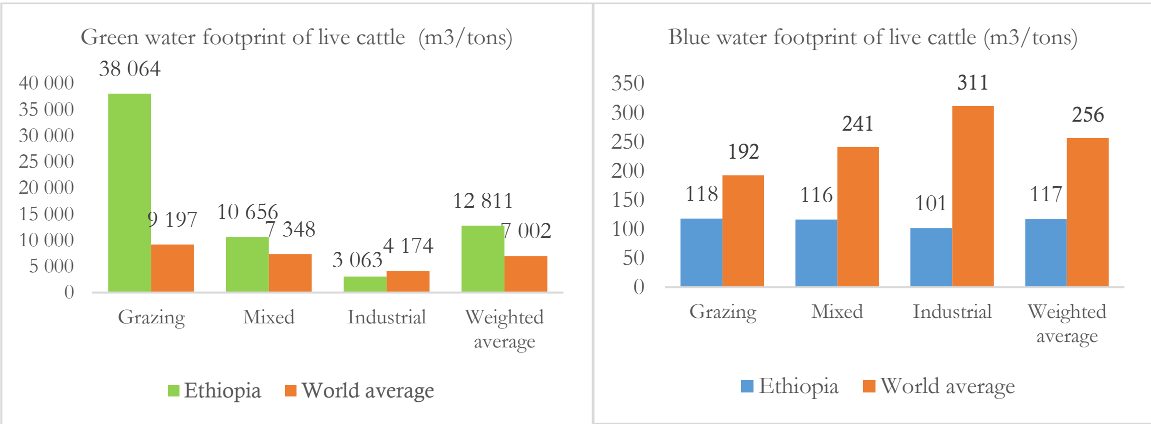

Figure 2. *Green and blue water footprints of live cattle in Ethiopia and the World, m³ per tons (Source: authors' compilation based on Mekonnen and Hoekestra, 2012)*

Grey water measures indirect consumption of water: the amount of freshwater needed to compensate for the pollution emitted by commodity. The Ethiopian cattle systems basically show no such pollution. Figure 3 has important policy implications: industrial systems may not consume as much water overall as other systems, but they pollute the environment to a significantly bigger extent.

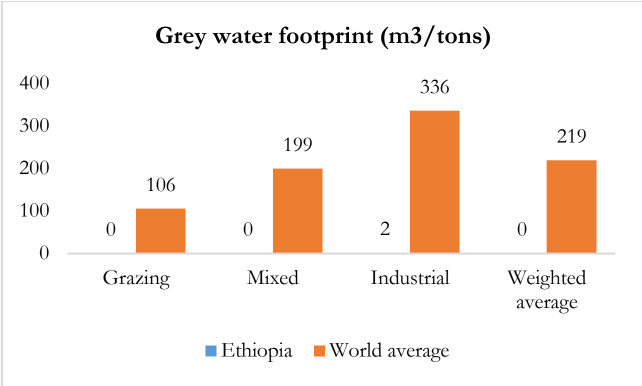

Figure 3. *Grey water footprint of live cattle in Ethiopia and the world, m³ per tons (Source: authors' compilation based on Mekonnen and Hoekestra, 2012)*

To sum up, water productivity in Ethiopia is low, and can be improved by a general increase in productivity via improved feeds, promotion of improved breeds and improved health. The water footprint of grazing systems is the highest, however most of this water consumption comes from rainwater in pastoral areas, that would unlikely be used for other purposes. Industrial systems have the lowest water footprint overall per kilo, but the amount of water polluted (grey water consumption) is higher than in other production systems.

4. Biodiversity

Biodiversity loss is an often neglected aspect when measuring environmental impact. Biodiversity refers to the range of animal, plant and microbial species (interspecific biodiversity) on earth as well as the richness of genes within a given species (intraspecific biodiversity). It encompasses the genetic variation among individuals within the same population and among populations (FAO, 2009). Extensive and intensive livestock production systems affect biodiversity differently. In extensive systems, a larger number of animal breeds are kept, and the animals make use of a wider variety of plant resources as feed. Lower productivity of the animals in this system nevertheless may increase pressure to encroach more on natural habitats. In the intensive systems, only few (in some cases single) animal breeds are kept, although each may be quite rich in terms of genetic background. These systems depend on few varieties of intensively managed feed crops, which are often blamed for ecosystem degradation. However, intensive land use may protect non-agricultural biodiversity by reducing pressure to expand crop and pasture areas. The root causes of biodiversity loss through livestock include the increasing demand and consumption of milk, meat, and eggs, which lead to greater need to grazing areas, grow crops and harvest fish to feed livestock (Reid *et al.*, 2010). In general, biodiversity loss occurs primarily through habitat degradation and destruction, land-use changes, physical modification of rivers or water withdrawal from them, climate change, invasive alien species, overexploitation, and pollution, with disproportionate impacts on poor people and with important implications for livelihoods, sustainable development and green growth (Daley, 2015; MEA, 2005, cited in Reid *et al.*, 2010). According to Reid et al (2010), livestock contribute directly or indirectly to all these drivers of biodiversity loss, from local to global levels. However, as biodiversity loss is caused by a combination of various processes of environmental degradation, it is difficult to isolate the share of the livestock sector in ruining biodiversity. A further complication is represented by the many steps in the animal food product chain at which environmental impact occurs (FAO, 2009).

