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2050

Livestock, health, livelihoods and the environment in Ethiopia

An integrated analysis

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Acronyms

ADNIS	Animal Disease Notification and Investigation System
AEZ	Agro-ecological zone
AMR	Antimicrobial resistance
AQUASTAT	FAO's global water information system
ASF	Animal source food
ASL2050	Africa Sustainable Livestock 2050
ATA	Agricultural Transformation Agency
bTB	Bovine tuberculosis
CAHI	Canadian Animal Health Institute
CH_4	Methane
CO_2e	CO_2 equivalent
CSA	Central Statistical Agency
DACA	Drug Administration and Control Authority
DALY	Disability-adjusted life year
DNA	Deoxyribonucleic acid
DOT	US Department of Transportation
DOVAR	Disease Outbreak and Vaccination Reporting
EEP	Expert Elicitation Protocol
EPT	Emerging Pandemic Threats
FAO	Food and Agriculture Organization of the United Nations
FDRE	Federal Democratic Republic of Ethiopia
FMHACA	Food, Medicine and Healthcare Administration and Control Authority
FPCM	Fat and Protein Corrected Milk
GBD	Global burden of disease
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information System
GLEAM	Global Livestock Environmental Assessment Model
GLW	Gridded Livestock of the World
HH	Household(s)
HIV/AIDS	Human immunodeficiency virus/acquired immunodeficiency syndrome
IDRS	Integrated Disease Surveillance and Reporting System
IPCC	Intergovernmental Panel on Climate Change

LSMS	Living Standards Measurement Study
LWP	Livestock Water Productivity
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries, Uganda
MEFCC	Ministry of Environment, Forest, and Climate Change
MERS-CoV	Middle East Respiratory Syndrome - Corona Virus
MMT	Million metric tonnes
MoA	Ministry of Agriculture
MoCT	Ministry of Culture and Tourism
MoANR	Ministry of Agriculture and Natural Resources
MoARD	Ministry of Agriculture and Rural Development
MoH	Ministry of Health
MoLF	Ministry of Livestock and Fisheries
MT	Metric tonnes
NAP-ETH	National Adaptation Plan of Ethiopia
NZAGRC	New Zealand Agricultural Greenhouse Gas Research Centre
OECD	Organisation for Economic Co-operation and Development
PCR	Polymerase Chain Reaction
PPP	Purchasing power parity
RuLIS	Rural Livelihoods Information System
SARS	Subacute respiratory syndrome
TLU	Tropical livestock unit
UNFCC	United Nations Framework Convention on Climate Change
USD	US Dollar
WF	Water footprint
WHO	World Health Organization
WTP	Willingness to pay
WWF	World Wildlife Fund

Preface

It is easy to talk "One Health". It is, however, a daunting challenge to operationalize "One Health", to embark on a truly multi-stakeholder multi-disciplinary approach to understand livestock sector dynamics and its multiple connections with people's livelihoods, public health and the environment. Yet, investing in "one health" is the only way to ensure a sustainable development of the livestock sector: a detailed understanding of the multitude goods and services that livestock generate as well as its potential negative impacts on society is fundamental to inform policy dialogue, avoid oversimplifications and arrive at agreed and actionable investments.

This report represents an attempt to operationalize the "One Health" concept in Ethiopia. It is the result of an open and continuous multi-stakeholder and multi-disciplinary dialogue, guided by the Ministry of Agriculture and Livestock, Ministry of Health, and Ministry of Environment, Forest and Climate Change in collaboration with the Africa Sustainable Livestock 2050 Programme of the Food and Agriculture Organization of the United Nations. Along this consultative process, national stakeholders have innovated under different perspectives. First, they have generated maps of beef and dairy cattle production systems in Ethiopia, which, for the first time ever, portray the different sub-production systems: the importance of characterizing the heterogeneity of livestock for informed policy decisions cannot be overstated. Second, they not only have assembled an unprecedented set of statistics for the different beef and dairy production systems but also assessed their impact on three societal dimensions, including public health, people's livelihoods and the environment. The value of having public health, livelihoods and environmental indicators that all refer to the same livestock production systems is essential to understand the trade-offs associated with any livestock sector policy or investment. Third, stakeholders have developed a methodology to assess in monetary terms the impact of zoonotic diseases, whose causative agents (the pathogens) are shared between animals and humans, both on livestock production and on human beings. Such a methodology is an invaluable input to measure the returns of policies and investments aimed at tackling zoonotic diseases, whose outbreaks can have major negative impact on society, such as bovine tuberculosis and anthrax. Innovation comes with risks and failure and, while we are aware that this report could be improved and expanded to cover additional production systems and zoonotic diseases, we believe it represents a major step towards "One Health" tuned livestock sector policies and investments in Ethiopia.

What is possibly most valuable is that this report represents a key milestone in a longer journey we have all embarked on: we have agreed to build on this report to continue an open and informed multi-stakeholder and multi-disciplinary dialogue about the long-term dynamics of the livestock sector in Ethiopia. Our objective is to appreciate its trends and likely future impacts on society in order to design and implement informed policies and investments today, which will ensure a sustainable development trajectory of the livestock sector in this country in the long-term, for the benefits of the future generations.

Fekadu Beyene (Prof.)
State Minister

1. Background and rationale

Nearly 75 percent of all new, emerging, or re-emerging diseases affecting humans have zoonotic nature. The severe acute respiratory syndrome (SARS), the H5N1 strain of avian influenza, the 2009 pandemic H1N1 influenza virus, the Middle East Respiratory Syndrome-corona virus (MERS-CoV), and the 2013/14 Ebola outbreak in West Africa are some of the notable reminders of how vulnerable the increasingly interconnected world is to new emerging zoonotic diseases. The speed at which zoonotic diseases increasingly emerge and spread presents serious public health, economic, and development concerns. It also underscores the need for the development of comprehensive disease detection and response capacities, particularly in "hotspot" regions where a confluence of risk factors increase the risk of zoonotic disease emergence. A large share of rural households depend on livestock for their livelihoods. Livestock also contribute about 14.5 percent to all human-induced greenhouse gas emissions. The future of African livestock will therefore influence the development trajectory of the African continent as whole.

With its population anticipated to more than double and an expected Gross Domestic Product (GDP) growth rate of over 3 percent per year in the coming decades, Africa is one of the fastest growing economic regions of the world. In Ethiopia in particular, human population is anticipated to grow from about 99 million in 2015 to almost 190 million in 2050, with the share of urban population almost doubling to nearly 40 percent over the same period. GDP per capita is expected to grow from less than USD 700 in 2015 to over USD 5 500 in 2050. As GDP and consumer purchasing power grow, so will the demand for livestock products such as meat, milk, and eggs. Indeed, available estimates suggest that consumption of milk, beef, sheep and goat meat, chicken meat, and eggs will increase by 263, 257, 217, 268 and 737 percent, respectively, between 2012 and 2050. In response to growing demands, producers will make significant investments in livestock farming systems and value chains with the aim of increasing supply of animal source foods. The growing demand for livestock products will thus provide opportunities for poor livestock keeping households to increase productivity and use livestock keeping as a vehicle out of poverty. However, livestock could also generate negative effects on public health, environment and livelihoods, as experience elsewhere, and in Asia in particular, has shown. Besides, in a rapidly changing environment, returns on investments are often uncertain: competitive, economic, operational, legal, financial, fiscal, reputational and other risks will affect the profitability of livestock farming. Some livestock farmers and enterprises will succeed, expand and thrive; while others will fail and exit the livestock business altogether. Understanding long-term changes in livestock systems and their likely impacts on society is therefore of paramount importance to formulate and implement policies that ensure healthy livestock systems for the future generations.

The government of Ethiopia has joined forces with the FAO Africa Sustainable Livestock 2050 (ASL2050) to ensure sustainable and healthy livestock systems in the country in 2050. Sustainable and healthy livestock systems play a key role in improving peoples' livelihoods, providing income, food and employment; they also improve public health, through one-health investments that tackle the emergence and spread of zoonotic diseases as well as antimicrobial resistance; and they address environmental degradation and climate change, and sustain biodiversity. To this end – under the guidance and support of a National Steering Committee comprising representatives of the Ministry of Agriculture and Livestock (MoAL)[1]; the Ministry of Environment, Forest, and Climate Change (MEFCC); and the Ministry of Health (MoH) – the government of Ethiopia and ASL2050 have agreed on the following three objectives:

- better understand how the livestock sector will look like in the next 30–40 years, with a focus on selected livestock systems of value chains;
- identify potential public health, environmental, and socio-economic implications of changing livestock systems, based on alternative long-term growth scenarios;
- identify policy gaps, and recommend priority reforms and investments, to ensure sustainable development of the livestock sector in the next three or four decades.

Achieving these objectives requires to:

- collect quantitative and qualitative information on current and future livestock systems and their effects on public health, livelihoods and the environment;
- interpret data and information to formulate future livestock systems scenarios;
- develop and agree upon alternative policy options to ensure a sustainable development of livestock in the next 30–40 years;
- identify capacity gaps and needs for national and regional governments to implement and operationalize selected policy options for a sustainable development of livestock in the long-term.

This report presents quantitative and qualitative information on the current livestock systems in Ethiopia and their effects on public health, livelihoods and the environment. The first part, *Cattle production systems in Ethiopia*, characterizes the major cattle dairy and beef production systems in the country. The second part, *Cattle and livelihoods*, focuses on estimating the benefits and services livestock, and cattle in particular, provide to households. The third part, *Cattle and the environment*, presents evidence on the livestock-environment nexus, with a focus on their impact on land, water, air, and biodiversity. The final part, *Cattle and public health*, presents assessments of the impacts of four zoonotic diseases (brucellosis, bovine tuberculosis, anthrax, and salmonellosis) on public health, including on the livestock sector and on humans.

[1] *Two Ministries, Ministry of Livestock and Fisheries and Ministry of Agriculture and Natural Resources, were merged in April 2018 to form the current Ministry of Agriculture and Livestock.*

2. Cattle production systems in Ethiopia

INTRODUCTION

This chapter presents descriptions of the cattle dairy and beef production systems in Ethiopia as agreed by key national stakeholders concerned with or affected by the livestock sector, and notably the Ministry of Agriculture and Livestock; the Ministry of Environment, Forest, and Climate Change; and the Ministry of Health. It is the first time these stakeholders have ever embarked on a multi-disciplinary process to jointly define livestock production systems, particularly cattle dairy and beef systems. Cattle dairy and beef were selected because of their relevance for the national economy and peoples' livelihoods, their being priority commodities in the current policy framework, and their anticipated growth in the coming decades[2].

The characterization of the cattle production systems involved a three-step approach:

Based on their knowledge and expertise, the stakeholders agreed on a narrative description of the cattle dairy and beef production systems.

They then validated and improved cattle distribution maps (Fig. 2.1) of the FAO Gridded Livestock of the World (GLW) and identified, for each administrative unit, the relative proportions of animals in the different production systems (for instance, 77 percent of the cattle population is found in the mixed crop-livestock and 14 percent in the pastoral/agro-pastoral system). (See Appendix A, Tables A1 and A2).

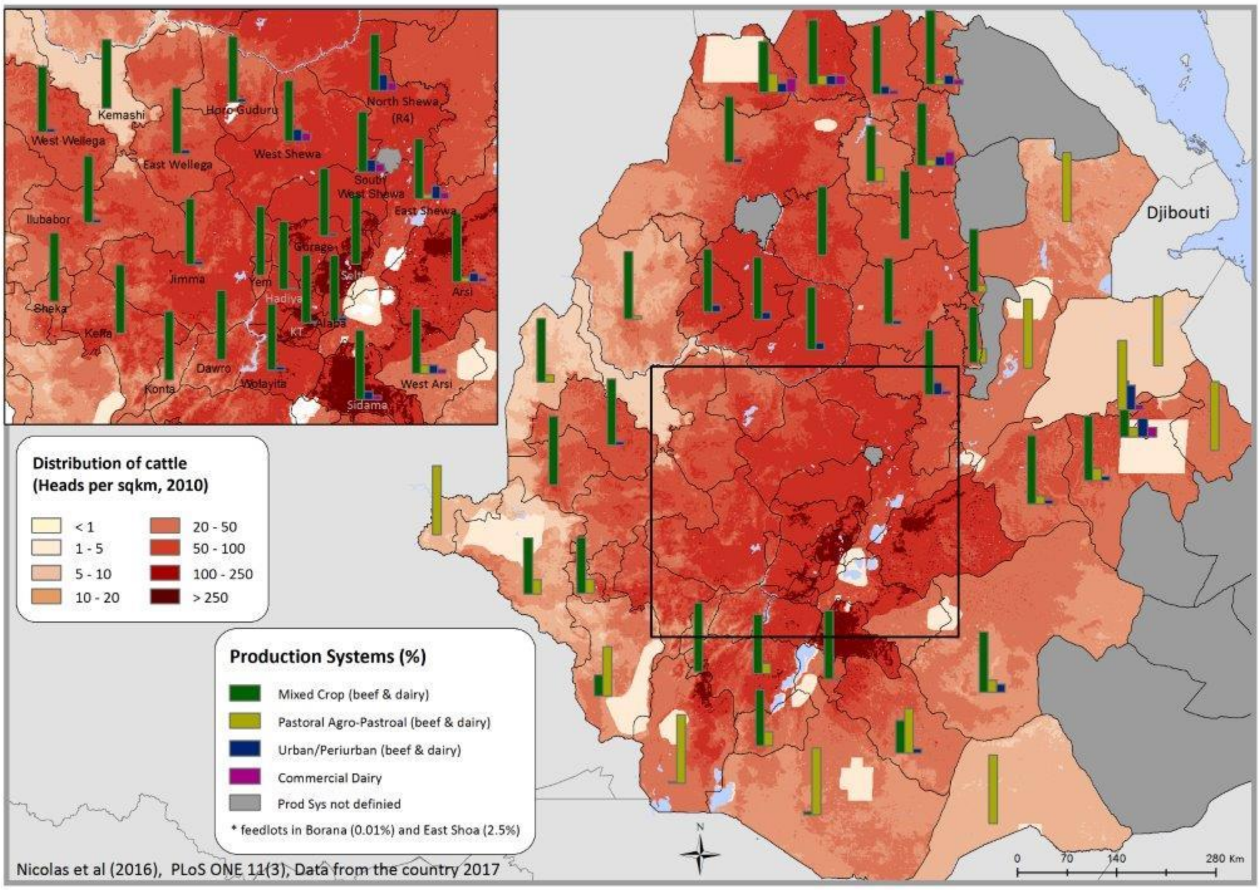
Finally, stakeholders have assembled datasets, policy documents, and published and unpublished literature on cattle dairy and beef production systems and generated statistics on the different production systems.

This approach, while not perfect, has three strengths:

- It is stakeholder driven, as stakeholders ex-ante defined the different livestock production systems.
- It allowed "adding-up" scattered information by using geographical locations as the common denominator.
- Its outputs can be visualized through combining maps and bar charts.

[2] *ASL2050 (2016) Country brief. Ethiopia. FAO, Addis Ababa.*

FIGURE 2. 1. CATTLE PRODUCTION SYSTEMS IN ETHIOPIA BY ZONE



Source: GLW

DAIRY CATTLE PRODUCTION SYSTEMS

Cattle production is one of the main agricultural industries in Ethiopia. Livestock production as a whole contributes about 45 percent to agricultural GDP (Behnke and Metaferia, 2011) –cattle being the most important generator. Currently, the country produces over 3.8 billion litres of milk (FAO and NZAGRC, 2017) and ~1 million tonnes of beef (Shapiro *et al.*, 2015) per year valued at USD 2.5 billion and USD 5.1 billion, respectively. Per capita consumption is approximately 19 kg of milk and 7 kg of beef per year (Dessie and Mirkena, 2011). The sector is highly heterogeneous comprising of the traditional pastoral/agro-pastoral and mixed crop–livestock production systems and the market-oriented intensive specialized producers. There are around 13 million cattle keeping households[3]. Stakeholders have identified four major dairy production systems in Ethiopia, including the commercial, the urban/peri-urban, the mixed crop-livestock, and the pastoral/agro-pastoral systems.

Commercial dairy

The specialized commercial dairy systems involving higher levels of investment are concentrated in the central highland plateau. In terms of scale of operation, the farms are classified as large-, small- or medium-scale. Being licensed farms with operational business

[3] *Sources: RuLIS dataset (FAO), Agricultural Sample Survey 2014 (Central Statistical Agency, Ethiopia)*

plans, they are market oriented specifically targeting consumers in urban areas. Producers tend to have a good understanding of dairy management. The commercial dairy system is labour and input intensive relative to other systems. The animals do not provide draft power but their manure is used as fertilizer.

The exact number of commercial dairy farms is not known but they represent a small fraction of total dairy farmers. The number of dairy cows in this system, however, is steadily growing and is estimated at ~3 percent of the total national milking cows. Geographically, they are concentrated mainly in the central highlands near major cities and towns. Average herd sizes can be more than 100 milking cows for large-scale farms; 30–100 for medium-scale and <30 for small-scale farms[4]. Genotypes kept are usually purebred exotic (predominantly Holstein Friesian), high-grade or crossbred dairy animals. Major feed types include hay, concentrated dairy mix, and industrial by-products. These are mainly purchased, though some farms cultivate own pasture. Main water source is tap or boreholes. Common animal health problems include mastitis, infertility, and bovine tuberculosis. These farms have access to vaccination, treatment and deworming services. Standard dairy housing or simple shelter may be used. Productive and reproductive performances are usually better with daily milk yield in the range of 15–20 litres per cow[5] and an average lactation yield of about 4 375 litres. These are market-oriented farms and milk and milk products are usually sold through formal markets (milk kiosks or supermarkets). A small proportion of the produce is used for home consumption.

Driven by the unprecedented increase in demand for milk and other dairy products, commercial dairy is a growing sub-system in Ethiopia. However, it is constrained by shortage of inputs particularly feed, genotypes, and veterinary services. Most commercial farmers are obliged to process the milk they produce into various dairy products but not all have the financial and infrastructural capabilities to meet such obligations.

Urban/peri-urban dairy

The urban/peri-urban production system is an expanding production system, largely found in the highlands and is concentrated in the Addis Ababa milk shed area as well as around the regional capital cities where an adequate market for fresh milk is readily available. There are about 5 200 dairy farms in Addis Ababa alone with an average herd size of 12 (Bogale *et al.*, 2000; 2014). It is practiced by many landless urban and sub-urban poor households. However, some businesspersons and retired civil servants also keep some dairy animals depending, wholly or partly, on hired labour. Producers are market oriented and respond to improved technical, input supply, and marketing services.

The number of urban and peri-urban dairy keepers is not accurately known; however, dairy cows kept in this system may account for about seven percent of dairy cattle population. The urban and peri-urban dairy system is concentrated in the Addis Ababa milk shed area and

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[4] Based on consensus at ASL2050 stakeholder technical meeting.

[5] *At the stakeholder technical meeting, large-scale commercial dairy farmers said the daily milk yield per cow is more than 20 liters.*

around regional capital cities. Average herd size is in the range of 5–10 cows. Typical breeds include high-grade or crossbred animals but indigenous cows are also kept. Crop residues, hay, concentrated dairy mix, industrial by-products (mainly purchased) constitute major feed resources. Vaccination, deworming and treatment of sick animals is fairly practised; however, health problems such as mastitis, infertility, and bovine tuberculosis are common. Main water sources are tap, river, borehole, and rainwater. Like in commercial dairy system, standard housing or simple shelter may be used. Milk yield ranges from 10 to 15 litres per day per cow with a lactation period of ~200 days. The bulk of produced milk is sold to neighbours through informal channels or to cafés and restaurants; a small amount is used for home consumption.

This is also a growing dairy production system in Ethiopia. However, it is constrained by shortage of inputs particularly feed, genotypes, and veterinary services. Milk handling is very poor as re-used plastic bottles and jerry cans that are difficult to clean are used for transport, and milk delivered through this system is mainly fed to infants and children. Nowadays, urban dairy producers are facing pressure from municipalities to shut down their farms because of public health and environmental issues.

Mixed crop–livestock

Mixed crop–livestock dairy production is a subsistence oriented farming system concentrated in the mid- and high-altitude agro-ecological zones where cereals and cash crops are dominant farm activities. Cattle are primarily kept to supply draft power needed for crop production. However, milk production is an integral part of the production system. The bulk of the total milk produced nationally and about three quarters of the liquid milk processed commercially is generated here.

Number of households (farms) that practise mixed crop-livestock mode of production is approximately 9.6 million[6] with average herd size of 4 milking cows. Main geographic location is mid- and high- altitude areas of Ethiopia. Predominantly indigenous breeds/ecotypes are kept. Natural pasture, crop residues, and weeds and crop thinning are the major feed types. The management style is mostly low-input, low-output traditional extensive system. About 65 percent of the total milking cows are found in this system and produce about 72 percent of the national annual milk output (FAO and NZAGRC, 2017). Vaccination against major diseases (anthrax, lumpy skin disease, contagious bovine pleuropneumonia, pasteurellosis, and blackleg) is provided by the public sector but individual households also use drugs sourced through both formal and informal outlets. Water is sourced from rivers and rainwater. Housing type can be open kraal, partition within family house or share the same room with humans. Milk yield per cow is 1.9 litres per day, on average (Felleke *et al.*, 2010).

Dairy production in the mixed crop-livestock system is pivotal to supplying the bulk of milk and milk products to the Ethiopian population although it is not essentially market-oriented. Smallholder farmers either sell excess milk informally to individual consumers and milk

[6] *Approximated from the total number of livestock keeping rural households and the proportion of rural population residing in the highland areas (~13 million and 0.74, respectively)*

collectors or process it into butter and cottage cheese for sale. Productivity per unit of land and per head of animal is extremely low. At the same time, poor service delivery systems, particularly veterinary services, make it prone to disease outbreaks and losses due to mortality and morbidity.

Pastoral/agro-pastoral

Pastoral/agro-pastoral production is the major system of milk production practiced in the lowland regions of Ethiopia where livelihoods are heavily dependent on livestock. Cattle dominate the livestock population followed by camel, goats, and sheep. Cows constitute about 40 percent of the herd. Major pastoral areas extend from the north-eastern and eastern lowlands (Afar and Somali) to the southern and south-western lowlands (Borana and South Omo).

Number of cattle keeping pastoral/agro-pastoral households is approximated to be 3.1 million[7]. Traditionally, their geographical location is in the lowland arid/semiarid areas of the country. Average herd size per household is usually in the range of 10–20 heads of cattle but large herds of >200 heads are common too particularly among the Borana (MoARD, 2007). Entirely indigenous breeds are kept. Population of milking cows in this system accounts for ~34 percent of the national milking cow population (FAO and NZAGRC, 2017). Communal rangeland pastures constitute the single most important feed resource; however, crop residues are used to a limited extent in agro-pastoral areas. As in the mixed crop-livestock system, animal health services (mainly vaccinations against major diseases such as anthrax, lumpy skin disease, contagious bovine pleuropneumonia, pasteurellosis, and blackleg) are provided by the public sector. In addition, individual households use drugs sourced through both formal and informal outlets. Water for both human and livestock uses is sourced from boreholes, deep wells, dams, rainwater, and rivers. No housing is provided for cattle except the night enclosures (*kraals*) to protect from theft and predators. Milk yield is low at ~1.5 litres per cow per day. Milk is produced for home consumption but excess milk or milk products are sold to nearby towns or highlanders.

Due to an erratic rainfall pattern – an important factor that determines availability of feed and water – milk production per unit area is low and highly seasonal. However, milk is usually produced in excess during the wet season and is either sold fresh to nearby urban centres or processed into butter to be traded with the highlanders in the peripheral markets for grains. The reliance of the agro-pastoral and pastoral systems on the overgrazed natural resource base makes them most vulnerable to climate change.

[7] *Approximated from the total number of livestock keeping rural households and the proportion of rural population residing in lowland areas (~13 million and 0.24, respectively)*

BEEF CATTLE PRODUCTION SYSTEMS

There is no specialized beef production system in Ethiopia; however, fattening of cattle and small ruminants is an important and lucrative activity[8]. Fattening or conditioning of animals for slaughter usually takes place at well-organized commercial feedlots or simply in the backyard of smallholder farmers. Farmers often see this as a profitable means of investing surplus cash for short term gain. Young or old oxen are fattened depending on the supply source. Farmers close to pastoral areas tend to purchase younger stock for feeding but in the heartland of the highlands older oxen are fattened at the end of their productive life. Feedlot operators, on the other hand, generally fatten young and intact males. There are four types of beef production systems in Ethiopia: the commercial feedlot system, peri-urban small-scale fattening, backyard fattening in the mixed crop-livestock system, and the pastoral/agro-pastoral livestock production system.

Commercial feedlot

Many feedlot operations are concentrated in the central Rift Valley particularly in East Shoa zone. Animals are entirely confined in a yard fitted with watering and feeding facilities for a finishing duration of 3–6 months. Feedlot operators prefer the Borana cattle breed due to its high market demand; however, highland Zebu originating from Arsi, Bale and Hararghe highlands are also used to a limited extent. In response to demands in the live animal export market, intact young males are commonly used for fattening. Crop residues such as *teff* and barley straw form the bulk of basal diets while industrial by-products such as wheat bran, oilseed cakes and molasses are used as supplementary feeds.

There are ~300 operating feedlots predominantly found in East Shoa, Oromia National Regional State. Feedlot operations are recently expanding to Borana zone of Oromia and North Gondar (Metema area) of Amhara. The number of animals kept on feedlot per batch may range between 100 and 1 500. Typical breed of cattle used in this operation is the Borana. Agro-industrial by-products (oilseed cakes, milling by-products, and crop residues) form the bulk of the feed resources. Animal health practices include vaccination and deworming. Many feedlot operators depend on borehole or tap as water sources. Housing is usually open shelter fitted with watering and feeding troughs. Productivity is low with estimated 110 kg carcass yield per animal on average with a dressing percent of 45–48 (MoARD, 2007). However, higher dressing percentage (e.g. 54 – 57) and hence higher carcass yield were reported for breeds such as Borana and Begait (MoARD, 2007). Annual value of production is estimated at ~ USD 211 million export revenue (ATA, 2016). Nonetheless, feedlot operators target both domestic and export markets.

The sector is currently attracting some foreign investors. For instance, Verde Beef Processing Plc. and Allana Group, both located at Adami Tullu near Zeway, are two world-class

[8] *The feedlot system in Ethiopia involves only the fattening or finishing of adult animals for a period of 3-6 months. Complete cycles of beef production such as the cow-calf, grower, finisher stages are not practised. Animals that end up in the feedlot are not necessarily raised for beef; they predominantly come from the pastoral/agro-pastoral system (from mixed crop-livestock to some extent) as extra animals to be disposed.*

beef operators owning fully integrated facilities with irrigated feed production capacity and a state of the art abattoir production facility. They are the largest cattle feedlot operators in the region with a capacity to feed, process and sell (including export) more than 130 000 and 73 000 carcasses per year, respectively.

Small-scale cattle fattening in peri-urban areas

Smallholder farmers and landless households around urban areas fatten a few animals at a time. The animals are often tethered and stall-fed. The fattening exercise is mostly done after the oxen have retired from farm work/ploughing in order to replace them with younger animals. Crop residues (*teff*, wheat, and barley straws) are used as basal feed whereas milling and oil industry by-products and *atela* (a residue from traditional distilling and brewing) are heavily used in fattening diets.

Geographic location of urban/peri-urban centres is in the mid-altitude areas. Average number of animals fattened at a time is 5 (range 1–8). Indigenous Zebu form a typical breed used in this system. Feed resources are mainly composed of crop residues supplemented with traditional brewery by-products (*atela*) and household leftovers. Housing is simple shelter or the animals are tethered in open area. Vaccination and deworming is practiced. Water is usually sourced from tap or borehole. Carcass yield per animal is 110 kg on average. With regard to marketing, it supplies to domestic consumers particularly during Ethiopian holidays.

It is an emerging system mostly practiced by landless households or unemployed youth or women's groups. The most critical challenges include shortage of land and feed, and lack of rewarding market outlets.

Cattle fattening in mixed crop–livestock production system

Traditional backyard cattle fattening is a deep-rooted and widely practiced cattle enterprise in highland areas although it is by and large a seasonal undertaking. Old oxen that retire from ploughing are commonly conditioned and finished. Usually, marketing of fattened animals is synchronized with Ethiopian holidays. Cattle fattening in this system almost entirely relies on locally available resources to minimize finishing costs. In areas like Hararghe, farmers buy young oxen from the adjacent lowland pastoralists and use them for ploughing for few years after which they fatten and sell them before they become old and emaciated.

An estimated 9.6 million rural households located in the mid- and high-altitude areas of the country practise mixed crop-livestock production; however, all of them do not necessarily fatten or condition their cattle before disposal. Small herds of animals (on average 1 to 4) are stall-fed per cycle. Duration of fattening period and cycles/year range from 2–12 months and 1–3 times, respectively. Typical breed used is the indigenous Zebu. Share of cattle population in the mixed crop-livestock system is ~77 percent of the national total. Major feed types include crop residues, green grass, agro-industrial by-products (a very recent practice), and household leftovers. Animal health services (vaccinations against major diseases such as anthrax, lumpy skin disease, contagious bovine pleuropneumonia, pasteurellosis, and blackleg) are provided by the public sector; individual households use drugs sourced through both formal and informal outlets. Water is obtained mainly from rivers and rain water. Animals are usually kept in a compartment that is part of the family's residence to protect from theft, adverse weather and predators. Yield and productivity per slaughtered animal on average is 110 kg carcass. This sub-system also supplies to domestic consumers particularly during Ethiopian holidays.

Crop cultivation and livestock production are strongly integrated in the mixed crop-livestock system, the two sectors complement each other well – livestock provides power, natural fertilizer (manure) and capital for crop production while the crop cultivation provides feed. Cattle are primarily kept to supply draft power needed for crop production. Despite the contribution of livestock to the economy and to smallholders' livelihoods, the production system is not adequately market-oriented. The typical Hararghe system is largely based on cut-and-carry feeding of individually tethered animals and hence it requires a significant amount of labour.

Pastoral/agro-pastoral

The pastoral/agro-pastoral cattle production system is a rangeland based livestock production system aimed at exploitation of the natural or semi-natural vegetation via domestic animals, in particular ruminants. The main product is milk and the main function of livestock is subsistence, although social and cultural functions are also important. Excess young males are sold off to highlanders, where they are used as draught oxen, or to feedlot operators. Herd size is maximized (depending on labour for herding, water drawing etc.) to ensure the highest chance of being left with a viable core herd after drought. Other risk aversion strategies used include keeping a mix of different animal species and splitting herds into different management units. Emphasis is put on a high proportion of females among all species to maximize milk production and the reproductive potential of the herd to recover after a decline. Ninety-five percent of the livestock exported from Ethiopia is supplied by the pastoral and agro-pastoral areas of Borana, Afar, and Somali. For instance, all 20 500 cattle kept on 180 feedlot centres in Oromia in 2007 were sourced from the southern (e.g. Borana) or south-eastern rangelands.

Geographical location of the pastoral/agro-pastoral cattle production system is in the lowland arid/semiarid areas. Average herd size is in the range of 10–20 heads; large herds of >200 heads are common too. Cattle population in this system accounts for ~14 percent of the national herd. Entirely indigenous breeds are kept. Feed types are predominantly communal rangeland pastures with a limited use of crop residues in agro-pastoral areas. Regarding animal health services, vaccinations against major diseases (anthrax, lumpy skin disease, contagious bovine pleuropneumonia, pasteurellosis, and blackleg) are provided by the public sector. Besides, individual households use drugs sourced through both formal and informal outlets. Water sources include boreholes, deep wells, dams, rain water, and rivers. No housing is provided except night enclosures (*kraals*). Households do not usually slaughter for home consumption rather they supply their animals to collectors for feedlot operators, exporters, highland farmers.

Livestock management is characterized by the adaptation of the feed requirements of the animals to the environment through migration. Land tenure is communal. Major challenges include seasonality of rainfall and the resulting unavailability of adequate feed and water, land degradation and deterioration of the range ecosystem due to overgrazing and invasive plant species.

CONCLUSION

This chapter assessed existing features of dairy cattle and beef production systems in Ethiopia, as described and characterized by the Ministry of Agriculture and Livestock; the Ministry of Health; the Ministry of Environment, Forest and Climate Change and other stakeholders such as the International Livestock Research Institute, the Ethiopian Live Animal Exporters' Association, and Dairy Producers' Association of Ethiopia.

This common understanding of livestock production systems supports multi-sectoral and multi-disciplinary dialogue among stakeholders to appreciate the production, public health and environmental dimensions of livestock and the formulation of coherent and effective policies and investments.

3. Cattle and livelihoods

INTRODUCTION

Livestock contributes to peoples' livelihoods through numerous channels including income, food, employment, transport, draft power, manure, savings and insurance, social status etc. Cattle production is one of the main agricultural industries in Ethiopia. This chapter presents estimates of the benefits livestock generate for households in different cattle production systems using data from the Central Statistical Agency (CSA) 2015/16 Ethiopia Socioeconomic Survey. The household survey data was designed to cover multi-topic information on peoples' livelihoods, and allows estimation of total income derived from all agricultural and non-agricultural activities. It was possible to identify and classify cattle keeping households in to one of the production systems due to the detailed information on location, herd size, breeds, marketing activities, feeding, watering, and housing practices. This grouping allowed us to analyse the contribution of cattle keeping to livelihoods through income and consumption, sorted by different production systems. Indeed, the survey was not designed specifically to characterize cattle keepers, therefore the representation at the sub-regional level might be different from the actual number of holdings in each system. However, this was the only source that gives detailed information on all income generating activities, production practices, and other household characteristics. At the same time, the small number of both commercial feedlots – which are attracting foreign investors and will play an important role in the country's future beef production – and large scale commercial dairy enterprises did not allow to include these operators in the livelihoods analysis. Hence, this chapter concentrates on the mixed crop-livestock, pastoral/agro-pastoral, and urban/peri-urban (small- and medium-scale) dairy commercial systems. Due to their nature, pastoral systems are likely to be underrepresented in the data. For more information on the survey design and sampling, please refer to Annex B.

POPULATION DEPENDING ON CATTLE

Cattle are a very common asset in Ethiopian households. Approximately 12.5 million households, or 70 percent of the total population, depend fully or partly on cattle for their livelihoods (Table 3.1). This figure is an underestimation, as it only includes people living in cattle keeping households and does not count everyone employed along the value chain. Cattle are predominantly kept in mixed crop-livestock system engaging more than 10 million households. The pastoral and agro-pastoral systems comprise nearly one million cattle keeping households. Statistics on holdings in the pastoral, urban/peri-urban and commercial dairy systems are not necessarily representative given the small number of observations in the sample.

TABLE 3. 1. Number of holdings and people keeping cattle

Production system	Number of cattle keeping households	Number of people living in cattle keeping households	Average household size
Mixed crop-livestock	10 583 073	57 715 530	5.5
Pastoral/Agro-pastoral	948 544	5 952 244	6.3
Urban/Peri-urban	612 644	3 439 022	5.6
Dairy commercial	425 733	2 283 074	5.4
Total	12 569 994	69 389 870	

CONTRIBUTION OF CATTLE TO HOUSEHOLD NET INCOME

Cattle keeping is not only very widespread, but it contributes substantially to income as well as to nutrition through consumption from households' own production. Net income was measured as the sum of all incoming revenues minus operating costs. In particular, the net income from livestock activities were measured as cash income (revenues from live animal and product sales) and value of products used for consumption minus operating costs such as live animal purchase, feed, water and medical expenses (see Annex B1 for detailed explanation).

Figure 3.1 shows the share of different activities in total disposable income by households in the different cattle production systems. These activities include livestock, crop, off-farm self-employment, wage income from employment (salaries) and transfers (including public and private, international and domestic transfers). Livestock is the biggest income contributor in pastoral and agro-pastoral (65 percent), dairy commercial (55 percent) and urban/peri-urban systems (47 percent). As mentioned before, the dairy commercial sector includes observations of small- and medium scale enterprises; if large-scale operations were included, this share would presumably be higher. In the mixed crop-livestock system, livestock is the second most important source of income (34 percent) after crop activities. Crops are the second most important contributors to total income in the pastoral and commercial systems, while wages from employment account for 20 percent of income in urban/peri-urban systems. It is important to note that the shares are influenced by the profitability of the activities in a given year. The share of livestock income in total income may be low in some households although livestock is an important income generating activity but the operating surplus was low due to high costs such as animal purchases.

FIGURE 3. 1. Share of different income sources in total annual household income, by production system

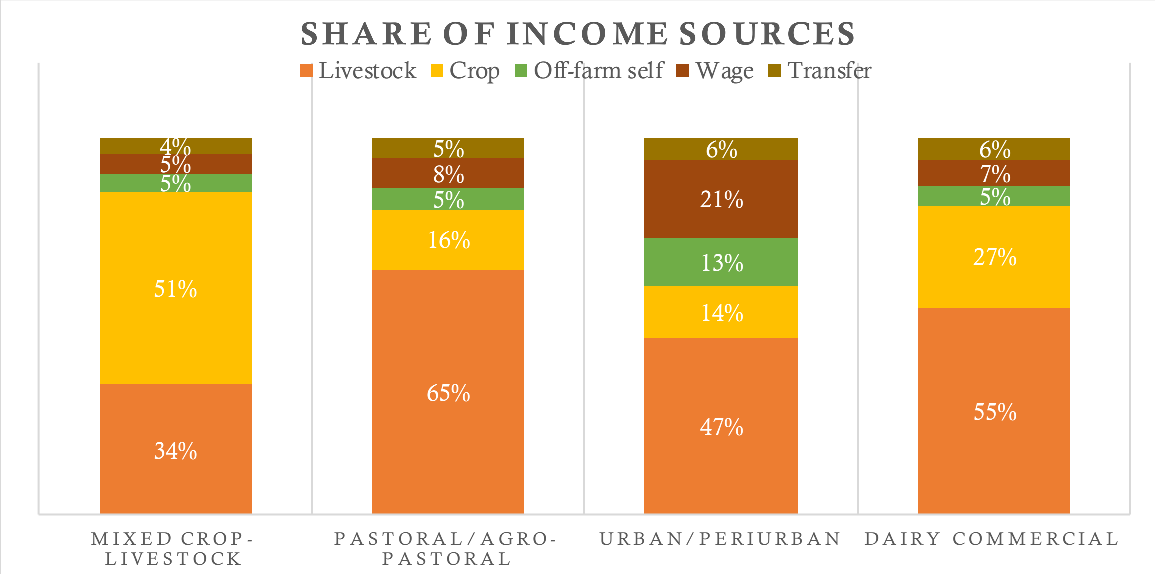


Table 3.2 shows the average annual household income (involving all income generating activities) and average annual income from livestock and cattle activities by the different cattle production systems defined by the stakeholders. Households in mixed crop-livestock systems have on average the lowest total income, followed by the pastoral/agro-pastoral, urban/peri-urban and dairy commercial systems.

TABLE 3. 2. Average annual total income, income from livestock and cattle activities per household

		Average annual HH income (Birr)	
Production system	Total income[9]	Livestock activities	Cattle activities
Mixed crop-livestock	14 512	6 260	4 698
Pastoral/Agro-pastoral	23 497	16 702	11 950
Urban/Peri-urban	26 968	10 511	9 664
Dairy commercial	32 080	19 499	18 279

Between 31 percent and 48 percent of total income is derived from cattle (Table 3.3).

These figures, however, are an underestimate as they do not account for the value of manure, draft power, social status, transport, savings, insurance etc. The last two columns of Table 3.3 show that in each production system, manure and draft power use is very common.

[9] *Total household income aggregates calculated by Rural Livelihoods Information System (RuLIS – FAO, forthcoming) based on Ethiopia Socioeconomic Survey 2015/16*

TABLE 3. 3. Share of livestock and cattle income over total net household income

Production system	Share of livestock income over total income	Share of income from cattle over total income	% of households using dung from cattle	% of households using draft power from cattle
Mixed crop-livestock	34%	31%	87%	69%
Pastoral/Agro-pastoral	65%	48%	41%	50%
Urban/Peri-urban	47%	43%	77%	42%
Dairy commercial	55%	48%	95%	80%

At the national level, mixed crop-livestock systems have the highest contribution to the total net income from different production systems, providing two thirds of the total net income generated (Table 3.4). However, the net income generated per animal sheds light on great differences in profitability which in turn emanates from productivity differences: mixed crop-livestock systems have an annual net income of 986 Birr per animal while one animal in the dairy commercial system provides nearly 3 000 Birr operating surplus.

TABLE 3. 4. Total net income and net income per animal by production systems

Production system (PS)	Total net cattle income by PS (Birr)	Share of total income by PS	Net annual income per cattle (Birr)
Mixed crop-livestock	49 714 112 414	67%	986
Pastoral/Agro-pastoral	11 335 347 421	15%	1 394
Urban/Peri-urban	5 920 532 190	8%	2 932
Dairy commercial	7 781 896 875	10%	2 922
TOTAL	74 751 888 900	100%	

Cattle keeping generates revenue through milk production (and derived products), beef production and sale of live cattle. Figure 3.2 shows the share of these activities in total revenue. Costs have not been accounted for in this graph, since some costs would be difficult to fairly allocate across the different activities. Milk production is the most dominant contributor across all production systems. This does not come as a surprise since households do not regularly slaughter animals for beef, rather they usually sell to traders, who in turn transfer the animals to feedlots and slaughterhouses for beef production.