The impacts of livestock on biodiversity are principally negative, although there are some positive impacts as well; these effects depend on the magnitude (or exposure) of livestock impacts, how sensitive biodiversity is to livestock, and how biodiversity responds to the impacts (Reid *et al.*, 2010). The negative impacts of livestock on biodiversity include heavier grazing impacts on plants when livestock population expand; biodiversity loss from forests as pastures and croplands for feed expand in the tropics; emission of GHG causing climate change and then affect biodiversity; disease spread by livestock to wildlife; simplification of landscapes through intensification; competition of livestock with wildlife; pollution of water sources with nutrients, drugs and sediments, with related effects on aquatic biodiversity; native biodiversity loss through competition with non-native feed plants; and overfishing to create fishmeal for livestock (Reid *et al.*, 2010). Smith (2003) reported that heavy grazing reduces the growth rate and reproductive potential of perennial grasses, and influences the competitive relationships among the different species, so that the heavily grazed perennial grass species loose competitive power over the lightly grazed ones, and subsequently, unpalatable and grazing tolerant annual species become dominant in heavily grazed patches. At heavy grazing pressures, grazing intolerant species disappear because they are highly nutritious and eaten before seed setting, or species that cannot tolerate physical damage die and these species are subsequently replaced by less palatable species (Smith, 2003; Hoshino *et al.*, 2009; Tessema *et al.*, 2011). The positive impacts include increasing efficiency of production, where fewer natural resources are used for each kg of milk, meat, or eggs produced; increased species diversity in moderately grazed pastures; and pastoral land uses protecting wildlife biodiversity in savanna landscapes (Reid *et al.*, 2010).

In many densely inhabited areas of Ethiopia, the original forest vegetation now exists only in protected patches around churches, while in the grazing lands much of the indigenous forest cover has been removed (Asefa *et al.*, 2003). The authors estimate that presently only 15 percent of the landscapes have natural vegetation cover. On the positive side, they observed the degraded grazing lands in northern Ethiopia, despite many centuries of overuse, had high resilience; nevertheless, they were not able to predict whether the original floral diversity removed by several centuries of overgrazing can be restored from soil seedbanks that might represent the original vegetation. The national forest cover has also decreased steadily over time, from 30 percent in the 1900s to less than 10 percent today. The annual loss of highland mountain forest cover has been estimated to be about 141,000 ha, resulting in loss of biodiversity among other things (Admassu *et al.*, 2013). Due to the declining area under forests, wildlife has been under pressure since the early 1970s. About 277 terrestrial mammals are found in Ethiopia, of which 31 are endemic to the country and 20 are highland forms. There are 862 bird species recorded in Ethiopia, of which 261 are species of international concern and 16 bird species are endemic to Ethiopia – the highest number in Sub-Saharan Africa. Of the 214 Palearctic migrant bird species found in Ethiopia, 47 of them usually summer here (James 2012, in Admassu *et al.*, 2013). There are about 63 globally recognized endemic bird sites in Ethiopia, mostly in the central highlands, the southern highlands, and the Juba-Sheballe Valley. The Abijata-Shalla Lakes National Park in the Rift Valley was established as a park due to the high diversity of water birds there. It is estimated that at least 6 reptiles and 34 amphibians are also endemic. Currently, seven mammal and two bird species have already been listed as critically endangered due to deforestation for agricultural expansion and settlement, lack of adequate knowledge of biological resources, and overexploitation including overgrazing (Admassu *et al.*, 2013).