Milk produced by smallholders is predominantly used for home consumption – in the mixed crop-livestock and pastoral/agro-pastoral systems only 25 percent to 33 percent of the production is sold. In the commercial dairy sector, however, milk is produced for market and the average annual net income from milk production is substantially higher than in the other production systems. It is important to note that the data mainly captures small-scale and some medium-scale commercial dairy farms. This becomes more evident if we consider farms with large herd size (farms with at least 10 cattle) where the proportion of milk sold increases to 92 percent (data not shown).

FIGURE 3. 2. Share of activities in total gross revenue from cattle

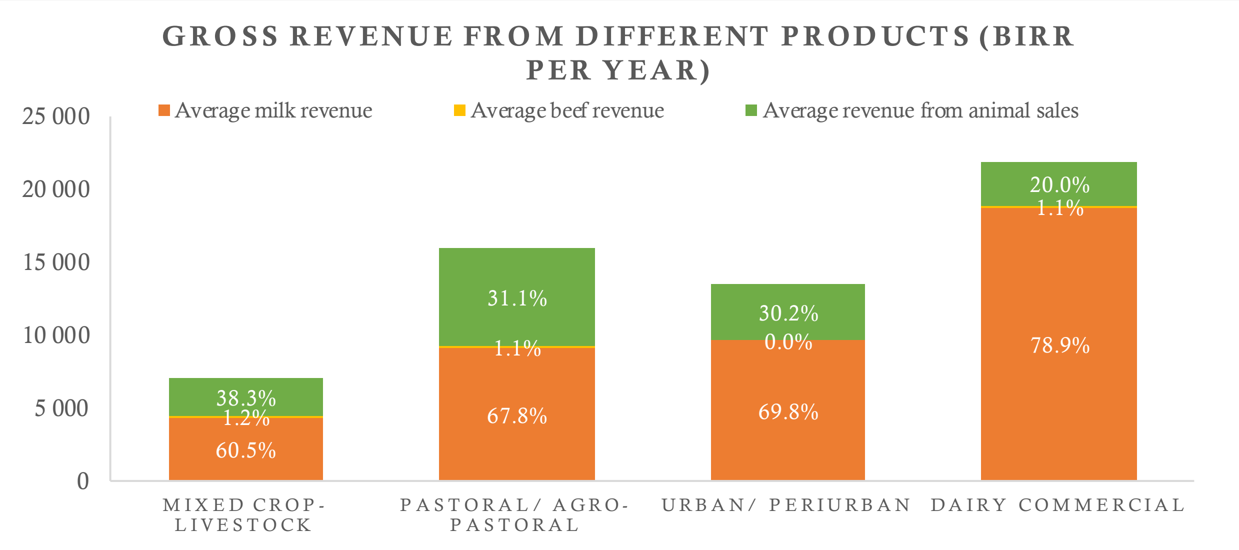


TABLE 3. 5. Average share of sales and consumption in milk production

Production System	Average revenue from milk production	% milk production sold	% milk production consumed
Mixed crop-livestock	4 333	25%	75%
Pastoral/Agro-pastoral	9 105	33%	67%
Urban/Peri-urban	9 624	44%	56%
Dairy commercial	17 918	87%	13%
All PS	5 706	30%	70%

CONTRIBUTION TO NUTRITION

The household survey probes detailed information on consumption practices for a reference period of 7 days. It reveals that only 54 percent of households in Ethiopia regularly consume animal source food[10]. Since these products are generally more expensive than other food commodities, consumption depends highly on income levels. Hence, poorer households have often incentives to sell rather than consume high-priced animal products. Table 3.6 presents consumption of milk by income group. Only 30 percent of the poorest households consume milk, and the consumed quantity is less than half of that consumed by the richest income quintile. Furthermore, the poorest 40 percent of households depend highly on their own production, with more than 70 percent of their consumption coming from their own animals.

Beef consumption from own production is generally low (Table 3.7). As shown in the income shares of different cattle activities above, most households do not slaughter the animal themselves but sell the live animals to traders or commercial feedlots. The same trend between income levels and consumption prevalence and quantity can be seen – the higher the household income the more the consumption of beef.

[10] *ASL2050 Ethiopia Country Brief*

TABLE 3. 6. Milk consumption in Ethiopia by income groups

Income group	Consuming dairy	Consumption per capita per week (g)	Share of own production in consumption
Poorest quintile	30%	324	71%
Moderately poor quintile	34%	427	72%
Middle quintile	45%	592	62%
Moderately rich quintile	44%	714	53%
Richest quintile	57%	779	31%

TABLE 3. 7. Beef consumption in Ethiopia by income groups

Income group	Proportion consuming beef	Consumption per capita per week (g)	Share of own production in consumption
Poorest quintile	5%	186	0%
Moderately poor quintile	6%	149	0%
Middle quintile	13%	191	3%
Moderately rich quintile	19%	221	3%
Richest quintile	40%	412	0%

Table 3.8 shows average weekly milk and meat consumption per capita and share of own production in consumption for the different production systems. Milk consumption is highest in the pastoral and agro-pastoral systems, and much of the consumed amount is from own production.

TABLE 3. 8. Milk and beef consumption in Ethiopia by production systems

Production system	Milk		Beef	
	Average weekly per capita consumption (g)	Share of own production in consumption (%)	Average weekly per capita consumption (g)	Share of own production in consumption (%)
Mixed crop-livestock	588	81%	262	3%
Pastoral/Agro-pastoral	1 047	81%	196	4%
Urban/Peri-urban	555	44%	293	0%
Dairy commercial	460	49%	246	0%

CONCLUSION

Results of the household survey show that livestock activities are major contributors to livelihoods through income and nutrition related benefits, with cattle and cattle products playing a significant role. These results are an underestimation because non-marketable livestock outputs, such as draft power and manure, have not been accounted for. They also underestimate the potential benefits livestock can generate if current productivity gaps due to lack of access to inputs, technology, information and basic services were addressed. For instance, among other things, there is a huge gap in veterinary service delivery – only 50 percent of the households have at least one cattle vaccinated while 34 percent reported they do not have access to veterinary services.

4. Cattle and the environment

INTRODUCTION

There are more than 56 million heads of cattle in Ethiopia, providing over 3.8 billion litres of milk (FAO and NZGGRC, 2017) and roughly one million tonnes of beef (Shapiro *et al.*, 2015) per year. Demand for milk and beef is projected to grow from its 2012 levels to 2050 by 263 and 257 percent, respectively (FAO, 2018). It is crucial that the rapidly growing and dominant cattle sector develops in a climate smart manner. The current environmental impact of cattle systems is by far larger than all other livestock species combined. Eighty-four percent of livestock emissions come from cattle (FDRE, 2011), the water footprint per tonne of cattle is more than three times that of small ruminants and poultry, and 40 percent of the land is grasslands and mainly grazed by cattle.

Livestock and the environment have a close and complex relationship. Livestock depend 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:

- Overgrazing and improper land conversion resulting in grassland degradation;
- Excessive application of manure from livestock production leading to nutrient overloading of cropland;
- Manure and effluent mismanagement resulting in water pollution (chemical and microbiological);
- Water withdrawals for the production of animal feed, drinking, cleaning and processing causing water stress[11];
- Greenhouse gas (GHG) emissions from enteric fermentation; manure management including manure left on pasture, range and paddock; and energy-use contributing to climate change;
- Airborne contaminants including gases, odour, dust, and microorganisms impairing air quality;
- Land use change and all of the above leading to biodiversity loss and reduced eco-system services.

In this chapter, we assess 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 reviews and assessments focus on issues related to four elements: land, water, biodiversity and air. These are closely interrelated, for example, biodiversity loss can cause

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

exhaustion of ecosystem services, or changes in soils can trigger altering hydrological patterns that result in water scarcity (Daley, 2015).

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 hectares (ha) for grazing including rangelands and pasturelands and 0.5 billion ha 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 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 impact on 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. This facilitates the rapid runoff of rainfall that eventually slightly erode the surface upon which it gathers and form gullies down stream. Roughly 35 percent of the world's land degradation is attributed to the grazing animals, in Africa 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 for crop production and overgrazing. It loses two billion metric tonnes 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 and soil erosion 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 (Gashaw *et al.*, 2014; Daley, 2015). Cultivation on steep slopes and clearing of vegetation has accelerated erosion in the highlands. 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 km^2 (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); and physical and biological soil degradation. Several factors including poverty, land fragmentation and high human and livestock population pressure act more indirectly as driving forces for land degradation. Pressure from human and livestock leads to huge removal of vegetation cover to meet increasing demands for grains, grazing areas, and fuel woods (Gebreselassie *et al.*, 2016). According to the authors, there have been dynamic land use and land cover changes in the country over the 2001–2009 periods. For example, in 2001 there were about 8.5 million ha of croplands, 5.5 million ha of forestlands and about 29 million ha of grasslands. In 2009, however, croplands increased to 11.3 million ha 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 obvious and generally agreed. These 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 direct or proximate 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 a 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 was greater in 95 percent of 19 instances and erosion was more in 81 percent of 32 instances (Evans, 1998). Similalry, Mwendere and Mohamed Saleem (1997) in their studies in Debre Zeit area found that heavy to very heavy grazing pressures 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 percent 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 through 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 crop cultivation in the fragile dryland areas has been a greater contributor to degradation in Ethiopia than livestock and wildlife grazing combined. The problem is aggravated when land is prepared for cultivation in the dry season because such a practice exposes topsoil to wind erosion and makes it difficult for native plants to re-establish.

Desta *et al.* (2000) reporting on the state of soil erosion in 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 per ha per year. About 29 percent of the total area of the region experienced high erosion rates (51–200 tonnes per ha per year); 31 percent experienced moderate erosion rates (16–50 tonnes per ha per year); 10 percent experienced very high erosion rates (>200 tonnes per ha per year); and the remaining 30 percent experienced low erosion rates (<16 tonnes per ha per year). The Region's soil loss rate is estimated at about 58 percent of the national rate. The spatial coverage of the Region, however, is only about one-sixth of the country, hence compared with other Regions, the soil loss rate per unit area is very high in Amhara Region. 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, in turn, have led to reduction in activities such as fallowing, planting trees and investing in conservation structures, while a reduction in cropland per capita has 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 land that is fertile 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. Moreover, 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 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 indicate.

In summary, 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 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).

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 the country is putting unprecedented pressure on available water resources. The average per capita water consumption in Ethiopia varies between 10 and 20 litres 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, 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 that of domestic use[12] 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.

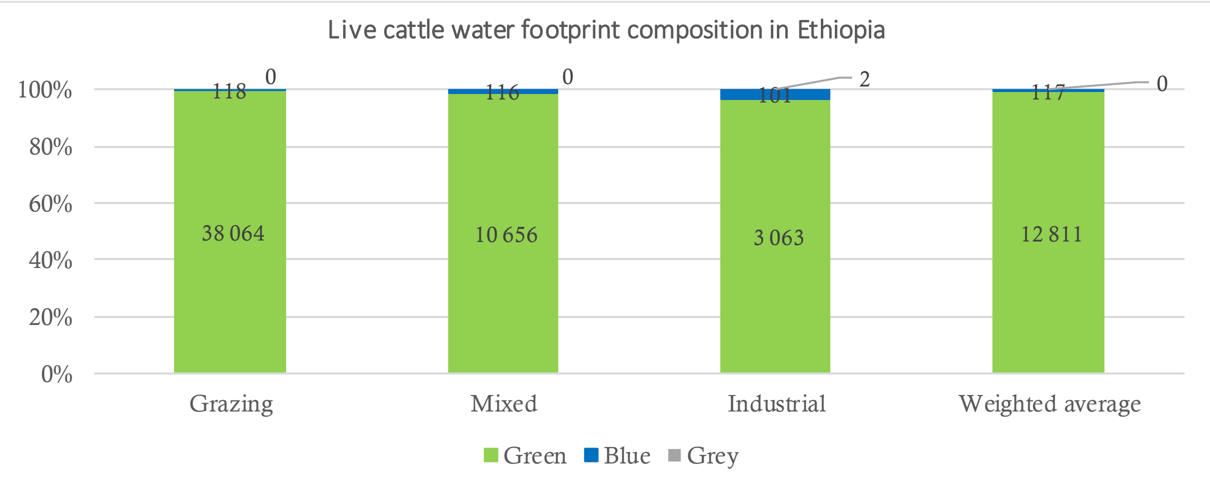
Bruegel *et al.* (2010) assessed production systems across the Nile Basin for differences in livestock water productivity (LWP) and found great differences between countries and production systems. The Ethiopian mixed systems were compared in particular with the Kenyan mixed systems due to their similar conditions. They found that LWP in Ethiopia were substantially lower than that of Kenya, the main driver being general low productivity rather

[12] *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.*

than specific water-related issues. However, the LWP across the whole Basin was generally inefficient mainly due to low productivity, high mortality rates and diseases.

Cattle production systems usually have different levels of water footprint according to their water usage for various purposes. Water footprints measure the amount of water consumed and polluted by an individual, entity or product. Mekonnen and Hoekestra (2010; 2012) conducted a thorough global assessment of the water footprint of farm animal products 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 (Chapagain and Hoekestra, 2003). The most important component of livestock related water footprints is water used for feed, calculated by production system based on feed conversion efficiencies (amount of feed needed to produce one unit of output) and by species. Figure 4.1 shows that in all production systems, green water consumption is the dominant form of cattle water consumption. In the next paragraphs, we compare the composition of water consumption of the Ethiopian livestock systems to the global average.

FIGURE 4. 1. Green, blue and grey water footprint of live cattle in Ethiopia, m^3 per tonne



Source: authors' compilation using data of Mekonnen and Hoekestra, 2012

The aggregate water consumption of live cattle is higher in Ethiopia than the global average; however, there are significant differences in the composition by source of water. Gerbens-Leenes *et al.* (2013) reveal three main drivers of the water footprint of meat production, 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. Though their study focused on the US, China and Brazil, the trends hold for Ethiopia also, as presented in Table 4.1 and Figure 4.2.

TABLE 4. 1. Green, blue and grey water footprints of live cattle by production system, m^3 per tonne

	Live cattle water footprints, m^3 per tonne							
	Grazing		*Mixed*		*Industrial*		*Weighted average*	
Type	*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**

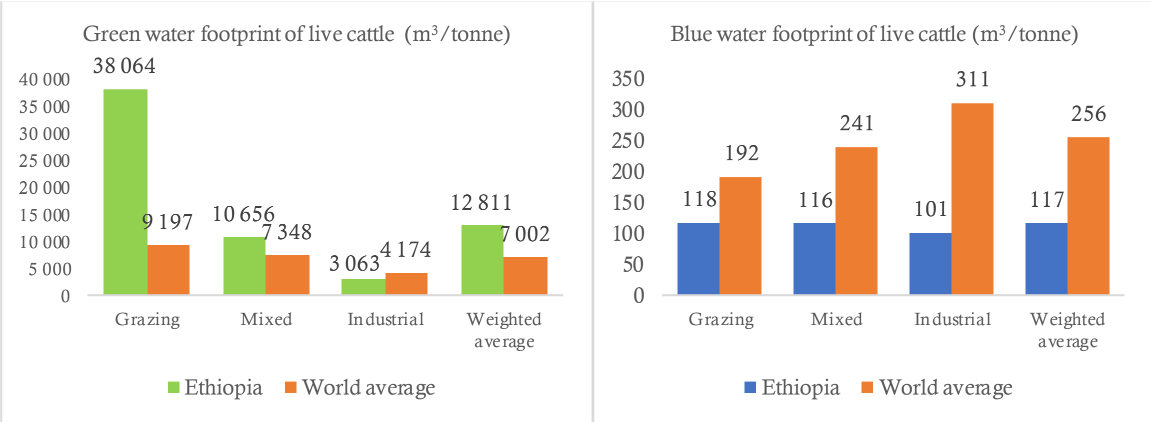
Source: authors' compilation using data of Mekonnen and Hoekestra, 2012

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 of blue water consumption across all production systems is less than half of the global average. The biggest difference between blue water consumption of the Ethiopian systems and the world average is found in the intensive systems, the Ethiopian consumption levels standing at one-third of the world average.

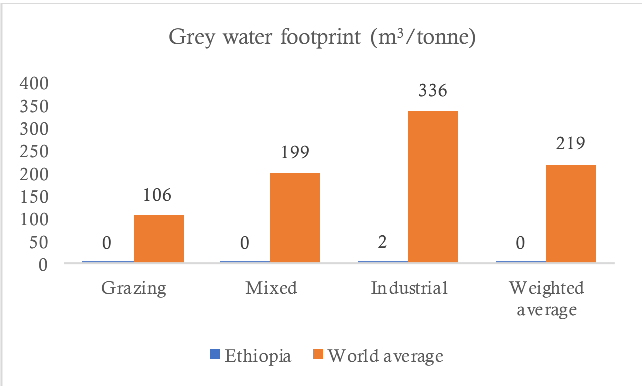
Grey water measures indirect consumption of water, i.e., the amount of freshwater needed to assimilate the pollution emitted by the commodity. The Ethiopian cattle systems show basically no such pollution. Figure 4.3 has important policy implications: industrial livestock systems in the country may not consume as much water overall as other systems, but they pollute the environment to a significantly bigger extent.

FIGURE 4. 2. Green and blue water footprints of live cattle in Ethiopia and the world, m³ per tonne



Source: authors' compilation using data of Mekonnen and Hoekestra, 2012

FIGURE 4. 3. Grey water footprint of live cattle in Ethiopia and the world, m³ per tonne



Source: authors' compilation using data of Mekonnen and Hoekestra, 2012

To summarize, 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 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 overall water footprint per kilo, but the amount of water polluted (grey water consumption) is higher than in other production systems.

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 expand 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 the 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 that cause 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 lose 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 savannah 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, 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 presently. The annual loss of highland mountain forest cover has been estimated at about 141,000 hectares, resulting in loss of biodiversity among other things (Admassu *et al.*, 2013). Due to the declining area under forest, 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 enable 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 that 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 croplands and positively affect the African rangelands (Alkemade *et al.*, 2015).

In general, the effects of grazing on rangeland biodiversity include the removal of biomass, trampling and destruction of root systems, and replacement of wild grazers by 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 19th century and spread across the continent and killed most of the continent's cattle and many of the ruminant wildlife such as buffaloes, giraffe, and eland. 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 croplands, irrigated land, and protected areas.

AIR

The livestock sector contributes significantly to global atmospheric warming and climate change through greenhouse gas (GHG) emissions (Steinfeld *et al.,* 2006). The sector is responsible for roughly 14.5 percent of all human-induced emissions estimated at 7.1 gigatonnes CO_2 equivalent (CO_2e) per annum (Gerber *et al.,* 2013). The sector accounts for 9 percent of anthropogenic CO_2 emissions – the largest share of this being due to land use changes such as deforestation caused by expansion of pastures and arable land for feed crop production. Livestock are also responsible for much larger share of methane and nitrous oxide (37 and 65 percent of anthropogenic emissions, respectively) – gasses with 23 and 296 times the global warming potential of CO_2 each (Steinfeld *et al.,* 2006).

Ethiopia's GHG emission per capita is very low compared to other countries. Its per capita emission of 1.3 tonne CO_2e is only one fifth of the world average of 6.3 tonne CO_2e (UNFCCC, 2017; CAHI, 2015). However, the country recognizes the importance of mitigating global carbon emissions and is committed to contribute to worldwide efforts. Ethiopia ratified the Paris agreement in 2017, and promotes the importance of the rapid economic growth happening in a climate-smart manner.

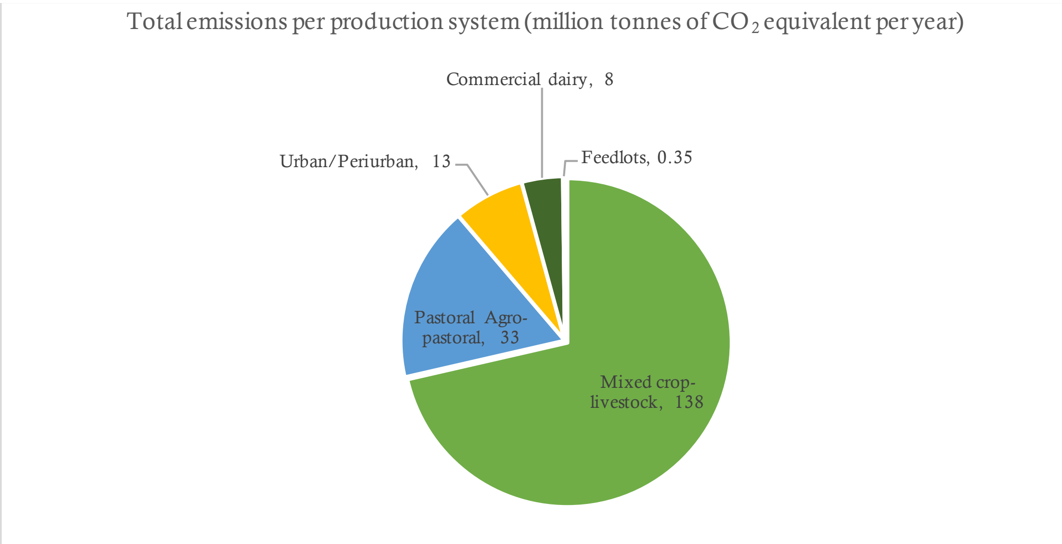
To quantify livestock GHG emissions in Ethiopia, we used data of the Global Livestock Environmental Assessment Model (GLEAM). The GLEAM is a GIS[13] framework that simulates the biophysical processes and activities along livestock supply chains under a life cycle assessment approach. The aim of GLEAM is to quantify production and use of natural resources in the livestock sector and to identify GHG environmental impacts of livestock in order 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 (CO_2), methane (CH_4) and nitrous oxide (N_2O). A Tier 2

[13] *Geographic Information System*

approach was applied for the calculation of most of the sources of emission (IPCC, 2006), including country specific factors. A Tier 1 approach was used by the MEFCC to estimate emissions from livestock sector in Ethiopia as indicated in the climate resilient green economy strategy (CRGE) (FDRE, 2011) and hence there is a significant difference between our results and that of the CRGE. To convert all emissions into CO_2 equivalent, the latest available global warming potential from IPCC (2014) are used (298 for N_2O and 34 for CH_4). The model is based on 2010 data for animal numbers and distribution, herd parameters, feed yields and rations and manure management systems.

Figure 4.4 presents the total emissions in million tonnes (MT) of CO_2e by cattle production systems. In total, the emissions of the cattle sector sum up to nearly 200 MT CO_2e[14]. Mixed crop livestock system is the biggest contributor to the sector's total GHG emissions, which is driven by the fact that roughly 77 percent of the cattle population is kept in this system.

FIGURE 4. 4. Total emissions by production system, MT CO_2 equivalent



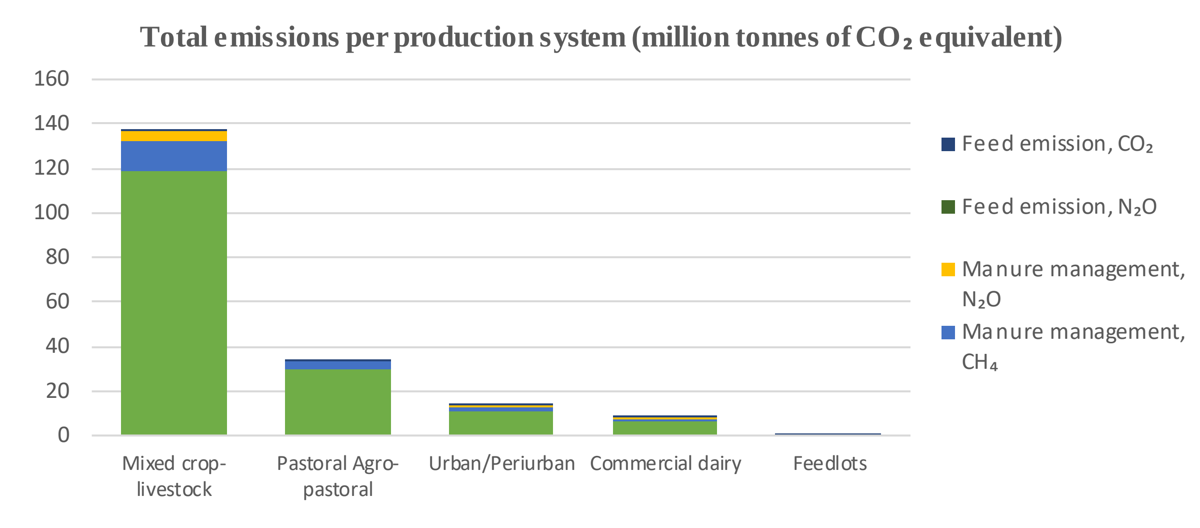
Source: FAO, GLEAM[15]

It is worth noting that the bulk of the emissions is in the form of CH_4 from enteric fermentation and its magnitude highly depends on feed digestibility (Fig. 4.5). Enteric fermentation is said to be typically lower in intensive systems where easily digestible feed is used contrary to extensive systems where animals depend on grazing or feed on less digestible materials such as crop residues.

[14] 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 were 64 MT CO_2e. (see FDRE, 2011).

[15] *Calculations were done using a Tier 2 approach (IPCC, 2006).*

FIGURE 4. 5. Total emissions by emission type



Source: FAO, GLEAM

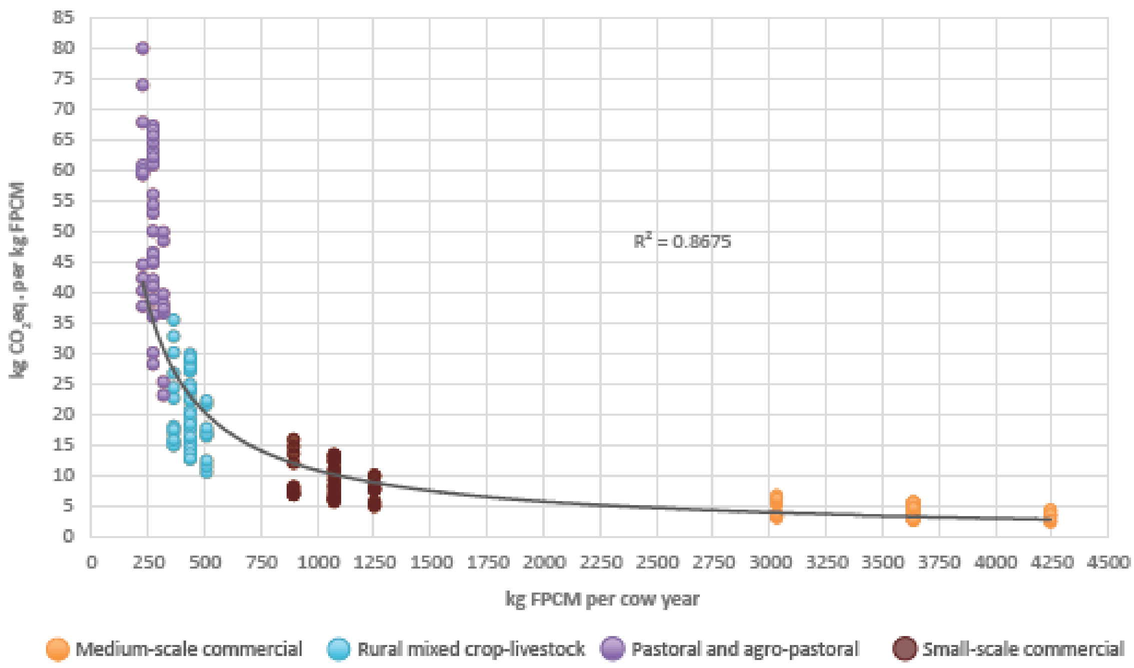
TABLE 4. 2. Total GHG emissions per head per year in CO_2 equivalents

Production system	Total emissions per head per year (CO_2 equivalent)
Mixed crop-livestock	3 162
Pastoral Agro-pastoral	4 253
Urban/Peri-urban	3 550
Commercial dairy	5 450
Feedlots	11 824

Source: FAO, GLEAM

Total emissions per head show that the dairy commercial and feedlot systems are more polluting per head of cattle. However, these production systems are more resource-efficient, hence emissions per unit of product show a different result. A recent pulbication on GHG emissions from dairy cattle and potential mitigation opportunities (FAO and NZAGRC, 2017) revealed a strong negative correlation between productivity and emissions per Fat and Protein Corrected Milk (Figure 4.6). It suggests that increasing milk production per cow from 250 kg to 900 kg can reduce emission intensity by 73 percent.

FIGURE 4. 6. GHG emission intensity of milk as a function of milk productivity by production system and district



Source: FAO and NZAGRC, 2017

CONCLUSION

The environment and livestock are closely related, having a mutual impact on each other: livestock depend on land and water availability, and at the same time emits polluting materials. However, 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 taking action towards supporting an environmental friendly society. The Ministry of Environment, Forest and Climate Change is implementing strategies, proclamations and regulations in response to environmental challenges (see the list in Annex C, C1), with the objective to develop a strong economy (reaching lower middle-income status by 2025) that is environmentally sustainable and resilient to current and future climate, while maintaining carbon emissions at the 2010 level.

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

5. Cattle and public health

INTRODUCTION

Zoonotic diseases, which jump the animal-human species barrier, are a major threat for society as they can both affect entire sectors of the livestock industry and reduce human capital. For example, it is estimated that avian influenza, at its peak, reduced chicken meat production by over one third in China (Huang *et al.*, 2017), and that the 2009 swine flu pandemic, which originated in Mexico, infected over 100 million people with a death toll of about 20 000 (Nathason, 2016). In rapidly changing societies such as Ethiopia, it is imperative that decision makers at all levels appreciate the current and future impact of the livestock sector on public health, the environment and livelihoods. This allows decision makers to take actions now that will ensure sustainable development of the livestock sector in the coming decades – a development that benefits producers, consumers and society in general – with limited negative effects on public health and the environment.

This chapter presents a monetary estimate of the impact of zoonotic diseases on Ethiopian society, with a focus on Brucellosis, Bovine Tuberculosis, Salmonellosis and Anthrax. Such an estimate is an important piece of information for decision makers both to quantify the returns of policies and investments aimed at preventing and managing zoonoses as well as to appreciate the benefits that such investments generate not only to the livestock sector but more broadly to society, such as through reduction in public health expenditure and saved human lives.

DATA AND INFORMATION ON ZOONOTIC DISEASES

Good quality data are essential for formulating policies and programmes that support the sustainable development of the livestock sector. In particular, the ability to measure the returns on investments made for the containment and management of such zoonotic diseases depends on the availability of data and information on:

- the incidence and prevalence of zoonotic diseases by livestock production system (e.g. intensive vs. semi-intensive vs. extensive);
- the use of antibiotics in livestock, disaggregated by production system;
- the incidence and prevalence of zoonotic diseases in humans, by category of people (e.g. farmers vs. market operators vs. consumers);
- the use of antibiotics and antimicrobial resistance in humans, by category of people;
- the reduction in the quantity and value of livestock production due to zoonoses, for example because of death and morbidity in animals; the reduction in labour productivity (zoonotic diseases can affect workforce in any sector of the economy); and the value of private and public resources used to deal with zoonoses, preventing their allocation for more productive purposes;

- the causes of zoonotic disease emergence and spread, which include inadequate vaccination coverage, inefficient biosecurity and biosafety measures, and lack of advocacy. Causes of AMR, for example, include non-therapeutic usage of antibiotics in animal production. These causes should be the target and focus of policy actions; as investing resources to measure zoonoses and AMR, without information on their root causes, is of little help for decision makers.
- the feasibility – in terms of financial resources and technical competencies – of possible interventions to tackle the root causes of the emergence and spread of zoonoses and of livestock-driven AMR. This information helps identify actionable interventions and estimate their different returns, i.e. to allocate available resources to maximise the benefits for society.

In Ethiopia, stakeholders have identified a multitude of zoonotic diseases that affect the country. The first five priority diseases are rabies, echinococcosis, anthrax, brucellosis, and leptospirosis (Pieracci *et al.*, 2016). The second tier of priority diseases includes Q fever, salmonellosis, bovine tuberculosis (bTB), leishmaniosis, cysticercosis (taeniasis), toxoplasmosis, and listeriosis (Feed the Future, 2016). Stakeholders also included anti-microbial resistance in pathogens due to the potential transmission of AMR microbes from livestock to humans (FAO, 2017). The Ministry of Agriculture and Livestock and the Ministry of Health are in charge of formulating policies and programmes on zoonoses and AMR. Obviously, they must rely on data and information from multiple sources to be able to formulate sound policies and programmes.

The Livestock Health and Feed Regulatory services of the Ministry of Agriculture and Livestock has access to two data reporting systems. These are the *Disease Outbreak and Vaccination Reporting* (DOVAR) and the *Animal Disease Notification and Investigation System* (ADNIS) that local authorities use to transmit information on animal diseases to the central government, including type of disease, location, numbers of animals affected (see Appendix D1 for lists of reportable diseases). ADNIS is for immediate event-based reporting, while the DOVAR is monthly. Not all zoonotic diseases in animals are notifiable – including bovine tuberculosis, brucellosis and salmonellosis – and many are not reported. Both ADNIS and DOVAR do not include information on the number of humans affected by the zoonosis for reportable diseases such as anthrax. The lack of consistency in the regularly gathered information makes it challenging for the Ministry to estimate the incidence and prevalence of zoonotic diseases with accuracy. In addition, when information on zoonotic diseases is available, it is not necessarily accurate, complete and/or on-time (Bahiru *et al.*, 2016; MoH, 2015). At the national level, disease outbreak reporting rate is still below the minimum requirements of the OIE (MoA, 2012). Under-reporting is particularly high in pastoral and agro-pastoral settings as livestock disease reporting system is constrained by lack of trained manpower, irregular reporting, poor recording and documentation and poor infrastructures (Zeryehun and Alemayehu, 2013). Widespread distribution of bovine brucellosis has been observed in Ethiopia with low prevalence in cattle kept under traditional husbandry (1.6–3.2 percent) and high prevalence in intensive dairy farming systems in peri-urban and urban areas

(~18–22 percent) (Tschopp *et al.*, 2013), respectively, but the disease is not well reported in both animals and humans. Zoonotic diseases that are not currently reported but are routinely investigated at abattoirs are substantially underestimated. For instance, Biffa *et al.* (2010) show that a high proportion (72 percent) of lesioned carcasses identified by detailed abattoir inspection procedures are not detected by the routine abattoir inspection. The latter procedure involves only visual examination and palpation of organs such as the liver and kidneys and palpation and incision of tracheobronchial, mediastinal and precrural lymph nodes, and the lungs while the former involves both visual examination and palpation of many organs and laboratory analysis.

The Ministry of Health sources data and information on zoonotic diseases in humans largely from the Integrated Disease Surveillance and Reporting System (IDRS), which includes both an event-based reporting system and a periodic routine reporting system. Through IDRS, local authorities gather and report information on some zoonotic diseases in humans (see Appendix D2). However, on several occasions financial and human constraints prevent local officers from duly reporting on all zoonotic diseases, which reduces the information base for the Ministry of Health. One of the reasons is that some zoonotic diseases, while badly affecting livestock, do not rank among the most important diseases for human beings.

As to AMR, Ethiopia prepared and implemented a National Strategy for the Prevention and Containment of Antimicrobial Resistance since 2011 though it focuses more on public health and less on AMR due to livestock production and environmental contamination. The 2009 national AMR baseline situation assessment (DACA, 2009) documented the review of 10 000 culture and sensitivity tests from across the country over a five-year period. The assessment revealed that most microorganisms that commonly cause infections in humans and animals showed a considerable degree of resistance to commonly used first-line antimicrobials. Evidences of misuse of antimicrobials by health care providers, unskilled practitioners, and animal husbandry and drug users abound (FMHACA, 2015).

Finally, even when data on the prevalence and incidence of zoonotic diseases are available, including both in animals and humans, there is no integrated information system in place that estimates their impact on society, such as on livestock production and labour productivity. For example, data are not easily available to assess the quantity and value of milk production lost due to brucellosis, or on the financial resources households and the government allocate to deal with zoonotic tuberculosis.

Given the current information system, the ministries in charge of livestock and public health are not in a position to generate accurate estimates of the incidence and prevalence of zoonoses and livestock-driven AMR or demonstrate the returns of programmes and investments for their management and control. This prevents the ministries from creating the necessary partnership between the government and citizens to effectively address issues that interweave public and private dimensions. The government, therefore, faces what is here defined as the “zoonotic disease and AMR information trap”. As there is little robust evidence to quantify the negative impacts of zoonotic diseases and AMR on society, stakeholders find it hard to sufficiently demonstrate the returns of programmes and investments that tackle zoonoses and AMR. This in turn makes it difficult to secure resources to tackle zoonotic diseases and AMR, and create the necessary partnerships between the government and the governed to address issues that cross all sectors of society.

In order to estimate the monetary impact of zoonoses on society, therefore, the Africa Sustainable Livestock 2050 initiative (ASL2050), under the guidance of a National Steering Committee first developed a methodology to estimate the monetary impact of zoonoses on society and then developed and implemented an expert elicitation protocol to assemble the required data and information. As the livestock sector in Ethiopia is heterogeneous, it was agreed to start designing and testing the methodology and protocol for two different livestock commodities, four zoonotic diseases and AMR. The two livestock commodities are cattle dairy and beef, while the four zoonotic diseases are bovine tuberculosis, brucellosis, salmonellosis and anthrax (see Box 5.1).

BOX 5.1. Cattle production systems, bovine tuberculosis, brucellosis, salmonellosis and anthrax

Cattle production is one of the main agricultural industries in Ethiopia. Livestock production as a whole contributes about 45 percent to agricultural GDP (cattle being the most important generator). The country produces over 3.8 billion litres of milk and ~1 million tonnes of beef per year valued at USD 2.5 billion and USD 5.1 billion, respectively. Five distinct cattle production systems prevail in Ethiopia: mixed crop-livestock (dairy and beef), pastoral/agro-pastoral (dairy and beef), urban/peri-urban (dairy and beef), commercial dairy, and commercial beef (feedlot) systems. The dairy sector is a major source of employment in rural areas, with the traditional production systems (mixed crop-livestock and pastoral/agro-pastoral systems) being pervasive and producing about 96 percent of milk in the country.

Bovine tuberculosis (bTB) is a chronic infectious disease in animals and humans caused by *Mycobacterium bovis (M. bovis*) of the *M. tuberculosis* complex. It is widely distributed throughout the developing world. In humans, tuberculosis caused by *M. tuberculosis* as well as by *M. bovis* has become increasingly important due to its association with HIV/AIDS. Symptoms in humans include fever, weight loss, night sweats, and in the most common form of pulmonary tuberculosis, coughing and bloodstained sputum. In animals, the clinical signs are coughing, dyspnoea, gastrointestinal problems, bone deformation, and emaciation. Diagnostic methods include direct staining of tissue, sputum or other secretions, bacterial culturing, or DNA amplification by PCR. The intradermal tuberculin test is the main diagnostic tool used in control programmes of bTB. The principal route of human infection with *M. bovis* is by ingestion of contaminated products such as infected milk. The economic impacts of bTB in humans result from treatment costs while in livestock economic impacts are related to production losses, e.g. reduced milk yield, weight loss, impaired draught power; and the cost of surveillance and control programs, e.g. complete or partial condemnation of carcasses, animal culls, and trade restrictions.

Brucellosis is a highly infectious, chronic disease in livestock and humans caused by *Brucella* bacteria. The major clinical signs in cattle are repetitive abortions, and the main symptoms in humans are a profuse undulant fever with muscle and bone pain. The disease can be detected through cell staining, serological tests or bacterial culture. Brucellosis transmission from cattle to humans is usually from ingesting unpasteurised dairy products or raw meat, and direct contact with infected blood or other secretions. Animal to animal transmission is usually from direct contact with infected bodily secretions. The economic consequences of brucellosis are a significant reduction in livestock productivity due to decreased milk production because of appetite loss, loss of young, as well as the impact of severe trade restrictions imposed on affected farms and countries.

Salmonellosis is a foodborne zoonotic disease caused by Salmonella bacteria. It is transmitted both from animals to humans and vice versa. The symptoms in humans include acute abdominal pain, diarrhoea, nausea, fever, and sometimes vomiting. When present, clinical signs in animals are similar – diarrhoea, fever and vomiting – but infection in animals is often asymptomatic. Diagnosis is based on clinical signs and isolation of the pathogen from the faeces, blood or tissues of affected animals or humans. Transmission from animals to humans is usually through contaminated food products of animal origin such as meat and eggs, or contaminated plant material such as lettuce. The socioeconomic impacts both in livestock (mainly in young stock) and in humans arise from losses in productivity due to sickness. Other economic impacts include public sector costs resulting from the investigation of cases, and healthcare costs.

Anthrax is a fatal disease of cattle, goats, sheep and horses caused by *Bacillus anthracis*, toxin-producing, encapsulated, aerobic or facultative anaerobic organisms. It also occurs in humans and wildlife. Human infection is by contact with infected animals or spore contaminated animal products through skin lesions (most common), ingestion and inhalation. Skin infection may be transmitted from person to person by direct contact or fomites. Ingestion and inhalation anthrax are not transmitted from person to person. Anthrax spores have been prepared in very finely powdered form to be used as agents of warfare and bioterrorism and increased fear of this pathogen. *B. anthracis* produces spores, which can survive for years in dried skins and fleeces. They are not destroyed by boiling, freezing, 5% carbolic lotion, or by stomach acid. Symptoms for the external form include malignant pustules. After inoculation of a small wound, a red, inflamed swelling appears, which grows to a size that would cover half the face or the breadth of an arm. The internal form may include pneumonia with haemorrhages (when the spores are drawn into the lungs) or ulcers of the stomach and intestines and gangrene of the spleen (when they have been swallowed). Diagnosis is by gram stain and culture. Treatment is with ciprofloxacin or doxycycline. Vaccines for animals and humans are available for prevention.