Although lack of quantitative indicators for grazing intensities makes its assessment difficult, shifts in livestock production would have a major impact on biodiversity change in rangeland ecosystems (Alkemade *et al.*, 2015). The authors predict that effect of livestock grazing is expected to decrease if African nations adopt science-based agricultural knowledge and technology. Their study shows where high-agricultural knowledge and technology enables considerable decrease in the area of exploited rangelands, natural rangelands can be restored with substantial improvement in mean species abundance compared with baseline scenario. This result suggests policies that foster high agricultural growth in croplands and a shift toward higher livestock productivity in mixed crop livestock systems release the pressure on biodiversity in rangeland ecosystems in regions where productivity is still low. Such policies slow down the conversion of rangelands into cropland and positively affect the African rangelands (Alkemade *et al.*, 2015).

The effects of grazing on rangeland biodiversity include the removal of biomass, trampling and destruction of root systems, and replacement of wild grazers with livestock. The combined effects depend on the extent of rangelands grazed by livestock, the grazing intensity, and the original type of vegetation, and land management. The impacts of livestock systems on biodiversity may also take the form of broad-scale habitat loss and fragmentation through livestock production. Combined effect of grazing and trampling alters species diversity and the balance of trees and grass. Livestock generated pollution affects the ecosystem and livestock are the major contributor to disease emergence, which sometimes affect biodiversity. For instance, rinderpest was introduced to Africa by imported cattle in the late nineteenth- century and spread across the continent and killed most of the continent's cattle and many of the ruminant wildlife such as buffaloes, giraffes, and elands. Bovine tuberculosis, a disease whose natural host is cattle, has now become a major disease of buffalo in Africa, possums in New Zealand, white-tailed deer in north and central US, and badges in UK and Ireland. On the other hand, livestock also have a positive role in biodiversity protection where their grazing slows converting rangelands into other uses like cropland, irrigated land, and protected areas.

5. Air

Ethiopia's GHG emission per capita is very low compared to other countries: 1.3 tonne CO2e per capita, one fifth of the World average (6.3 tonne CO2e per capita) (UNFCC, 2017; CAIT, 2015). However, the country recognizes the importance of mitigating global carbon emissions and is committed to contribute to world-wide efforts. Ethiopia ratified the Paris agreement in 2017 and promotes the importance of the rapid economic growth happening in a climate-smart manner.

To quantify livestock GHG emissions, we use data of the Global Livestock Environmental Assessment Model (GLEAM). The GLEAM is a GIS (Geographic Information System) framework that simulates the bio-physical processes and activities along livestock supply chains under a life cycle assessment approach. The aim of GLEAM is to quantify production and use of natural resources in the livestock sector and to identify environmental impacts of livestock to evaluate the effectiveness of alternative scenarios for adaptation and mitigation to move towards a more sustainable livestock sector. GLEAM identifies three main groups of emissions along production chains. Upstream emissions include those related with feed production, processing and transportation. Animal production emissions comprise emissions from enteric fermentation, manure management and on-farm energy use. Downstream emissions are caused by the processing and post-farm transport of livestock commodities. Three gases are considered in GLEAM: carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). A Tier 2 approach is applied for the calculation of most of the sources of emission (IPCC, 2006), including country specific factors. The CRGE calculation represents a Tier 1 approach, hence there will be a significant difference between the two results. To convert all emissions into CO2 equivalent, the latest available global warming potential from IPCC (2014) are used (298 for N2O and 34 for CH4). The model is based on 2010 data for animal numbers and distribution, herd parameters, feed yields and rations and manure management systems.

Figure 4 presents the total emissions in million tonnes of CO_2 equivalents by cattle production systems. In total, the emissions of the cattle sector sum up to nearly 200 MT CO_2e[3]. Mixed crop livestock system is the biggest contributor to the sector's total GHG emissions, which is driven by the fact that roughly 80% of the cattle population is kept in this system.

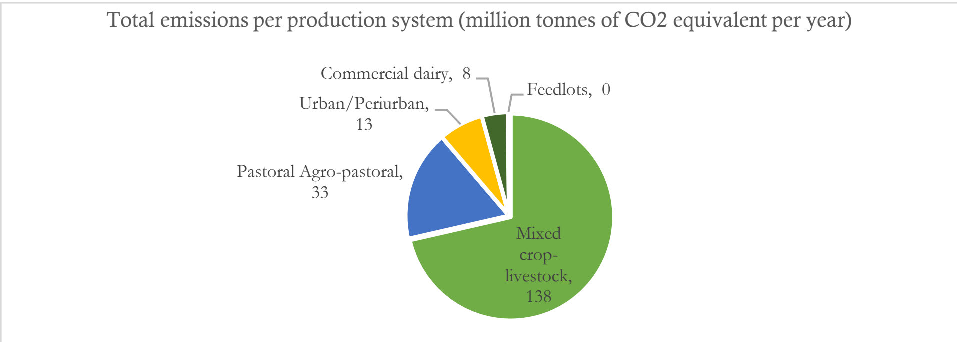

Figure 4. *Total emissions by production system, MT CO2 equivalent (Source: FAO, GLEAM)*