METHODOLOGY TO ESTIMATE MONETARY IMPACT OF ZOONOTIC DISEASES IN LIVESTOCK AND PUBLIC HEALTH

The monetary impact of the priority zoonotic diseases on society was determined as the sum of the losses in value (USD) due to morbidity and mortality in infected animals and humans over the period of one year as follows:

Livestock and Public Health USD Impact

=

Value of animals lost (mortality)

+

Value of production decrease in infected animals

+

Social cost of mortality in humans

+

Social cost of morbidity in humans

The methodology used to calculate the value of the different variables in the equations is briefly discussed below both for animals and humans. Detailed explanation and data sources are described in the Annexes (Annex D3 to D7).

Cattle

In cattle systems, an infected animal will either die, be culled or salvage slaughtered or survive but suffer from production decrease. Both the value of the animals lost as well as the decreased production should be estimated to calculate the total loss due to occurrence of a disease in animals. Figure 5.1 depicts a flowchart that highlights the different cattle-related variables the protocol data allows estimating, including the value of animals lost due to the disease (in red) and the value of production decrease in survivors (in dark orange). The cost of treating sick animals are not accounted for as data on farmers' expenses on veterinary goods and services by disease are not available. However, a small proportion of farmers have usually access to animal health services and their expenses on veterinary services are typically negligible (CAHI, 2015; MAAIF, 2016). The value of animals lost was calculated as the sum of:

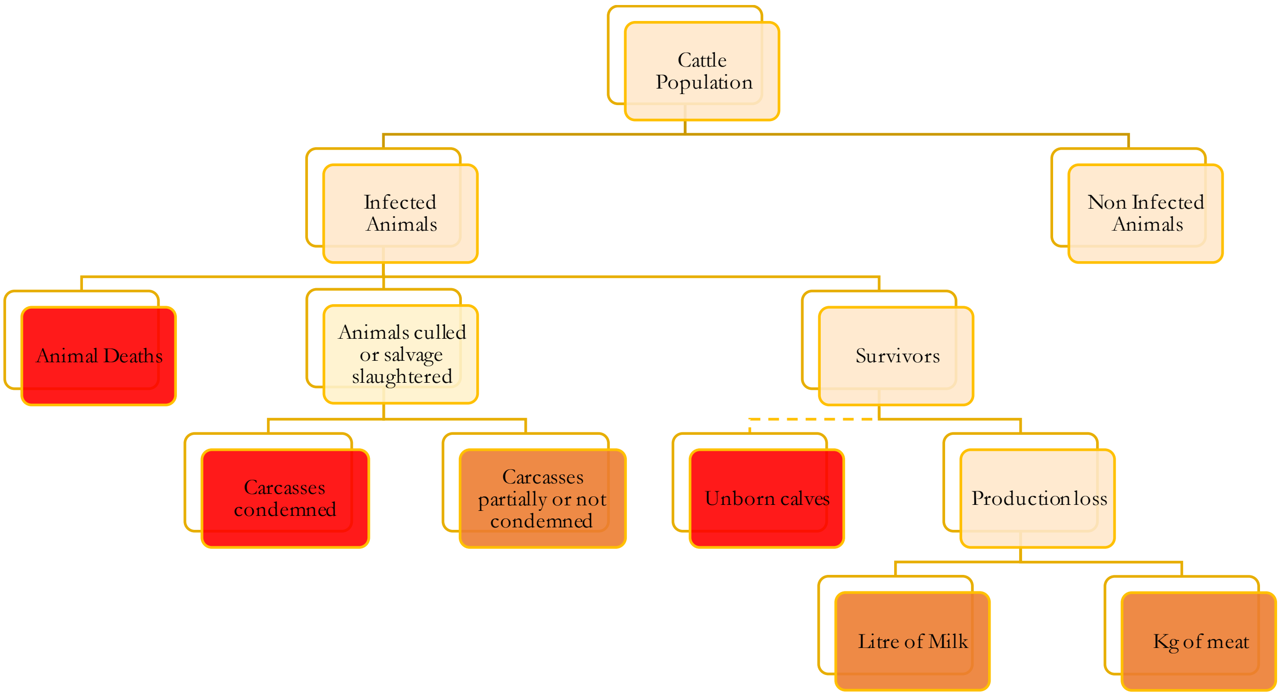
- the number of animal deaths multiplied by the farm-gate price of an adult animal;
- the number of carcasses fully condemned multiplied by the farm-gate price of an adult animal;
- the number of unborn calves, due to fertility reduction in survivors, multiplied by the farm-gate price of a young animal.

The value of production decrease in survivors was calculated as the sum of:

- the number of carcasses partially or not condemned animals multiplied by the farm-gate price of an adult animal discounted by 50 percent;

- The number of lost lactation periods – which is equal to the number of unborn calves, or the number of cows infected by the disease and affected by fertility loss – multiplied by the average litre per lactation and by the market price of one litre of milk;
- The number of cows infected by the disease and not affected by fertility loss, multiplied by the average reduction in lactation milk production in litres and by the market price of one litre of milk;
- The number of survivors multiplied by the average dressed weight lost and by the market price of one kg of beef.

FIGURE 5. 1. Cattle-related variables in the USD loss calculation



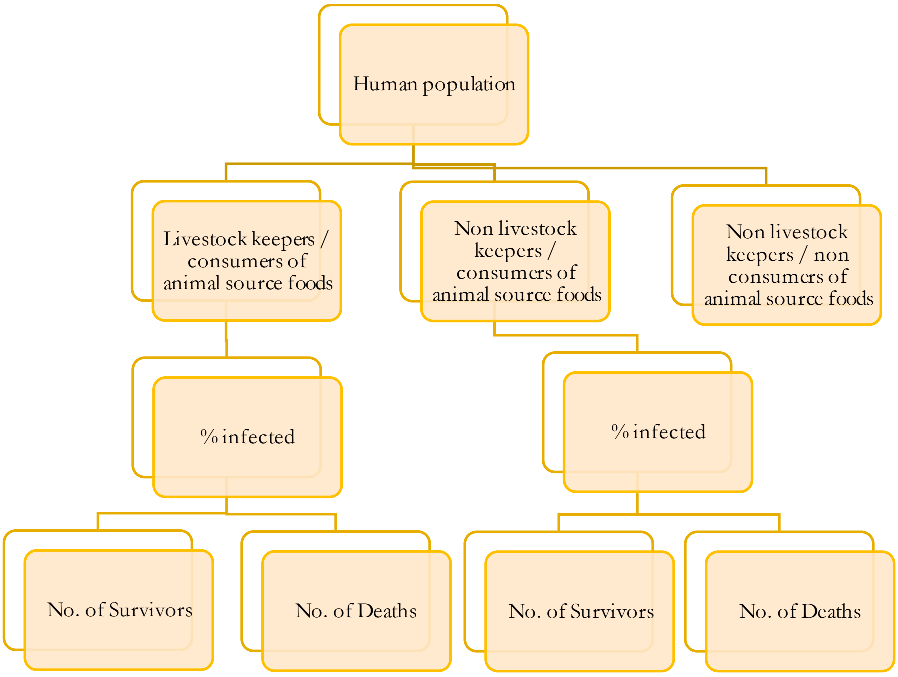
Humans

Zoonotic diseases are transmitted from animals to humans through direct and indirect contact, via vectors and through food consumption. Different categories of people, therefore, face different risks of contracting zoonotic diseases[16]. To estimate the impact of morbidity and mortality due to zoonotic diseases in humans, we have split the population at risk in three broad groups: (i) non-livestock keepers and non-consumers of animal source foods; (ii) non-livestock keepers and consumers of animal source foods; (iii) livestock keepers and consumers of animal source foods.

[16] *Occupations at higher risk of infection include also veterinarians, culling personnel, slaughterhouse workers and all that are in direct contact with live animals and animal material. It is however not possible to obtain good information on the number of such workers, let alone knowing how many of them are already included in the other two categories. We assume that the majority are already living in a livestock keeping household or are consumers of animal source foods.*

Figure 5.2 depicts a flowchart that highlights the different human-related variables the protocol data allows estimating, including the number of infected people, as well as survivors and deaths, by category of people. We assume there are no infections among the non-livestock keepers and non-consumers of animal source foods.

Figure 5. 2. Human related variables in the USD loss calculation



To attach value to the impacts of mortality and morbidity in humans, we estimated the willingness to pay for a disability adjusted live year (Box 5.2). The economic cost of the zoonotic disease was calculated as the sum of:

- The total number of survivors multiplied by the average number of working days lost (proxy for duration of the disease) expressed in years and the DALY disability weight measuring the severity of the disease[17] and by the society's willingness to pay for one year of healthy life.
- The total number of deaths multiplied by the average number of years of life lost – given by the difference between life expectancy and average age at infection – and society's willingness to pay for one year of healthy life.

[17] *A DALY disability weight measures the severity of a disease and can take values from 0 to 1, zero meaning completely healthy and 1 meaning death. DALY weights by disease are provided by the WHO Global Burden of Disease.*

BOX 5.2. The willingness to pay for a disability-adjusted life year

To estimate the social cost of the disease, we estimated the Disability-Adjusted Life Years (DALY), a method used by the World Health Organization (WHO) to quantify the burden of disease from mortality and morbidity[18]. One DALY can be interpreted as one year of healthy life lost. It is a health gap measure that combines both time lost due to premature mortality and the time spent in sickness. For each disease, a disability weight is attached to the DALY, which measures the severity of a disease during sickness.

We calculated the willingness to pay for a DALY to arrive at its value in monetary terms. We started from the yearly value of a statistical life calculated for the United States. The value of a statistical life has been calculated at USD 9.5 million by the US Department of Human and Health Services and at USD 9.6 million by the US Department of Transportation (DOT, 2016), and is used to value the reduction of fatalities and injuries. To translate the latter into a yearly value, we used the OECD's discounting approach (Quinet *et al.*, 2013):

$$VSL = \sum_{t=0}^{T} VSLY * (1 + \delta)^{(-t)}$$

where VSL is the value of statistical life, VSLY the yearly value, t is a discrete variable going from the present (0) to the expected end of the individual's life (T) and δ is the discount rate. Using a discount rate of 3 percent (ERG, 2014) and the expected life span of 79 years (World Bank, 2017), we calculated around 400 000 USD as a yearly value of a statistical life in the US, that will represent society's willingness to pay for a healthy year of life or for a DALY. To translate this value in the Ethiopian context, we used the benefit transfer methodology presented in Hammitt and Robinson (2011), which takes into account the differences in real GDP per capita, as measured in purchasing power parity (PPP) and the elasticity of the willingness to pay for risk reduction with respect to income (see Annex D6 and D7):

$$VSLY_{Country} = VSLY_{US} * \left(\frac{GDP\ per\ capita\ in\ PPP_{Country}}{GDP\ per\ capita\ in\ PPP_{US}}\right)^{elasticity}$$

AN EXPERT ELICITATION PROTOCOL FOR ASSEMBLING INFORMATION ON ZOONOSES AND AMR

When there is insufficient or unreliable data, or when data is either too costly or physically impossible to gather, expert elicitations are a promising tool to obtain good quality information. They are a scientific consensus methodology to get experts' judgements on the distribution of variables and parameters of interest, including those whose value is either unknown or uncertain. An important feature of expert elicitation is that experts not only provide information on the unmeasured, but can also suggest values that differ from those in the scientific literature or from official statistics (the official knowns), for example if they believe some causal linkages are underestimated or some issues are underreported. The public sector, but more frequently private parties, have used expert elicitations for a multitude of purposes, such as to investigate the nature and extent of climate change; the cost and

[18] *http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/*

performance of alternative energy technologies; and the health impact of air pollution (Morgan, 2014). The World Health Organization has used an expert elicitation to estimate the global burden of foodborne diseases (WHO, 2015).

The expert elicitation protocol developed to generate the data and information needed to estimate the monetary impact of zoonotic diseases included a variety of sections and questions as follows:

- For animals and for each zoonotic disease, the protocol included questions on the number of cases; number of deaths; number of salvage slaughtered; number of culls; number of carcasses condemned; production lost due to morbidity; and underreporting. Questions were asked by the different cattle production systems, including dairy commercial, feedlot, urban/peri-urban (dairy and beef), mixed crop-livestock, and pastoral/agro-pastoral systems as defined and quantified by stakeholders using available data and information.
- For humans and for each zoonotic disease, the protocol included questions on the number of cases; the average age of the person affected; the number of deaths; and the number of working days lost per case. Questions were asked by different category of people, including livestock keepers and consumers.
- The protocol did not collect price data, necessary to estimate the monetary values of the cost of any disease. For livestock, we sourced price data for live animals and animal products from the Central Statistical Agency, the Ethiopian Customs and Revenue Authority, and Bureau of Trade of Addis Ababa City Administration. For humans, we estimated the yearly value of statistical life to proxy the willingness to pay (WTP) for a so-called disability-adjusted life year (DALY) as described in Box 5.2.
- For antimicrobial resistance, the protocol included four questions: the proportion of cattle farms using antibiotics, by production system; trends on use of antibiotics in cattle farms, by production system; trends in antimicrobial resistance in humans; and experts' concerns about antimicrobial resistance in humans.

We used a snowball sampling approach to identify the experts to interview, with representatives of the ASL2050 Steering Committee initially suggesting names of renowned national experts, including two animal and two human health experts for each zoonotic disease. We then asked these experts to recommend additional experts to interview, and so on. When this snowball approach occasionally interrupted, we retook the expert unveiling process. The final sample comprised 42 experts, including 28 animal health experts and 14 human health experts. The sample is biased towards animal health experts, one of the reasons being that there are few human doctors with expertise in the selected zoonotic diseases. However, animal health experts were often able to respond to human health questions as, being specialised in zoonotic diseases, they typically operate at the interface between animal and human health. We conducted the interviews in September and October 2017, analysed the data in November and validated the results with stakeholders in January 2018.

RESULTS

We validated the expert elicitation protocol data through a three-step process. First, we generated summary statistics for the key variables to estimate and reviewed them with members of the ASL2050 Steering Committee. Second, for those variables whose values were implausible, we consulted relevant literature. Finally, we presented the summary statistics and literature review at a workshop involving protocol respondents to arrive at consensus on measures of central tendency. Table 5.1 presents the reference population, prevalence and fatality rate data that were used to calculate the monetary impact of the selected zoonotic diseases on society.

TABLE 5. 1. Key protocol-variables underpinning the USD loss calculation

Type of zoonotic disease and variables	Total population		
		Humans (101 407 000)	
	Cattle	Cattle keepers	Consumers[19]
	56 682 162	70 072 237	15 109 643
Brucellosis			
Total number of cases per annum	672 594	114 387	11 332
Prevalence (cases/total population)	1.11%	0.163%	0.075%
Fatality per annum	56 652	1 521	755
Fatality rate (deaths/cases)	9.03%	1.3%	6.67%
Bovine TB			
Total number of cases per annum	3 052 600	3 929	907
Prevalence (cases/total population)	5.39%	0.006%	0.006%
Fatality per annum	319 295	761	151
Fatality rate (deaths/cases)	10.46%	19.4%	16.67%
Anthrax			
Total number of cases per annum	266 136	10 279	1 209
Prevalence (cases/total population)	0.47%	0.015%	0.008%
Fatality per annum	214 723	5 354	151
Fatality rate (deaths/cases)	80.68%	52.1%	12.50%
Salmonellosis			
Total number of cases per annum	757 551	47 834	12 088
Prevalence (cases/total population)	1.34%	0.068%	0.080%
Fatality per annum	328 611	1 675	151
Fatality rate (deaths/cases)	43.38%	3.5%	1.25%

[19] *Excluding cattle keepers*

BRUCELLOSIS

Brucellosis in cattle

Table 5.2 shows the economic impact of brucellosis measured as value of animals lost and value of production lost by production system. Brucellosis caused an estimated economic loss of 377.93 million USD per annum (expressed as PPP) in cattle despite the perceived low prevalence. The mixed crop-livestock and urban/peri-urban production systems suffer the most compared to the other production systems. The economic losses caused by the disease appear to be due more to reduced or foregone production rather than death of the infected animals. Total loss expressed as percentage of contribution of livestock to GDP and as percentage of total GDP were 1.96 percent and 0.21 percent, respectively.

TABLE 5. 2. Prevalence of brucellosis and estimates of its economic costs by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Estimated prevalence, percent	1.50	0.50	2.00	1.00	1.20	1.11
Value of animals lost (million USD PPP)	8.19	-	14.50	30.50	5.55	58.74
Value of production lost (million USD PPP)	61.46	0.28	100.73	137.24	19.42	319.18
TOTAL (million USD PPP)	69.65	0.28	115.22	167.79	24.97	377.93
Total loss, percent of livestock share in GDP[20]	0.36	0.001	0.60	0.87	0.13	1.96
Total loss, percent of GDP[21]	0.04	0.000	0.06	0.09	0.01	0.21

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 5.3 below shows the same estimates by case and as percentage of the farm-gate price of a healthy animal. The loss per case is normally higher than the price of an animal per se given the average value of production loss per head (unborn calves, milk production loss, and meat production loss) is higher than the average monetary value of an animal. In most cases, losses are not merely due to death of the infected animals but also to impaired production/reproduction, foregone production, and producers' or government's decision to salvage slaughter or cull other animals out of precaution.

The average total loss per case (PPP) and loss per case estimated as a percentage of farm-gate price of a healthy animal[22] were estimated to be USD 1 458.64 and 47.98 percent of the value of a healthy animal, respectively. Highest total losses per case happen in the intensive/semi-intensive production systems (dairy commercial, feedlot, and urban/peri-urban) compared to the extensive systems.

[20] *Contribution of livestock to GDP (PPP): $19.23 billion. (Source: Own calculation based on Behnke and Metaferia, 2011).*
[21] *The GDP (PPP) was $177.95 billion (2016 estimate). (Source: The World Bank. Available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?locations=ET)*
[22] *The average price of a healthy adult animal differs by production system*

TABLE 5. 3. Estimates of value lost per case due to brucellosis by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Average
Value of animals lost per case (USD PPP)	379.80	-	190.64	70.05	58.88	139.87
Value of production lost per case (USD PPP)	2 848.51	1 899.02	1 325.23	315.22	205.83	1 318.76
TOTAL loss per case (USD PPP)	3 228.31	1 899.02	1 515.87	385.27	264.71	1 458.64
Loss per case, percent of price of healthy animal	56.67	50.00	40.43	55.00	37.79	47.98

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Brucellosis in humans

As described above, the social cost of the disease is estimated as the sum of the cost of mortality and cost of morbidity. In particular, we estimated the impact of the disease for two sub-groups: cattle keepers who are in frequent contact with the animals and are also potentially consuming cattle source products, and individuals who are not livestock keepers but might be infected largely through consumption. Results are shown in Table 5.4 for the total population group and per case. In 2017 in Ethiopia 1 521 cattle keepers died of brucellosis, on average at age of 23.60 yrs. According to the World Bank (WB, 2017), the expected life span of an individual in the country is 65 yrs., meaning we account for 1 521 deaths * (65 –23.60) years lost all together. Hence the total social cost of brucellosis among livestock keepers in Ethiopia was estimated at 150 700 768 USD (PPP), valuing the loss of one year at 2 100 USD (the willingness to pay for one year of healthy life, i.e., the yearly value of statistical life calculated for Ethiopia). The monetary loss caused by brucellosis among consumers during the same period was 74 719 967 USD.

To put these numbers in context, Table 5.4 also shows the results as a percentage of GDP. This comparison should be regarded with caution: the GDP is an annual value, whereas mortality costs include the individual's future years remaining up to the expected end of his/her life. The total social cost of brucellosis, 225 420 735 USD (PPP), is equivalent to about 0.13 percent of the national GDP.

TABLE 5. 4. Estimates of the annual public health costs of brucellosis in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	71 060.96	35 515	106 576.17
Years lost due to morbidity (YLD)	701.32	65.72	767.04
DALYs (YLL + YLD)	71 762.27	35 580.94	107 343.21
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	150 700 768	74 719 967	225 420 735
Total social cost as percent of GDP (USD PPP)	0.09	0.04	0.13

Cost of brucellosis in animals and humans in 2017

To compare the cost of a zoonotic disease in animals and humans, we must address the fact that mortality costs consider the "loss" of future years as described above, whereas all other estimates refer to losses encountered in the reference year.

FIGURE 5. 3. USD cost of brucellosis in humans and animals (percent)

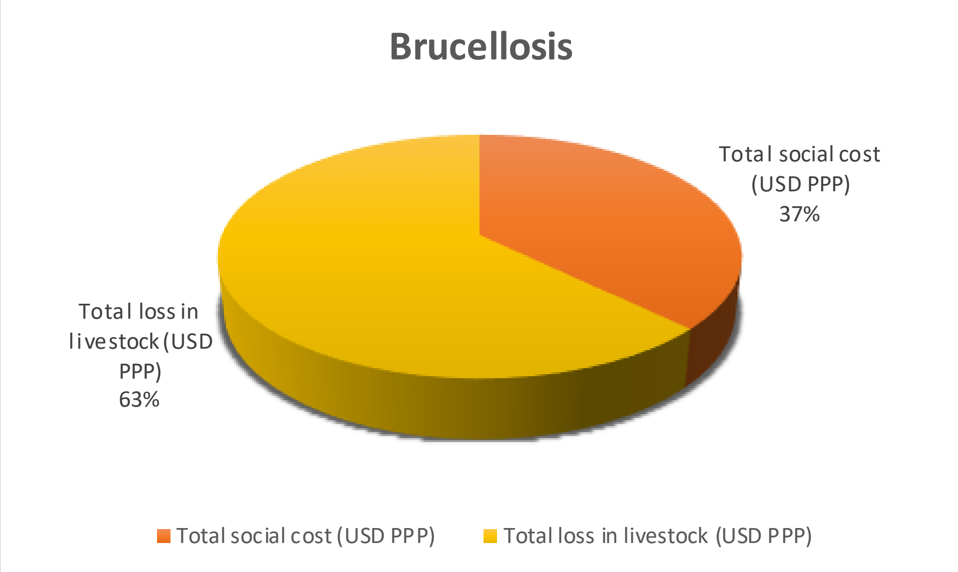


Table 5.5 presents the value of the public health costs of brucellosis for livestock keepers versus the costs for the different cattle production systems whereas Figure 5.3 shows the relative weight of total costs in humans (including consumers) and animals. The disease caused the highest losses in the mixed crop-livestock production system both in terms of social cost and losses due to animal mortality and foregone production. The loss in animals in the urban/peri-urban production system was also very high compared to dairy commercial and pastoral/agro-pastoral systems. The total social cost of brucellosis was relatively low among livestock keepers in the dairy commercial and urban/peri-urban production systems.

TABLE 5. 5. Annual costs of brucellosis in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	69 656 069	282 310	115 229 873	167 797 959	24 968 335	377 934 546
Livestock keepers (USD PPP)	4 211 414	-	5 882 896	115 241 687	25 364 770	150 700 768

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Bovine tuberculosis in cattle

Table 5.6 shows the value of animals lost and the value of production lost due to bTB by production system. There was high prevalence of the disease in the dairy commercial and urban/peri-urban production systems that usually keep exotic, grade or crossbred animals. The disease caused significant economic losses both in terms of wasted animals and foregone production. The highest loss was due to reduced and foregone production rather than to mortality. Total economic losses in the urban/peri-urban and dairy commercial systems were estimated at USD 1.5 and 1.2 billion (PPP), respectively, and ~USD 3.5 billion overall. This is a huge economic loss representing about 18 percent of the contribution of livestock to GDP and 1.96 percent of total GDP (PPP).

TABLE 5. 6. Prevalence of bovine tuberculosis and estimates of its economic costs

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Estimated prevalence, percent	30.00	3.00	20.00	4.00	1.50	5.39
Value of animals lost (million USD PPP)	292.64	225.85	358.28	244.60	22.02	917.78
Value of production lost (million USD PPP)	930.71	0.55	1 142.60	446.56	41.30	2 561.74
TOTAL (million USD PPP)	1 223.36	0.78	1 500.87	691.18	63.32	3 479.52
Total loss, percent of livestock share in GDP	6.36	0.004	7.80	3.59	0.33	18.09
Total loss, percent of GDP	0.69	0.000	0.84	0.39	0.04	1.96

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 5.7 shows estimates of losses by case and as percentage of the farm-gate price of a healthy animal. Here too, total losses per case (USD PPP) were highest in the intensive systems of dairy commercial and urban/peri-urban cattle production amounting to 2 834.93 and 1 974.43 dollars PPP, respectively. Again, most of the losses were due to impaired and/or foregone production. The highest loss expressed as percentage of farm-gate price of a healthy animal (76.67 percent) was estimated in the pastoral production system. The overall loss per case was roughly 52 percent of the value of a healthy animal.

TABLE 5. 7. Estimates of values lost per case due to bovine tuberculosis by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Average
Value of animals lost per case (USD PPP)	678.15	253.20	471.33	140.41	186.80	345.98
Value of production lost per case (USD PPP)	2 156.77	621.62	1 503.10	256.34	350.25	977.62
TOTAL loss per case (USD PPP)	2 834.93	874.82	1 974.43	396.75	537.05	1 323.60
Loss per case, percent of price of healthy animal	49.76	23.03	52.66	56.64	76.67	51.75

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Bovine tuberculosis in humans

Table 5.8 gives estimates of the public health cost of bTB in Ethiopia. The estimated total public health costs (USD PPP) of the disease among livestock keepers in all production systems and consumers were USD 74 740 696 and 12 781 597, respectively. This amounted to 0.05 percent of total GDP.

TABLE 5. 8. Estimates of the annual public health costs of bovine tuberculosis in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	35 530.48	6 045.37	41 575.85
Years lost due to morbidity (YLD)	60.33	41.11	101.44
DALYs (YLL + YLD)	35 590.81	6 086.47	41 677.28
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	74 740 696	12 781 597	87 522 293
Total social cost as percent of GDP (USD PPP)	0.04	0.01	0.05

Cost of bovine tuberculosis in animals and humans in 2017

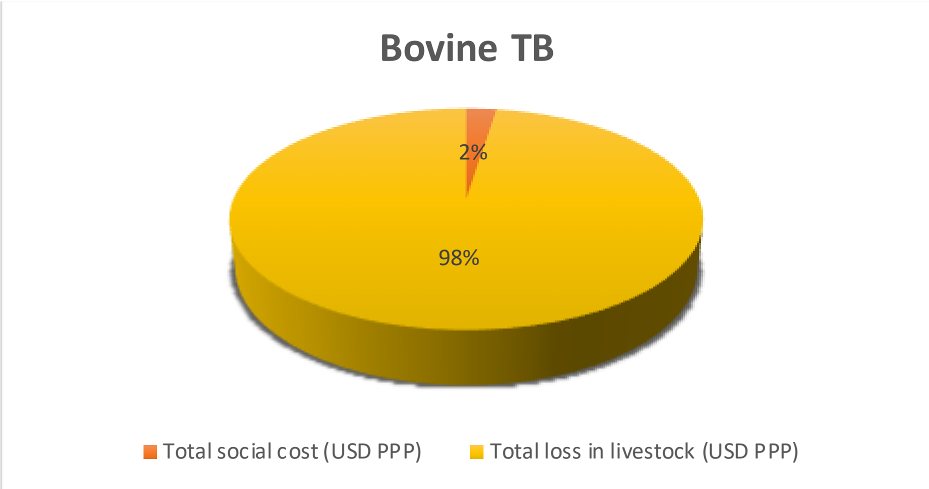
Table 5.9 compares the public health costs of bTB in livestock keepers to costs for the cattle sector by production system. Urban/peri-urban and commercial dairy sectors suffered the most in terms of loss incurred due to death of animals, reduced and foregone production amounting to USD 1 500 876 724 and 1 223 364 444 (PPP), respectively. The public health costs were higher in mixed crop-livestock and pastoral/agro-pastoral cattle production systems, largely due to their sheer sizes. Figure 5.4 presents the shares of the monetary costs of bTB in animals and humans (livestock keepers and consumers). The estimated monetary cost of the disease in animals accounted for 98 percent of the total loss it caused.

TABLE 5. 9. Annual costs of bovine tuberculosis in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	1 223 364 444	780 309	1 500 876 724	691 183 046	63 321 549	3 479 526 073
Livestock keepers (USD PPP)	2 090 959	-	2 903 802	57 155 167	12 590 767	74 740 696

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

FIGURE 5. 4. USD cost (percent) of bovine tuberculosis in cattle and humans



ANTHRAX

Anthrax in cattle

Table 5.10 shows the value of animals lost and the value of production lost by production system. Even though the overall prevalence of anthrax based on expert opinions was generally low, the total economic cost of the disease reached USD 162.86 million (PPP) of which two-third was from the mixed-crop livestock system. Much of the loss (~90 percent) was attributed to the immediate death of the affected animals. The total losses as percent of contribution of livestock to GDP and total GDP were 0.85 percent and 0.09 percent, respectively.

TABLE 5. 10. Prevalence of anthrax and estimates of its economic costs

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Estimated prevalence, percent	0.10	0.10	0.20	0.50	0.50	0.47
Value of animals lost (million USD PPP)	8.19	0.11	28.50	91.52	16.51	144.85
Value of production lost (million USD PPP)	-	-	-	15.25	2.75	18.00
TOTAL (million USD PPP)	8.19	0.11	28.50	106.78	19.27	162.86
Total loss, percent of livestock share in GDP	0.04	0.001	0.15	0.56	0.10	0.85
Total loss, percent of GDP	0.005	0.000	0.02	0.06	0.01	0.09

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 5. 11. Estimates of value lost per case due to anthrax by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Average
Value of animals lost per case (PPP)	5 697.01	3 798.05	3 749.56	420.30	420.30	2 817.04
Value of production lost per case (USD PPP)	-	-	-	70	70	28.02
TOTAL loss per case (USD PPP)	5 697.01	3 798.05	3 749.56	770.55	770.55	2 845.06
Loss per case, percent of price of healthy animal	100	100	100	70	70	88

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Table 5.11 shows losses per case of anthrax and as percent of the farm-gate price of a healthy animal. In the intensive/semi-intensive systems, occurrence of the disease entails total loss of the value of the infected animals. Some fraction of the value is usually recovered in the form of salvage slaughtering among livestock keepers in the mixed crop-livestock and pastoral/agro-pastoral production systems despite apparent health risks.

Anthrax in humans

The social costs of anthrax measured as DALYs were 187 596.58 and 6 045.57 among livestock keepers and consumers, respectively, whereas the corresponding monetary costs (USD PPP) were 393 952 817 and 12 695 693 USD among the two risk groups, respectively (Table 5.12). Overall, the total social cost of anthrax is 406 648 510 USD (PPP) amounting to 0.23 percent of GDP (PPP).

TABLE 5. 12. Estimates of the annual public health costs of anthrax in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	187 595.65	6 045.37	193 641.02
Years lost due to morbidity (YLD)	0.93	0.20	1.13
DALYs (YLL + YLD)	187 596.58	6 045.57	193 642.15
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	393 952 817	12 695 693	406 648 510
Total social cost as percent of GDP (USD PPP)	0.22	0.01	0.23

Cost of anthrax in animals and humans in 2017

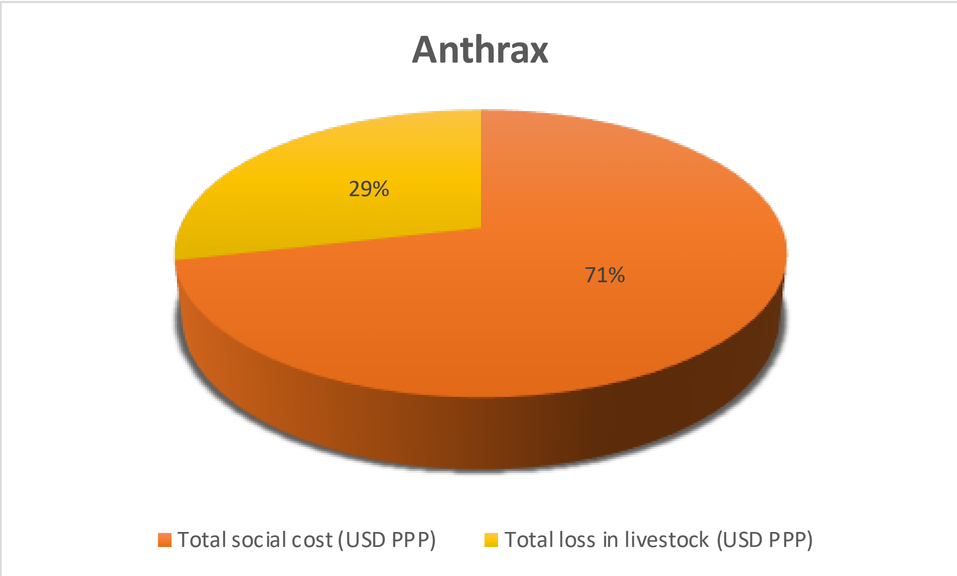
Table 5.13 compares the total public health and livestock-related monetary costs (USD PPP) caused by anthrax. These social costs were the highest in the mixed crop-livestock system followed by the pastoral/agro-pastoral system. Comparing the total public health costs (in both livestock keepers and consumers) to the value of loss in animals showed that more than two-thirds of the economic impact of anthrax was on public health (Figure 5.5).

TABLE 5. 13. Annual costs of anthrax in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	8 194 832	112 924	28 502 608	106 780 519	19 271 776	162 862 659
Livestock keepers (USD PPP)	2 385 745	-	7 604 710	339 974 415	43 987 947	393 952 817

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Figure 5. 5. USD cost (percent) of anthrax in humans and animals.



SALMONELLOSIS

Salmonellosis in cattle

The estimated prevalence of salmonellosis was relatively high in the commercial dairy and urban/peri-urban production systems whereas it was low in the mixed crop-livestock production system. The value of animals lost and the value of production lost due to salmonellosis were thus different in the different production systems as indicated in Table 5.14. The total economic impacts of the disease, in fact, was highest in the urban/peri-urban and the mixed crop-livestock systems at ~242 and ~229 million USD (PPP), respectively. The total loss as percentage of the contribution of livestock to GDP and total GDP were 3.29 percent and 0.36 percent, respectively.

TABLE 5. 14. Prevalence of salmonellosis and estimates of its economic costs

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Estimated prevalence, percent	3.50	1.50	3.00	1.00	2.00	1.34
Value of animals lost (million USD PPP)	82.33	0.56	214.11	152.14	27.61	477.17
Value of production lost (million USD PPP)	21.45	0.36	27.83	76.27	29.58	155.50
TOTAL (million USD PPP)	103.78	0.92	241.95	228.81	57.19	632.68
Total loss, percent of livestock share in GDP	0.54	0.005	1.26	1.19	0.30	3.29
Total loss, percent of GDP	0.06	0.001	0.14	0.13	0.03	0.36

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

The value of animals lost, value of production lost, and the total loss as percentage of the farm-gate price of a healthy animal expressed on per case basis are given in Table 5.15. The economic cost of salmonellosis due to mortality was significantly higher than the loss due to impaired production and reproduction across all production systems except in the pastoral/agro-pastoral system where the impact due to animal death and impaired and/or foregone production were comparable. The total losses per case in the intensive systems were similar (USD PPP 2 121.98, 2 078.08, and 2 061.47 for urban/peri-urban, feedlot and dairy commercial systems, respectively). In the mixed crop-livestock system, three-quarters of the value of infected animals (as percentage of farm-gate price of a healthy animal) was lost. On the other hand, a little more than a third of the animals' value was lost in the dairy commercial system. Overall, salmonellosis caused about 55 percent loss in the value of sick animals across all production systems.

TABLE 5. 15. Estimates of value lost per case due to salmonellosis by production system

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Average
Value of animals lost per case (USD PPP)	1 635.32	1 266.02	1 877.83	350.25	175.67	1 061.02
Value of production lost per case (USD PPP)	426.15	812.07	244.15	175.12	188.17	369.13
TOTAL loss per case (USD PPP)	2 061.47	2 078.08	2 121.98	525.37	363.84	1 430.15
Loss per case, percent of price of healthy animal	36.19	54.71	56.59	75.00	51.94	54.89

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

Salmonellosis in humans

The public health cost of salmonellosis among livestock keepers and consumers was estimated to be USD (PPP) 161 033 995 and 10 503 000, respectively (Table 5.16). The total public health cost of salmonellosis, 171 536 995 USD (PPP), was equivalent to 0.10 percent of the national GDP.

TABLE 5. 16. Estimates of the annual public health costs of salmonellosis in Ethiopia

	Livestock keepers	Consumers	Total
Years of life lost due to mortality (YLL)	76 629.74	4 987.69	81 617.43
Years lost due to morbidity (YLD)	53.11	13.74	66.85
DALYs (YLL + YLD)	76 682.85	5 001.43	81 684.28
Willingness to pay for one year of healthy life (USD PPP)	2 100	2 100	2 100
Total social cost (USD PPP)	161 033 995	10 503 000	171 536 995
Total social cost as percent of GDP (USD PPP)	0.09	0.01	0.10

Cost of salmonellosis in animals and humans in 2017

Table 5.17 compares the total cost (USD PPP) of salmonellosis in humans and animals. The public health costs of the disease in humans and losses in animals were the highest in the mixed crop-livestock systems followed by the pastoral/agro-pastoral systems. These costs were relatively low for the urban/peri-urban and dairy commercial systems. They were inestimable for the feedlot system. Much of the total cost of salmonellosis, about four-fifths of all costs, was due to its negative impacts on cattle production and productivity rather than on public health (Figure 5.6).

Figure 5. 6. USD cost (percent) of salmonellosis in animals and humans

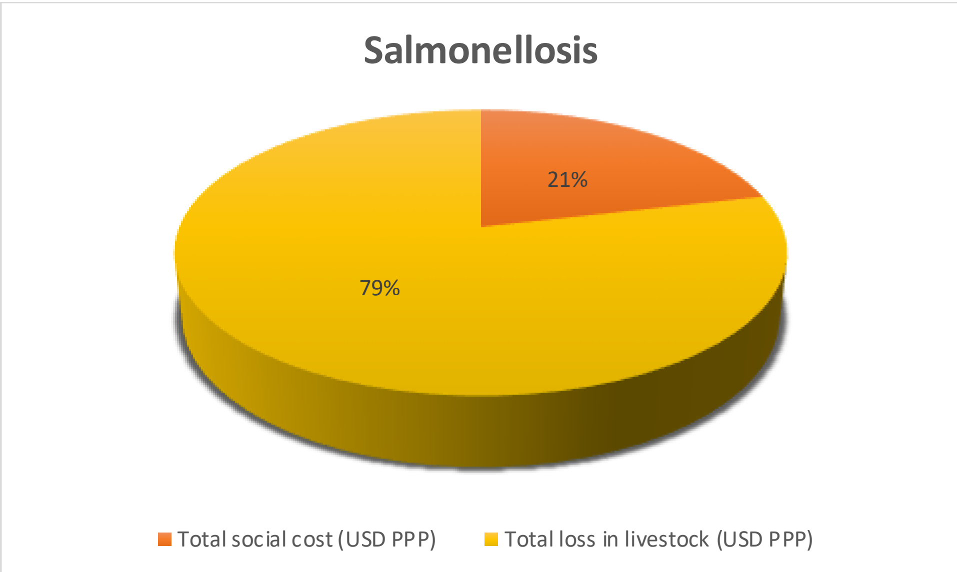


TABLE 5. 17. Annual costs of salmonellosis in humans and cattle in different production systems

	Dairy C.	Feedlot	U/P-U	Mixed	P/A-P	Total
Animals (USD PPP)	103 785 702	926 787	241 956 389	228 815 398	57 198 313	632 682 589
Livestock keepers (USD PPP)	4 178 398	-	8 697 139	114 206 417	33 952 041	161 033 995

Dairy C. = Commercial Dairy; Feedlot = Beef Feedlot; U/P-U = Urban/Peri-urban; Mixed = Mixed Crop Livestock; P/A-P = Pastoral/Agro-pastoral

DISCUSSION

Prevalence and fatality

Prevalence estimates of the four zoonotic diseases in animals along the different production systems were generally within previously reported levels. Prevalence estimates abound for brucellosis and bovine tuberculosis. They are scant for anthrax and salmonellosis in animals, though estimates for salmonellosis in cattle products (mainly milk and meat) are numerous.

The overall brucellosis prevalence estimate of 1.11 percent in the current study was lower than many reports coming from any of the production systems. Asmare *et al.* (2014) reported a prevalence of 4 percent (ranging between 1.5 percent and 10 percent) for intensive dairy production systems. For mixed crop-livestock system, brucellosis prevalence estimates vary widely with ranges between 0 percent and 50 percent and average of 7.2 percent (Jergefa *et al.*, 2009; Tolosa *et al.*, 2010; Megersa *et al.*, 2012; Girma, 2012; Tadesse, 2016). In pastoral/agro-pastoral system, the reported average prevalence is 7.2 percent ranging between 0 percent and 22 percent (Dinka and Chala, 2009; Megersa *et al.*, 2011; Tschopp *et al.*, 2015; Tadesse, 2016). Estimates of cattle seroprevalence in the world range between 3 and 15 percent (Bosilkovski, 2015).