[3] Note that this value is obtained using a Tier 2 approach. With the Tier 1 approach the total GHG emissions of the entire livestock sector are 64 MT CO2eq. (see CRGE, 2011)

CO_2 emissions from enteric fermentation are driving emission: these depend on feed digestibility and are hence typically lower in intensive systems, where easily digestible feed is used instead of grazing.

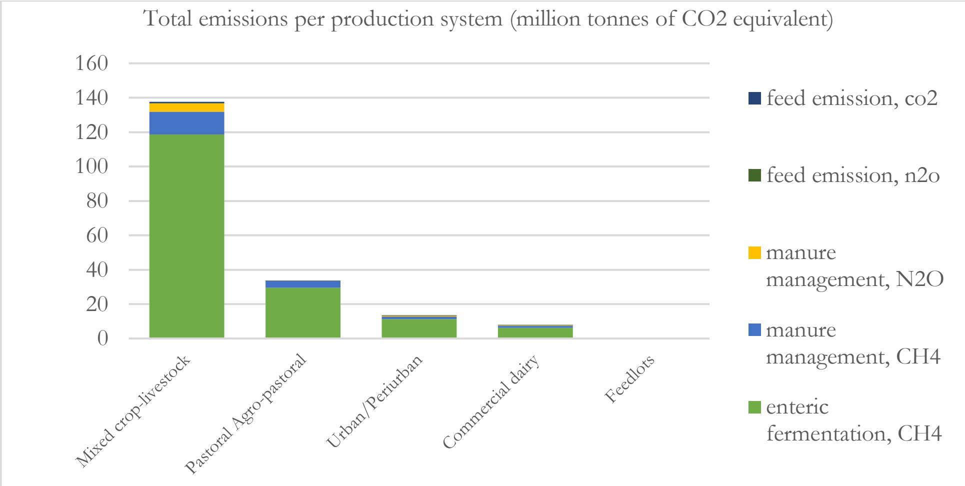

Figure 5 Total emissions by emission type (Source: FAO, GLEAM)

Table 2. *Total GHG emissions per head per year in CO2 equivalents (Source: FAO, GLEAM)*

Total emissions per head per year (co2 equivalent)	
Mixed crop-livestock	3 162
Pastoral Agro-pastoral	4 253
Urban/Peri-urban	3 550
Commercial dairy	5 450
Feedlots	11 824

Total emissions per head show that the dairy commercial and feedlot systems are more polluting per head of cattle than the other systems. However, these production systems are more resource-efficient, hence emissions per production unit show a different results. A recent publication on GHG emissions from dairy cattle and potential mitigation opportunities (FAO & NZGGRC, 2017) revealed a strong negative correlation between productivity and emissions per fat and protein corrected milk (Figure 5). It suggests that increasing milk production per cow from 250 kg to 900 kg can reduce emission intensity by 73 percent.

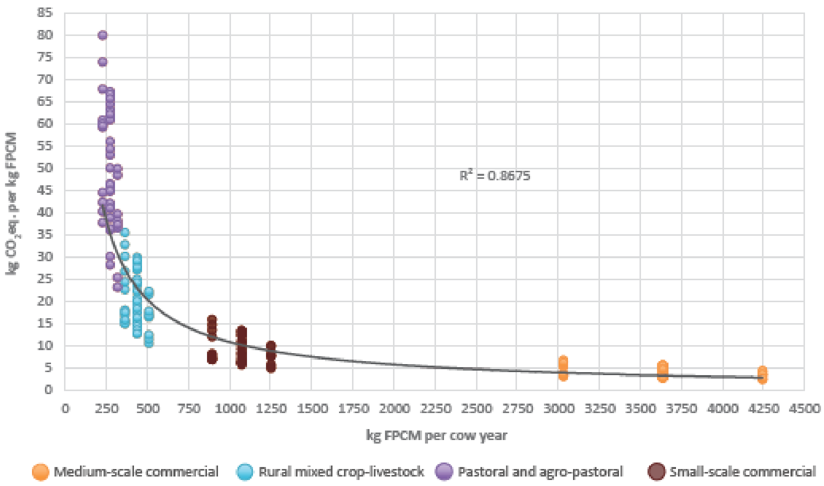

Figure 6. *GHG emission intensity of milk as a function of milk productivity by production system and district (Source: FAO & NZGGRC, 2017)*