The overall prevalence level of 5.39 percent for bTB found in this study is in line with the national estimate of 5.8 percent (Sibhat *et al.*, 2017) though available estimates vary widely. In the urban/peri-urban dairy systems, prevalence level ranging from 8.14 to 30 percent was reported (Ameni *et al.*, 2003b; Firdessa *et al.*, 2012; Disassa *et al.*, 2016). Bovine tuberculosis is also widely prevalent in the traditional production systems of mixed crop-livestock with values ranging between 1.6 percent and 22.2 percent (Vordermeier *et al.*, 2012; Tschopp *et al.*, 2013; Tschopp *et al.*, 2015) and pastoral/agro-pastoral with values from 0.6 to 4.4 percent (Tschopp *et al.*, 2010; Gumi *et al.*, 2011). It should be noted that clinical signs of tuberculosis in cattle are variable depending on the location and extent of the lesions. Even with advanced disease, visible signs are frequently absent. General findings include anorexia, dyspnea, weight loss, weakness, and low-grade fluctuating fever. Often the main sign of tuberculosis is emaciation, despite adequate nutrition and care (Salman and Steneroden, 2015). Thus, the reported prevalence rates are possibly an under estimation of the true disease prevalence.

The overall prevalence of anthrax found in this study (0.47 percent) is possibly on the low side but overall consistent with the available evidence. Published literatures do not report on anthrax prevalence; however, estimates calculated from case reports to the Disease Outbreak and Vaccination Reporting (DOVAR) database of the Ministry of Agriculture and Livestock do not markedly differ from the current estimates except for feedlot where it is somewhat higher (4.28 percent vs. 0.10 percent). At the same time, available sources indicate high fatality rates (~32 percent) among herds affected by anthrax outbreaks which is consistent with the findings presented in this study (MoA, 2010, 2012; Bahiru *et al.*, 2016). In cattle, anthrax usually manifests as peracute or acute disease; the peracute form typically occurs at the beginning of an outbreak and animals are found dead without premonitory signs, the acute form also runs a short course of about 48 h with severe depression, lethargy, abortion and fever (Salman and

Steneroden, 2015). In Ethiopia, anthrax is probably underreported in both humans and animal populations due to under-diagnosis and lack of effective reporting and alerting systems. Salman and Steneroden (2015) contend that this is the reality at a global level too.

Prevalence estimates of salmonellosis in the present study were slightly higher in the intensive dairy systems (3 percent to 3.5 percent) than in other production systems, as would be expected, and are in agreement with few available literatures that reported prevalence levels ranging from 0 to 5 percent (Bekele and Ashenafi, 2010; Eguale *et al.*, 2016). Dailey (2011) did not identify any salmonella strains from samples originating from semi-intensive dairy system in the central highland. Alemayehu *et al.* (2003) reported prevalence of 0.6 to 3.1 percent for salmonellosis in feedlot systems. Reta *et al.* (2016) found a prevalence of 3.30 percent in the pastoral/agro-pastoral production systems. Salmonella is often carried asymptomatically in cattle, but young, stressed or pregnant animals are the most susceptible to infection, which may result in enteritis and septicaemia (Leedom and Spickler, 2013).

The overall animal fatality rates estimated in the present study were 9.03 percent, 10.46 percent, 80.68 percent and 43.38 percent for brucellosis, bTB, anthrax and salmonellosis, respectively. There is no much information on these zoonotic diseases and their effects in causing mortalities in cattle in Ethiopia. Exceptions include Ameni *et al.* (2010) who reported mortality rates of 0.6 to 4.4 percent in pastoral/agro-pastoral cattle production systems due to bTB; Shiferaw (2004) who found a fatality of 7.7 percent in cattle kept in mixed crop-livestock system due to anthrax; and Pegram *et al.* (1981) who recorded a mortality of 6.76 percent in calves due to salmonellosis in a more likely mixed crop-livestock production system. The following fatality rates were also reported for anthrax: 42.7 percent (OiE, 2017) and 33 percent (MoA, 2012).

Available literature and data on prevalence and mortality of zoonotic diseases in humans are very scarce, making it difficult to validate the results of this study. In the present study, the estimated prevalence of brucellosis was 0.16 and 0.08 percent in cattle keepers and consumers, respectively. The reviewed literature (Tolosa, 2004; Regassa *et al.*, 2009; Haileselassie *et al.*, 2011; Girma, 2012; Tibesso *et al.*, 2014; Workalemahu *et al.*, 2015; Desta, 2016; Gebremichael *et al.,* 2016; Tadesse, 2016; Yilma *et al.*, 2016; Pal *et al.*, 2017; Tsegaye *et al.,* 2017; Wakene and Mamo, 2017) provide estimates on regions, zones, ecological zones or town areas, reporting prevalence rates with large variation between 0 and 34 percent, with the mode of most studies being 3 percent. It is not surprising that at the national level, we find a significantly lower prevalence, since most of the studies were conducted in areas where the risk of infection is high (e.g. commercial dairy farms or abattoirs).

Similarly, prevalence rates for bTB in humans were lower than those reported in the literature. For both cattle keepers and consumers, prevalence was 0.006 percent in this study. The findings of the literature (Ameni *et al.*, 2003; Ayele *et al.*, 2004; Shitaye *et al.*, 2007; Tschopp *et al.*, 2010; Tschopp *et al.*, 2011; Gumi *et al.*, 2012; Tschopp *et al.*, 2012; de Garine-Wichatitsky *et al.*, 2013; Gumi, 2013; Müller *et al.*, 2013; Tschopp *et al.*, 2013; Mengistu *et al.*, 2015; Bekele *et al.*, 2016; Endalew *et al.*, 2017) vary between 0.41 and 24 percent, but are again based on different reference periods and small samples.

Prevalence rates of salmonellosis in cattle keepers and consumers were estimated at 0.07 and 0.08 percent, respectively. Similar to the findings above, these rates were lower than the ones found in the literature, that range from 0.2 to 14.6 percent (Sibhat *et al.*, 2009; Beyene *et al.*, 2011; Tesfaw *et al.*, 2013; Abebe *et al.*, 2014; Adimasu *et al.*, 2014; Mengistu *et al.*, 2014).

The number of anthrax cases reported to the Ministry of Health were 575 and 848 cases in 2014 and 2015, respectively (MoH, 2015, 2016) with fatality rates of 1.22 and 5.90 percent, respectively during the two reporting years. Bahiru *et al.* (2016) found a fatality rate of 1.70 percent among anthrax patients nationally. On the other hand, Shiferaw (2004) reported a very high fatality rate of 50 percent for a single anthrax outbreak in northern part of the country. According to Grace *et al.* (2012), the total number of anthrax cases and deaths globally in unspecified year were 11 000 and 1 250, respectively, implying a fatality rate of 11.36 percent.

It is worth noting that prevalence of bTB, salmonellosis and brucellosis increases with the level of intensification. Moreover, bTB and salmonellosis, despite their economic and social impacts, were not among the five priory zoonotic diseases ranked for Ethiopia few years ago. The five priority zoonotic diseases in tier-one were rabies, anthrax, brucellosis, leptospirosis, and echinococcosis (Pieracci *et al.* 2016).

Economic impacts in animals

The studied zoonotic diseases cause significant losses in animal production and productivity. They cost the nation an estimated sum of 24.19 percent of the current contribution of livestock to GDP and 2.62 percent of the total GDP. In monetary terms, the loss is equivalent to USD 4 653 005 867 (PPP). Bovine tuberculosis alone was estimated to cause roughly 18 percent of the loss to livestock GDP or 1.96 percent to total GDP. These estimates were 3.29 percent and 0.36 percent for salmonellosis; 1.96 percent and 0.21 percent for brucellosis and 0.85 percent and 0.09 percent for anthrax, respectively. Costs of surveillance, prevention, and loss of access to markets were not considered in the present study.

Brucellosis has principal socio-economic and public health importance within countries and is considered significant in the international trade in animals and animal products (Neubauer, 2010). Brucellosis causes appreciable economic losses to the livestock industry and huge economic losses not only to dairy farmers but also to sheep, goat and pig farmers in infected areas, resulting from abortions, sterility, birth of weak offspring, decreased milk production, weight loss in animals, lameness, reduced breeding efficiency, veterinary attendance costs, the cost of culling and replacing animals, and vaccination costs (Nicoletti, 2010).

It is difficult to find literature and official record information on economic losses due to zoonotic diseases in the country and elsewhere. To put economic results in perspective, we thus compared the results of this study with those of Kenya and Uganda implemented with same methodology used here. We aggregated results by intensive and extensive systems for the sake of comparability. Table 5.18 and 5.19 present such results for brucellosis and bovine tuberculosis, respectively. Anthrax and salmonellosis in cattle were not investigated in Kenya and Uganda. The prevalence of brucellosis and the total loss as share of GDP were lower in Ethiopia than the other two countries, even though fatality rates were higher. Prevalence rates of bovine tuberculosis were higher in Ethiopian intensive systems compared to the other countries, and even though fatality was lower, the value of animal and production loss with respect to the cattle GDP was very high.

TABLE 5. 18. Prevalence, fatality and cost of brucellosis in Ethiopia, Kenya and Uganda

Brucellosis	Prevalence, percent		Fatality, percent		Total animal and production loss as percent of cattle GDP	
Production systems	*Intensive*	*Extensive*	*Intensive*	*Extensive*	*Intensive*	*Extensive*
Ethiopia	2	1	5	10	1	1
Kenya	4	9	2	1	3	5
Uganda (beef)	10	10	5	5	2	9

TABLE 5. 19. Prevalence, fatality and cost of bovine tuberculosis in Ethiopia, Kenya and Uganda

Bovine TB	Prevalence, percent		Fatality, percent		Total animal and production loss as percent of cattle GDP	
Production systems	*Intensive*	*Extensive*	*Intensive*	*Extensive*	*Intensive*	*Extensive*
Ethiopia	23	4	7	13	14	4
Kenya	1	2	21	25	2	4
Uganda (beef)	4	4	22	22	1	10

Public health impacts of the zoonotic diseases

The principal socio-economic effects of brucellosis in humans are reflected in medical care and reduced productivity (Nicoletti, 2010). The disease in humans is characterized with prolonged illness resulting in loss of vitality, loss of income and manpower, long-term treatment, and medical care costs. The impact of bTB can be severe when combined with immune system compromising disease conditions such as HIV that allow for co-infection and increased morbidity and mortality (Miller and Sweeney, 2013). Salmonella is a major cause of foodborne diseases globally. The global burden of zoonotic disease from salmonella is high (Miller and Sweeney, 2013). An estimated 93.8 million illnesses and 155 000 deaths result each year from non-typhoidal salmonella, the clear majority of which are foodborne (Majowicz *et al.*, 2010). In the European Union alone over 100 000 human cases are reported each year with an estimated overall economic burden as high as 3 billion EUR a year (EFSA, 2018). Salmonella strains that are resistant to a range of antimicrobials have emerged since the 1990s and are now a serious public health concern being 1 of 4 key global causes of diarrhoeal diseases (WHO, 2018). Salmonella is most prevalent where livestock are farmed intensively (Leedom and Spickler, 2013). Transmission is generally through the faecal-oral route and humans generally contract salmonellosis through consumption of contaminated food including meat, eggs, and unpasteurized milk products. Less often salmonella is transmitted through green vegetables contaminated by manure. Humans are much less susceptible to anthrax than herbivores. Infection occurs by contact to infected animals or contaminated animal products (WHO, 2008; Hörmansdorfer, 2015). Thus, human anthrax is an occupational disease of farmers, veterinarians, butchers, slaughterhouse workers or workers in the fur, leather or wool industry, but also in transport or dock workers (Hörmansdorfer, 2015; Cook *et al.*, 2017).

Recent estimates of the burden of zoonotic diseases indicate that zoonoses contribute to 26 percent of the DALYs lost to infectious diseases and 10 percent of the total DALYs lost in low income countries, respectively, and to 1 percent of DALYs lost to infectious disease and to 0.02 percent of the total disease burden in high income countries (Grace *et al.,* 2012). Particularly in low income countries, this burden is amplified by losses associated with malnutrition, also closely linked to zoonotic disease (Grace *et al.,* 2012). The Global Burden of Disease dataset registered a total of 38 million DALYs in 2016 in Ethiopia (GBD, 2018). The sum of DALYs caused by the four zoonotic diseases as calculated in this study was 424 347, which is equivalent to 1.1 percent of the total.

In Ethiopia, the total disability-adjusted life years lost due to brucellosis among livestock keepers and consumers were estimated at 71 762 and 35 581 DALYs, respectively. In monetary terms, these losses were equivalent to USD PPP 225.42 million per annum or 0.13 percent of the total GDP. These estimates were 35 590 and 6 086 DALYs, 87.52 million USD and 0.05 percent of GDP for bTB; 187 596 and 6 045 DALYs, 406.65 million USD and 0.23 percent of GDP for anthrax; and 76 682 and 5 001 DALYs, 171.53 million USD and 0.10 percent of GDP for salmonellosis, in that order.

We also compared the public health impacts of brucellosis and bTB in Ethiopia to those estimated for Kenya and Uganda (Tables 5.20 and 5.21). Generally, much lower brucellosis prevalence was estimated in Ethiopia. Estimated prevalence of bTB was similar in the three countries. Fatality rates due to both diseases were much higher in Ethiopia; however, the overall economic loss in terms of GDP was much lower than the monetary losses estimated for Kenya and Uganda due to the diseases.

TABLE 5. 20. Prevalence, fatality and public health costs of brucellosis in Ethiopia, Kenya and Uganda

Brucellosis (Human)	Prevalence, percent		Fatality, percent		Total social cost as percent of GDP
	Cattle keepers	*Consumers*	*Cattle keepers*	*Consumers*	*All*
Ethiopia	0.2	0.1	4	7	0.13
Kenya	7	0.5	1	0.4	1.7
Uganda (beef)	2.4	0.1	0.6	1	0.35

TABLE 5. 21. Prevalence, fatality and public health costs of bovine tuberculosis in Ethiopia, Kenya and Uganda

Bovine TB (Human)	Prevalence, percent		Fatality, percent		Total social cost as percent of GDP
	Cattle keepers	*Consumers*	*Cattle keepers*	*Consumers*	*All*
Ethiopia	0.1	0.1	19	20	0.05
Kenya	0.1	0.03	8.5	5	0.14
Uganda (beef)	0.1	0.1	8	6	0.14

CONCLUSION

Full assessment of the economic and social impacts of zoonotic diseases is challenging particularly where sources of reliable information and the means to acquire them are limited. In this chapter, we presented an attempt to assess the value of losses due to morbidity and mortality in animals and humans due to four zoonotic diseases – brucellosis, bTB, anthrax, and salmonellosis – in Ethiopia. This included both developing a theoretical framework and developing an expert elicitation protocol to gather the data and information needed to quantify the monetary impact of zoonoses on society.

The increase of complexity of livestock production and the associated value chains has led to changes in the food systems, which in turn carry new challenges from zoonotic diseases in particular their impact, and the costs of surveillance, control and prevention. Direct losses to the animal and public health sectors, connected mainly to value losses due to morbidity and mortality in humans and animals, and indirect losses, such as the economic cost caused by the reaction to diseases and the limiting of its negative effects, all contribute to this undesirable impact. Morbidity and mortality of animals due to zoonotic diseases carry also other losses related to the wider social, cultural and economic value of animals and their health and welfare benefits to people. In Ethiopia, cattle are the main source of livelihoods, income and employment; they also provide draught power and organic fertilizer, and serve as a form of insurance and status to livestock keepers in the different production systems.

Ethiopia is particularly vulnerable to the impacts of zoonotic diseases due to the very close relationship and interaction between livestock and humans and since more than 80 percent of households in the country keep livestock. In mixed crop-livestock system (and among some households in the urban/peri-urban areas), humans and livestock may dwell under the same roof. Several cattle farms, mainly dairy, are also found within urban settings – for instance, there were ~ 5 200 dairy farms in Addis Ababa city alone (Bogale *et al.,* 2014). Moreover, about 82 percent of the milk in the country is supplied to consumers unpasteurized and rural communities including pastoralists have the habit of drinking raw milk and eating raw meat. These factors constitute significantly high risk and burden of zoonotic diseases emanating from cattle production systems.

It is imperative that the importance of evaluating the impact of zoonotic diseases to inform and facilitate decision-making increases because of the imminent changes in the size and form of livestock production. However, currently there are difficulties to get data to measure monetary and social impacts of zoonotic diseases. We experimented with a new methodology, including the design and implementation of an expert elicitation protocol and the assessment in monetary terms of zoonotic diseases on society. Results suggest impacts of zoonotic diseases are high, both from a livestock production and human health perspectives. These support the importance of a one-health approach. Ethiopia may consider refining the expert elicitation protocol and expand it to other diseases to provide information base for decision makers.

6. Conclusion

The Ethiopian cattle sector widely affects the society both in positive and undesirable ways, including human, animal and environmental health. The sector is anticipated to undergo rapid growth and transformation in the coming decades, because of the implementation of the Livestock Sector Master Plan and, more fundamentally, because the anticipated population and economic growth, which will provide major incentives for increased production and productivity in the livestock sector. A detailed understanding of the multitudes of the positive and negative impacts of the livestock systems in general, and those of cattle in particular, is fundamental to inform policy dialogue and ensure appropriate actions are taken today for a sustainable development of livestock in the long-term. Given the multiple roles livestock play in society, analyses of the cattle sector using a “One Health” multi-disciplinary approach is essential to appreciate the trade-offs associated to any livestock sector policy and investment, i.e. to understand how the sector contributes to livelihoods, provides food and nutrition and differently impacts on the environment and public health.

This report is the result of a multi-disciplinary multi-stakeholder process and provides a One Health assessment of the effects and impacts of the cattle sector on Ethiopian society, chiefly on livelihoods, public health and the environment. In order to arrive at a common consensus of the role of cattle in Ethiopian society, national stakeholders have innovated under different perspectives. First, they have generated maps of beef and dairy cattle production systems in Ethiopia, which, for the first time ever, portray the different sub-production systems: the importance of characterizing the heterogeneity of livestock for informed policy decisions cannot be overstated. Second, they not only have assembled an unprecedented set of statistics for the different beef and dairy production systems but also assessed their impact on three societal dimensions – public health, people’s livelihoods and the environment. The value of having public health, livelihoods and environmental indicators that all refer to the same livestock production systems is essential to understand the trade-offs associated with any livestock sector policy or investment, i.e. to implement a One Health approach. Third, stakeholders have developed a methodology to assess in monetary terms the impact of zoonotic diseases, whose pathogens are shared between animals and humans, both on livestock production and on human beings. Such a methodology is an invaluable input to measure the returns of policies and investments aimed at tackling zoonotic diseases, whose outbreaks can have major negative impact on society, such as bovine tuberculosis and anthrax. Innovation comes with risks and limitations and, while we are aware that this report could be improved and expanded to cover additional species, their production systems and zoonotic diseases, we believe it represents a major step towards “One Health” oriented livestock sector policies and investments in Ethiopia.

Available evidences gathered in this report suggest that the upcoming changes in cattle production systems present both opportunities and challenges to society. For example, intensification can result in higher incomes for farmers, increased availability of animal source foods, lower emission per unit of produce and more efficient response to emerging diseases. However, these changes come coupled with many challenges: relatively few farmers will benefit from productivity and income increase, and many will be forced to exit the livestock sector and look for other employment opportunities, usually by migrating to urban centres. Emissions per unit of product will be lower but more concentrated; waste management will become increasingly a challenge. Besides, inappropriate use of antibiotics could lead to antimicrobial resistance in humans. Novel human-animal-ecosystem dynamics will likely create new public health threats and some novel or emerging zoonotic diseases may have pandemic potential, add to existing food safety hazards and proliferation of antimicrobial resistant pathogens.

The longer-term future of Ethiopian livestock, and of the cattle sector in particular, is still in the making and can be shaped by informed decisions taken today. This report represents an important piece of information for improved decision-making and is a clear demonstration that the Ministry of Agriculture and Livestock, Ministry of Health and the Ministry of Environment, Forest and Climate Change have the capacity to effectively adopt a One Health approach to explore the multitude of trade-offs associated with livestock sector growth and transformation. The challenge, however, is to adopt a One Health not only in sector analysis but also in policy design and implementation, which will support sustainable transformational pathways of the livestock sector from an environmental, livelihoods and public health perspectives.