Conclusions

Ethiopia is facing a complex variety of environmental challenges that will develop further as the country's economy - including the cattle sector - grows (Daley, 2015). Therefore, environmental issues are an important priority in the policy agenda of the country. The environment and livestock are closely related, having a mutual impact on each other: livestock depends on land and water availability, and at the same time emits polluting materials. The huge cattle sector in Ethiopia is a major user of available natural resources such as land and water, though a big part of this would hardly be used for other purposes. As intensification grows, the efficiency of production increases in terms of GHG emissions, water and land use. However, the opportunity cost of the used water and land is much lower, particularly in pastoral systems. When managed prudently, animal production can play an integral role in the food system, making use of marginal lands and rainwater, turning co-products into edible goods, contributing to crop productivity and turning edible crops into highly nutritious, protein-rich food (Mottet, *et al.*, 2017).

The Ethiopian government is acting towards supporting an environmental friendly society. The Ministry of Environment, Forest and Climate Change (MEFCC) is implementing strategies, proclamations and regulations in response to environmental challenges (see list in Annex 1). The Climate-Resilient Green Economy's (CRGE) vision is to develop a strong and growing economy (reaching middle-income status by 2025) that is resilient to current and future climate, while maintaining carbon emissions at the 2010 level. Livestock was identified as one of the most significant contributors to the country's overall emissions, and six abatement levers were identified that can be grouped in four categories. These are enhancing and intensification of diversifying the animal mix (largest abatement potential), value chain efficiency improvement for farmers and pastoralists (2 levers), increasing small-scale and medium-scale mechanization, and improved rangeland and pastureland management techniques (CRGE, 2011).

The National Adaptation Plan of Ethiopia (NAP-ETH) supports integrating climate change adaptation in the long-term development plan of the country. The most vulnerable sectors identified by the plan are agriculture, livestock, forestry, health, transport, power, industry, water and urban areas. The NAP-ETH recommends using a climate smart improvement of agricultural productivity to enhance food security. Furthermore, mainstreaming endogenous adaptation practices, developing and implementing adaptation technologies, strengthening drought and crop insurance mechanisms and establishing efficient value chain and marketing systems are suggested (Teshome, 2017).

The effective implementation of current policies and strategies, to be continously revised and adaped in the coming decades, also in view of the anticipated growth and transformation of the livestock sector, is of paramount importance to ensure an environmental sustainable development of Ethiopia, for the current and future generations.

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ANNEX

Annex 1. Ethiopia's response to major environmental problems (Ministry of Environment, Forestry and Climate Change)

Pollution:

- Industrial Pollution control proclamation (Proc No. 300/2002)
- Solid waste management proclamation (Proc No. 513/2007)
- Environmental impact assessment proclamation (Proc No. 299/2002)
- Prevention of industrial pollution (Regulation No. 159/2008)

Climate:

- Climate resilient green economy strategy (CRGE- 2011)
- Climate resilient strategy of agriculture, forestry, water and energy
- Intended Nationally Determined Contribution (INDC)
- National Adaptation Plan (NAP-ETH)

Annex 2.1 Determination of upstream emissions calculated in GLEAM

• **N2O from pasture and crop cultivation.** Nitrous oxide emissions from cropping include direct N2O, and indirect N2O from leaching and volatilization of ammonia. It was calculated using the IPCC (2006) Tier 1 methodology. Synthetic N application rates were defined for each crop at a national level, based on existing data sets (primarily FAO's fertilizer use statistics, http://www.fao.org/ag/agp/fertistat/index_en.htm). Crop residue N was calculated using the crop yields and the IPCC (2006, Volume 4, Chapter 11, p. 11.17) crop residue formulae;

• **CO2 arising from loss of above and below ground carbon brought by land use change.** In GLEAM, land-use changes are considered as the transformation of forest to arable land for feed crops and that of forest to pasture. Emissions are generally quantified according to IPCC Tier I guidelines (IPCC, 2006). The expansion of feed crops is limited to soybean and to palm oil production.

• **CO2 from field operations.** CO2 from the on-farm energy use associated with field operations (tillage, manure application, etc.) and crop drying and storage. Energy is used on-farm for a variety of field operations required for crop cultivation, such as tillage, preparation of the seed bed, sowing and application of synthetic and organic fertilizers, crop protection and harvesting. The type and amount of energy required per ha, or kg, of each feed material parent crop was estimated. In some countries, field operations are undertaken using non-mechanized power sources, i.e. human or animal labour. The energy consumption rates were adjusted to reflect the proportion of the field operations undertaken using non-mechanized power sources;

• **CO2 arising from the manufacture of fertilizer and pesticide.** The manufacture of synthetic fertilizer is an energy-intensive process, which can produce significant amounts of GHG emissions, primarily via the use of fossil fuels, or through electricity generated using fossil fuels. The emissions per kg of fertilizer and pesticide will vary depending on the factors such as the type of fertilizer and pesticide, the efficiency of the production process, the way in which the electricity is generated, and the distance the fertilizer is transported;

• **CO2 arising from crop transport and processing.** Pasture and crop residues, by definition, are transported minimal distances and are allocated zero emissions for transport. Non-local feeds are assumed to be transported between 100 km and 700 km by road to their place of processing. In countries where more of the feed is consumed than is produced (i.e. net importers), feed that are known to be transported globally (e.g. soybean meal) also receive emissions that reflect typical sea transport distances. Emissions from processing arise from the energy consumed in activities such as milling, crushing and heating, which are used to process whole crop materials into specific products. Therefore, this category of emissions applies primarily to feeds in the by-product category; and

• **CO2 from blending and transport of compound feed.** Energy is used in feed mills for blending non-local feed materials to produce compound feed and to transport it to its point of sale.

• **CH4 from rice cultivation.** Rice, differently from all the other feed crops, produces significant amounts of CH4. These emissions per hectare are highly variable and depend on the water regime during and prior to cultivation, as well as the nature of the organic amendments. The average CH4 flux per hectare of rice was calculated using the IPCC Tier 1 methodology as described in the Volume 4, Chapter 5.5.

Annex 2.2 Determination of animal production emissions in GLEAM:

• **CH4 from enteric fermentation.** Emissions from enteric fermentation (kg CH4/head) are a function of feed digestibility (DE), i.e. the percentage of gross energy intake that is metabolized. An enteric methane conversion factor, Ym (percentage of gross energy converted to methane) is used to calculate the methane emissions from enteric fermentation. A Tier 2 approach is applied for the calculation of enteric CH4 emissions due to the sensitivity of emissions to diet composition and the relative importance of enteric CH4 to the overall GHG emissions profile in ruminant production.

• **CH4 from manure management.** Calculating the CH4 per head from manure using a Tier 2 approach requires (a) estimation of the rate of excretion of volatile solids per animal, and (b) estimation of the proportion of the volatile solids that are converted to CH4. The volatile solids excretion rates are calculated using Equation 10.24 from IPCC (2006). Once the volatile solids excretion rate is known, the proportion of the volatile solids converted to CH4 during manure management per animal per year can be calculated using Equation 10.23 from IPCC (2006). The CH4 conversion factor depends on how the manure is managed. In this study, the manure management categories and emission factors in IPCC (2006, Volume 4, Chapter 10, Table 10A-7) were used. The proportion of manure managed in each system is based on official statistics (such as the Annex I countries' National Inventory Reports to the UNFCCC), other literature sources and expert elicitations.

• **N2O emissions arising during manure management.** Calculating the N2O per head from manure using a Tier 2 approach requires (a) estimation of the rate of N excretion per animal, and (b) estimation of the proportion of the excreted N that is converted to N2O. The N excretion rates are calculated using Equation 10.31 from IPCC (2006) as the difference between intake and retention. N-intake depends on the feed dry matter intake and the N content per kg of feed. The feed dry matter intake depends, in turn, on the animal's energy requirement (which is calculated in the system module, and varies depending on weight, growth rate, milk yield, pregnancy, weight gain and lactation rate and level of activity) and the feed energy content (calculated in the feed module). N retention is the amount of N retained in, either as growth, pregnancy live weight gain or milk. The rate of conversion of excreted N to N2O depends on the extent to which the conditions required for nitrification, denitrification, leaching and volatilization are present during manure management. The IPCC (2006) default emission factors for direct N2O (IPCC, 2006 Volume 4, Chapter 10, Table 10.21) and indirect via volatilization (IPCC, 2006 Volume 4, Chapter 10, Table 10.22) are used in this study, along with variable leaching rates, depending on the AEZ.

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