7. APPENDICES

Appendix A

TABLE A1: Cattle distribution by region and production system in Ethiopia

Region	Heads	Proportion by production system (%)			
		Mixed crop-livestock	Pastoral/agro-pastoral	Commercial	Urban/peri-urban
Afar	1 580 313	0	100	0	0
Amhara	14 710 911	92	1	0	7
B. Gumuz	659 587	96	4	0	0
Dire Dawa	49 880	0	70	5	25
Gambella	278 584	15	85	0	0
Harari	62 401	60	10	10	20
Oromia	22 925 730	76	12	4	9
SNNPR	11 215 636	77	19	1	3
Somali	645 166	0	100	0	0
Tigray	4 578 181	71	9	10	10
Total	56 706 389	77	14	3	7

TABLE A2: Cattle distribution by zone and production system in Ethiopia

Region	Zone	Mixed crop-livestock	Pastoral/agro-pastoral	Dairy Commercial	Feedlots	Urban/peri-urban
Region 14	Addis Ababa	NA	0	NA	0	NA
Afar	Zone 1	0	997 288	0	0	0
Afar	Zone 2	0	NA	0	0	0
Afar	Zone 3	0	583 025	0	0	0
Afar	Zone 4	0	NA	0	0	0
Afar	Zone 5	0	NA	0	0	0
Amhara	Argoba Sp. Woreda	18 729	2 081	0	0	0
Amhara	Waghimra	288 674	72 168	0	0	0
Amhara	North Gondar	3 060 273	0	0	0	161 067
Amhara	South Gondar	1 707 436	0	0	0	0
Amhara	South Wolo	1 563 041	0	0	0	82 265
Amhara	East Gojam	1 707 531	0	0	0	189 726
Amhara	West Gojam	2 048 309	0	0	0	227 590
Amhara	Awi	934 511	0	0	0	103 835
Amhara	North Shoa	1 114 095	0	69 631	0	208 893
Amhara	North Wolo	859 951	0	0	0	0
Amhara	Oromia Zone	232 884	58 221	0	0	0
B. Gumuz	Kemeshi	41 977	0	0	0	0
B. Gumuz	Metekel	511 452	21 310	0	0	0
B. Gumuz	Asosa	67 397	7 489	0	0	0
B. Gumuz	Mao Komo	0	0	0	0	0

Contd.

TABLE A2: *Contd.*

Region	Zone	Mixed crop-livestock	Pastoral/agro-pastoral	Dairy Commercial	Feedlots	Urban/peri-urban
Dire Dawa	Dire Dawa	0	34 916	2 494	0	12 470
Gambella	Mezhenger	16 784	4 196	0	0	0
Gambella	Agnuwak	22 593	5 648	0	0	0
Gambella	Nuer	0	214 153	0	0	0
Gambella	Itang Special	0	0	0	0	0
Harari	Harari (Hundene zone)	37 441	6 240	6 240		12 480
Oromia	Kelem Wellega	517 961	0	0	0	0
Oromia	Guji	563 394	774 667	0	0	70 424
Oromia	Illu Aba Bora	1 109 111	0	0	0	46 213
Oromia	West Wellega	970 048	0	0	0	51 055
Oromia	East Hararghe	849 810	159 339	0	0	53 113
Oromia	East Shoa	803 021	57 359	86 038	28 679	172 076
Oromia	Arsi	2 023 122	126 445	126 445	0	252 890
Oromia	Bale	1 176 922	235 384	0	0	156 923
Oromia	West Arsi	1 467 800	195 707	97 853	0	195 707
Oromia	North Shoa (Oromia)	1 077 668	0	153 953	0	307 905
Oromia	East Wellega	884 869	0	0	0	46 572
Oromia	Jimma	2 090 101	0	0	0	110 005
Oromia	South West Shoa	828 615	0	110 482	0	165 723
Oromia	West Hararghe	847 604	99 718	0	0	49 859
Oromia	West Shoa	1 554 960	0	207 328	0	310 992
Oromia	Horo Guduru Wellega	626 143	0	0	0	32 955
Oromia	Borana	52 639	1 000 026	0	1 053	0
SNNP	Alaba Sp.Woreda	158 527	0	0	0	8 344
SNNP	Basketo Sp.Woreda	48 774	0	0	0	0
SNNP	Kembata Tambaro	353 152	0	0	0	7 207
SNNP	Shaka	137 652	0	0	0	0
SNNP	Yem Sp. Woreda	69 693	0	0	0	0
SNNP	Gedeo	107 137	0	0	0	1 082
SNNP	Sidama	1 811 540	0	106 561	0	213 122
SNNP	Dawro	303 640	0	0	0	0
SNNP	Gamo Gofa	1 126 091	198 722	0	0	0
SNNP	Hadiya	794 883	0	0	0	24 584
SNNP	Kaffa	931 307	0	0	0	0
SNNP	Konta Sp. Woreda	102 302	0	0	0	0
SNNP	Wolayta	758 164	0	0	0	39 903
SNNP	Gurage	905 034	0	0	0	27 991
SNNP	Bench Maji	97 333	227 109	0	0	0
SNNP	Segen People	327 466	81 867	0	0	0
SNNP	South Omo	33 469	1 639 965	0	0	0
SNNP	Silte	573 013	0	0	0	0

Contd.

TABLE A2: *Contd.*

Region	Zone	Mixed crop-livestock	Pastoral/agro-pastoral	Dairy Commercial	Feedlots	Urban/peri-urban
Somali	Nogob	0	NA	0	0	0
Somali	Afder	0	NA	0	0	0
Somali	Doolo	0	NA	0	0	0
Somali	Jijiga (Fafan)	0	380 041	0	0	0
Somali	Jarar	0	NA	0	0	0
Somali	Korahe	0	NA	0	0	0
Somali	Liben	0	250 599	0	0	0
Somali	Shabelle	0	NA	0	0	0
Somali	Shinille	0	14 526	0	0	0
Tigray	Southern Tigray	495 340	50 991	109 266	0	72 844
Tigray	Central Tigray	668 330	0	39 314	0	78 627
Tigray	North West Tigray	1 300 779	185 826	185 826	0	185 826
Tigray	Eastern Tigray	350 149	21 884	21 884	0	43 769
Tigray	Western Tigray	422 140	153 505	115 129	0	76 753
Total		43 552 780	7 860 417	1 438 444	29 732	3 800 790

Appendix B

B1. LIVESTOCK INCOME CALCULATION

Livestock income is calculated using the approach of the FAO Rural Livelihoods Information System. On the revenue side, cash income from live animal and product (milk, meat, eggs etc.) sales and value of products consumed at home is counted. There is some information that we cannot capture using the survey: a proper evaluation of the change in the value of stock cannot be done, since weight gain/loss and changes in value due to age are not available. Additionally, value of dung and draft power use are not included, though the prevalence of use is asked and presented in the tables of the text. On the cost side, we deduct the value of livestock purchased and other operational costs including feed, water, medical expenses etc. Livestock sales and purchase prices are determined using self-reported values, taking the median price for each species at the lowest administrative level where at least 3 prices are observable.

Revenues (+)	Costs (–)
Livestock activities: change in the cash value of the stock at the average price	
Livestock sold (alive)	Livestock bought Livestock additional expenditures[23] Crop used as feed Technical assistance/extension costs
Livestock products and by-products production	
Livestock products/by-products sold Livestock products consumed	Livestock by-/products additional expenditures

B2. HOUSEHOLD SURVEY DESIGN AND SURVEY WEIGHTS

The Ethiopia Socioeconomic Survey 2015/16 round is based on a sample of nearly 5 000 households and is representative at the regional level for Amhara, Oromia, SNNP and Tigray. For other regions, estimates can be produced as a combined as “Other regions”. The sample has been determined based on location and population, therefore there are some limitations when looking at livestock statistics.

The survey weights are used to extrapolate the information on the sample to the population. Simply put, each household in the sample is assigned a weight, which represents the number of households that household is representative of. The sum of the weights, therefore, is equal to the total number of households in the country. As these weights have been designed based on population and location, therefore overestimate cattle population in areas where humans are more densely populated than cattle and underestimate in areas where the density of human population is lower than that of cattle. For more information on the survey design, please refer to the Basic Information Document of the survey[24].

[23] *Total value of additional cash expenditures on hired labour [1], fodder [2], medicine [3], vaccination [4], utensils [5].*
[24] *http://microdata.worldbank.org/index.php/catalog/2783*

B3. ADDITIONAL TABLES

TABLE B3.1. Herd size distribution by production system

Production system	Herd size					
	10th percentile	25th percentile	Median	Mean	75th percentile	90th percentile
Mixed crop-livestock	1	2	4	5	6	10
Pastoral, Agro-pastoral	2	4	7	9	13	19
Urban/Peri-urban	1	2	3	4	4	6
Dairy commercial	3	4	6	6	7	10

TABLE B3.2. Income from beef production, percentage sold and consumed

	Average income from beef production	% beef sold	% beef own consumption
Mixed crop-livestock	0	80%	20%
Pastoral/Agro-pastoral	92	100%	0%
Urban/Peri-urban	0	0	0%
Dairy commercial	17	0	100%
All PS	**73**	**87%**	**13%**

TABLE B3.3. Net household (HH) income of total population

		Average annual HH income (Birr)			Share of livestock income over total income	Share of income from cattle over total income
	Number of HHs	Total income	Livestock activities	Cattle		
National	20 015 122	18 699	4 956	3 311	26%	21%
Urban HHs	5 401 056	29 000	640	443	4%	3%
Rural HHs	14 614 066	14 893	6 551	4 371	33%	28%
Poor HHs (societal poverty line)	10 633 943	14 844	5 108	3 172	28%	24%
Livestock keeper HHs	14 529 923	15 820	6 824	4 561	35%	29%
Cattle keeping HHs	12 569 994	16 425	7 835	5 374	38%	33%
Cattle keeping HHs, male ownership	3 294 360	15 813	6 535	4 600	36%	38%
Cattle keeping HHs, female ownership	1 991 702	15 155	8 723	4 803	40%	33%
Cattle keeping HHs, joint ownership	6 785 785	16 936	8 047	5 750	38%	32%

TABLE B3.4. Share of own production in consumption

Share of own consumption	Milk	Beef
National	56%	1%
Urban HHs	10%	0%
Rural HHs	75%	3%
Poor HHs (societal poverty line)	63%	0%
Livestock keeping HHs	74%	2%
Cattle keeping HHs	79%	3%
Cattle keeping HHs, male ownership	80%	3%
Cattle keeping HHs, female ownership	75%	0%
Cattle keeping HHs, joint ownership	79%	3%

Appendix C

C1. 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)

C2.1 DETERMINATION OF UPSTREAM EMISSIONS CALCULATED IN GLEAM

N_2O from pasture and crop cultivation. Nitrous oxide emissions from cropping include direct N_2O, and indirect N_2O 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.

CO_2 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 1 guidelines (IPCC, 2006). The expansion of feed crops is limited to soybean and to palm oil production.

CO_2 from field operations. CO_2 from the on-farm energy use is 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.

CO_2 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.

CO_2 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), feeds 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.

CO_2 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.

CH_4 from rice cultivation. Rice, differently from all the other feed crops, produces significant amount of CH_4. These emissions per hectare are highly variable and depend on the water regime during and prior to cultivation, and the nature of the organic amendments. The average CH_4 flux per hectare of rice was calculated using the IPCC Tier 1 methodology as described in the Volume 4, Chapter 5.5.

C2.2 DETERMINATION OF ANIMAL PRODUCTION EMISSIONS IN GLEAM

CH_4 from enteric fermentation. Emissions from enteric fermentation (kg CH_4/head) are a function of feed digestibility (DE), i.e. the percentage of gross energy intake that is metabolized. An enteric methane conversion factor, Y_m (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 CH_4 emissions due to the sensitivity of emissions to diet composition and the relative importance of enteric CH_4 to the overall GHG emissions profile in ruminant production.

CH_4 from manure management. Calculating the CH_4 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 CH_4. 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 CH_4 during manure management per animal per year can be calculated using Equation 10.23 from IPCC (2006). The CH_4 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 judgement.

N_2O emissions arising during manure management. Calculating the N_2O 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 N_2O. 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, as either growth, pregnancy live weight gain or milk. The rate of conversion of excreted N to N_2O 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 N_2O (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.

Appendix D

D1. LIST OF ANIMAL DISEASES REPORTED BY LOCAL AUTHORITIES TO THE DOVAR SYSTEM

African horse sickness, African swine fever, anaplasmosis, anthrax, babesiosis, black quarter, brucellosis, camel pox, canine distemper, contagious bovine pleuropneumonia, contagious echtyma, contagious caprine pleuropneumonia, dourine, echinococcosis, equine herpes virus, ehrlichiosis (cowdriosis), foot and mouth disease, fowl cholera, fowl typhoid, gumboro, haemosepticemia, highly pathogenic avian influenza, infection coryza, lumpy skin disease, lymphangitis, maedi visna, malignant cattle fever, Marek's disease, Newcastle disease, pest des petits ruminants, Pullorum disease, rabies, Rift Valley fever, sheep and goat pox, streptothricosis, trypanosomiasis, and tuberculosis.

D2. LIST OF HUMAN DISEASES, INCLUDING SYMPTOMS, REPORTED BY LOCAL AUTHORITIES

Immediately Reportable Diseases: Acute flaccid paralysis (Polio), anthrax, avian human influenza, cholera, dracunculiasis (guinea worm), measles, neonatal tetanus, pandemic influenza a, rabies, smallpox, severe acute respiratory syndrome (SARS), viral haemorrhagic fevers, and yellow fever.

Weekly Reportable Diseases: Dysentery, malaria, meningococcal meningitis, relapsing fever, severe malnutrition, typhoid fever, and typhus.

D3: DATA SOURCES ON IMPACT OF ZOONOTIC DISEASES

- Protocol data: After a thorough review of available literature and data, the ASL 2050 team designed an Expert Elicitation Protocol to gather information needed to calculate the economic and public health impacts of the priority zoonotic diseases in the country. More than 42 experts were interviewed in Ethiopia. The questions were asked in relative terms (i.e. per 1 000 cattle, per 100 000 consumers etc.) and were converted to national numbers using information from the production system briefs (animal population), number of livestock keepers (household surveys) and number of consumers (World Bank Consumption Database).
- Household survey data: The Ethiopia Socioeconomic Survey 2015/16 (Central Statistical Agency) was used to determine the number of households keeping livestock.
- World Bank Consumption Database: The World Bank Consumption Database provides information on the share of households consuming cattle and poultry products.
- Global Livestock Environmental Assessment Model (GLEAM): The GLEAM is a GIS 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 in order to contribute to the assessment of adaptation and mitigation scenarios to move towards a more sustainable livestock sector. Dressing rates, estimates on share of adult cow population and calving rates were provided by the model.

D4. EQUATIONS

We determined the economic and public health impact in monetary terms, as a sum of the value of animals lost due to the diseases, the loss from salvage slaughtering and culling, the loss from production decrease and the social cost of human mortality and morbidity. The following sections describe the calculations and the sources of data for these components.

Economic and Public Health impact (USD)

=

Value of animals lost (I)

+

Loss from salvage slaughter and culling (II)

+

Loss from production decrease (III)

+

Social cost of human mortality (IV.1)

+

Social Cost of human morbidity (IV.2)

D4.1. Value of animals lost (I)

The value of animals lost comprises three main components: the value of animals that died due to the disease, the value of animals whose carcass had to be condemned and the value of calves that were not born due to fertility decrease caused by the disease:

Value of animals lost

=

Number of animals died due to disease (I.1)

*

Animal farm-gate price (I.2)

+

Number of carcasses condemned (I.3)

*

Animal farm-gate price (I.2)

+

Number of unborn calves (I.4)

*

Calf farm-gate price (I.5)

D4.2. Number of animals died due to the disease (I.1)*:* The number of animals died due to the disease was asked in the protocol per 1 000 animals for brucellosis, bovine TB, anthrax and salmonellosis.

D4.3. Adult animal farm-gate price (I.2): To attach a monetary value to the number of animals lost, country data on the adult animal farm-gate price was used.

D4.4. Number of carcasses condemned (I.3)*:* The number of carcasses condemned was asked in relative terms (see I.1) for cattle related diseases.

D4.5. Number of unborn calves (I.4): The Protocol gathered information on the fertility loss in percentages due to cattle related diseases. To estimate the number of unborn calves, we determined the number of calves that were likely to be born among the infected animals in the given year by calculating the number of survivors as the difference between cases and deaths available from the Protocol and multiplying this with the share of adult cows and the calving rate that is available by production system in GLEAM. Then we applied the fertility loss in percentages to the number of calves that were to be born among survivors:

Number of unborn calves (I.4)

=

Number of survivors (Protocol: cases-deaths)

*

Share of adult cows (Country data and literature)

*

Calving rate (Country data and literature)

*

Fertility loss (Protocol)

D5. SALVAGE SLAUGHTER AND CULLING (II)

Carcasses (or parts thereof) may be condemned after culling (or salvage slaughter), therefore we must subtract the number of carcasses condemned to avoid double counting. The loss due to culling or salvage slaughtering one animal is determined as the difference in the sales value of a healthy adult animal and the salvage value. The salvage value of an animal has been calculated using a discount rate on the full price, given by experts consulted during the validation of the Protocol data.

Loss from salvage slaughter and culling (cattle)

=

(Number of salvage slaughter + Number of animals culled – Number of carcasses condemned) (II.1)

*

(Animal farm-gate price (I.2) – Salvage value (II.2))

D5.1. Number of salvage slaughter, animals culled and carcasses condemned*:* available from Protocol data, in relative terms (per 1 000 cattle) and converted to absolute numbers using cattle population data from the countries' Production Systems Spotlights.

D5.2. 'Salvage value' of culls / salvage slaughter: A discounted price of culled animal (or salvage slaughtered), estimated using the discount rate given by experts consulted at the validation of Protocol results.

D6. LOSS FROM PRODUCTION DECREASE (III)

Animals that are infected but not dead suffer a decrease in productivity, notably weight loss, milk production decrease and fertility loss. To evaluate the economic impact of a disease we estimate the value of total decrease in production:

Loss of production decrease (cattle)
=
Loss of meat production (III.1)
+
Loss of milk production (III.2)

D6.1. Loss of meat production (III.1)

Loss of meat production
=
Number of survivors (cases-deaths, Protocol)
*
Weight loss in kilograms per head (Protocol)
*
Dressing percentage (Country data and literature)
*
Price of beef per kg (Country data, FAOSTAT)

D6.2. Loss of milk production (III.2)

Loss of milk production
=
Loss from foregone lactation period (III.2.1)
+
Loss from milk productivity decrease (III.2.2)

D6.2.1. Loss from forgone lactation period (III.2.1):

Loss from foregone lactation period
=
Number of unborn calves (see I.5 above)
*
Average litres per lactation (Country data by production system)

D6.2.2. Loss from milk productivity decrease (III.2.2):

Loss from milk productivity decrease
=
Number of cows affected by productivity decrease (III.2.1)
*
Milk loss in litres per lactation period (Protocol)

D6.2.1.1 Number of cows affected by productivity decrease: The number of cows affected by productivity loss are those survivors who were likely to have a calf and were not affected by the fertility loss (i.e. they had a calf):

Number of survivors (cases-deaths from Protocol)
*
Share of adult cows (Country data and literature)
*
Calving rate (Country data and literature)
*
(1-Fertlity loss) (Protocol)

Variables:

Number of livestock keepers by production system: We estimated the number of people who are exposed to risk of disease through direct contact with animals. We use household survey data (LSMS and DHS) to estimate the number of people living in households keeping cattle. We assume that the distribution of livestock keepers among production systems are the same as the distribution of the number of farms among production systems. We use the animal population per production system and the average herd size to estimate the number of farms per production system.

Number of consumers who are not livestock keepers: In cases where people can be affected by the disease through consumption, we need to calculate the number of consumers but to avoid double-counting, we do not include livestock keepers. We determine the number of non-livestock keepers using household survey information described above. We use the share of households reporting consumption of cattle products using the Global Consumption Database of the World Bank.[25]

[25] *http://datatopics.worldbank.org/consumption/detail*

D7. DALY

A disability adjusted life years (DALYs) are calculated as the sum of the years of life lost due to premature mortality in the population and the equivalent "healthy" years lost due to disability during the sickness of survivors.

DALY

=

Number of deaths (Protocol)

*

(Average life expectancy (World Bank) – Average age of infection (Protocol))

+

Number of survivors (Protocol)

*

Duration of disease (Protocol)

*

DALY weight (WHO)

D8. WILLINGNESS TO PAY FOR A DALY

To attach a monetary value to a DALY, we need to determine the willingness to pay (WTP) for a healthy year of life, i.e. the WTP to avoid a DALY. We use the value of statistical life calculated by the US Department of Transport, and translate it into a yearly value using the expected life span and a discount rate, following the methodology of the OECD. Then we translate this value into country context using a benefit transfer methodology. This methodology takes into account the differences in GDP per capita and the elasticity of the willingness to pay for a healthy life (i.e. how WTP changes as income grows).

Willingness to pay for a healthy life year

=

Willingness to pay for a healthy life year in the United States (PPP) (see below)

*

(GDP per capita in PPP of country / GDP per capita in PPP of US)^{elasticity}

Willingness to pay for a healthy life in the United States (PPP)

=

Value of Statistical Life (US Department of Transport)

/

$\sum t=0...T(1+\text{discount rate})^{t}$

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