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*The monetary impact of  
zoonotic diseases on society*

# KENYA

Evidence from three zoonoses



Republic of Kenya



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# The monetary impact of zoonotic diseases on society

## Evidence from three zoonoses in Kenya

### 1. Introduction

In Kenya, population growth, urbanization and gains in real per capita income will result in increased consumption of animal source foods. This will provide incentives for livestock producers and other actors along the value chain to rapidly expand and improve their businesses to satisfy the growing consumers' demand (FAO, 2017a). 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 leave the livestock business altogether.

Livestock being private business, the key role for the government of Kenya is to ensure that policies - largely implemented through public investments, laws and regulations - support a smooth and socially desirable transformation of the sector in the coming years. This is easier said than done because livestock has broader, often negative impacts on society. For example, grasslands degradation, microbiological water pollution, excess greenhouse gas emissions, animal epidemics and zoonotic diseases, are all consequences of inappropriate livestock farming practices that reduce societal welfare.

Zoonotic diseases, which cross the animal-human species barrier, are a major threat for society – they can affect entire sectors of the livestock industry and reduce human capital. For example, it is estimated that the 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). The government of Kenya is taking steps to prevent, manage and control zoonotic diseases. One of the notable steps is the implementation of the “One Health” approach through the formation of an inter-ministerial coordination unit referred to as the Zoonotic Disease Unit (ZDU). ZDU facilitates collaboration between the human, animal, and environmental health sectors of prevention, control and management of zoonotic diseases (Mbabu *et al.*, 2014). However, given the current zoonotic disease information system, the Ministry of Agriculture, Livestock and Fisheries and the Ministry of Health find it challenging to generate accurate estimates of the incidence and prevalence of zoonoses, assess their impact on society, and measure the benefits of programmes and investments for their prevention, management and control (Morgan, 2014). In other words, the Ministries have difficulties in allocating public resources to tackle zoonotic diseases efficiently.

The Africa Sustainable Livestock 2050 initiative (ASL2050), under the guidance of a National Steering Committee comprising representatives of the Ministry of Agriculture, Livestock and Fisheries and the Ministry of Health, has designed and implemented an expert elicitation protocol to assemble information on selected zoonoses and on antimicrobial resistance. The protocol was designed to gather the data needed to measure the impact of zoonoses on society in monetary terms, thereby providing the government with a key piece of information in order to allocate taxpayers' money efficiently. Because three quarters of new infectious diseases emerging in humans have a zoonotic origin and because the anticipated growth of Kenya which is likely to modify the drivers influencing the emergence and re-emergence of zoonotic pathogens, the value of accessing information to measure the costs and benefits of preventing, managing and controlling zoonoses cannot be overstated.

This brief, validated by stakeholders, presents the results of the ASL2050 expert elicitation protocol on zoonotic diseases. Since this was the first time an expert elicitation protocol on zoonotic diseases was implemented in Kenya and attaching monetary values to some variables based on numerous assumptions, results are not cast in stone. What matters, however, is that stakeholders have used a One Health

approach to experiment with a new methodology to look at zoonotic diseases – a methodology that they may or may not scale up or replicate to provide decision-makers with information on how to best allocate admittedly scarce public resources.

## **2. An expert elicitation protocol to assemble information on zoonoses and Antimicrobial resistance (AMR)**

When data is insufficient or unreliable, or when data is either too costly or physically impossible to gather, expert elicitation is a promising tool to obtain good quality information. It is a scientific consensus methodology to get experts' judgements on the distribution of variables and parameters of interest, including also unknown or uncertain values. An important feature of expert elicitation is that experts not only provide information on the unmeasured, but also suggests values that differ from those in scientific literature or from official statistics (the official knows), if they for example believe that causal linkages are underestimated or that certain issues have been underreported. The public sector, but more frequently private parties, have used expert elicitation for a large number of purposes, such as to investigate nature and the extent of climate change; the cost and performance of alternative energy technologies; and air pollution impact on human health (Morgan, 2014). The World Health Organization has used expert elicitation to estimate the global burden of foodborne diseases (WHO, 2015).

In Kenya, the current information system does not provide the government with sufficient information on the incidence, prevalence and impact of zoonoses on society, which makes it challenging to measure the returns on investments aimed at their prevention, management and control. The Africa Sustainable Livestock 2050 initiative (ASL2050) has therefore designed and implemented an expert elicitation protocol to assemble information on selected zoonoses and antimicrobial resistance. Necessary data was gathered to measure the impact of zoonoses on society in monetary terms. The collection and dissemination of evidence relating to the economic cost of diseases, coupled with information regarding the cost of alternative interventions for disease control and management information, should guide decisions allocating taxpayers' money.

- As it was the first time an expert elicitation protocol on zoonoses was implemented in Kenya, the protocol focuses on two livestock species, three zoonoses, and antimicrobial resistance. The two livestock species are cattle (dairy and beef) and poultry (chicken for meat), while the three zoonoses are bovine tuberculosis, brucellosis of cattle, and poultry salmonellosis (Morgan, 2014). These were selected because of their relevance not only for Kenya but also for other ASL2050 countries implementing the protocol, including Burkina Faso, Egypt, Ethiopia, Nigeria and Uganda, countries that will facilitate cross-learning.
- For animals and for each zoonosis, the protocol includes 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 directed at the different cattle and poultry production systems<sup>1</sup>, as defined and quantified by stakeholders using available data and information (FAO, 2017b).
- For humans and for each zoonosis, the protocol includes 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 categories of people, including livestock keepers, and consumers.

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<sup>1</sup> For cattle, the different production systems include beef and dairy systems: dairy - intensive system, dairy - semi-intensive system, dairy - extensive system, beef - feedlot system, beef - semi-intensive system, beef - extensive pastoralism and beef - extensive ranching. Poultry production includes intensive, semi-intensive and free-range systems.

- The protocol did not collect price data, necessary to estimate the monetary values of the cost of any disease. For livestock, price data for live animals and animal products from reports of State department of Livestock was sourced and gaps were filled by consulting experts and the members of the ASL2050 Steering Committee. For humans, the yearly value of statistical life was estimated to proxy the willingness to pay (WTP) for disability-adjusted life year (DALY), which is the amount citizens are willing to pay to ensure one year of healthy life (box 1). The WTP for a DALY allows the cost associated with mortality and morbidity to be calculated as detailed in the next section.
- For antimicrobial resistance, the protocol includes four questions: on the proportion of cattle and poultry farms using antibiotics, by production system; on trends on use of antibiotics in cattle and poultry farms, by production system; on trends in antimicrobial resistance in humans; and on experts' concerns about antimicrobial resistance in humans.

**Box 1. The willingness to pay for a disability-adjusted life (per year)**

To estimate the social cost of the disease, we estimate 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<sup>2</sup>. 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 calculate the willingness to pay a DALY to get its value in monetary terms. The value of a statistical life (in the US) has been calculated to be USD 9.5 million by the US Department of Human and Health Services and to be USD 9.6 million by the US Department of Transportation (DOT, 2016), and is used to value the reduction of fatalities and injuries. Translating the latter into a yearly value, we use 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  $\delta$  is the discount rate. Using a discount rate of 3 percent (ERG, 2014) and the expected life span of 79 years (World Bank, 2017), around 400 000 USD as a yearly value of a statistical life in the US represents society's willingness to pay for a healthy year of life or for a DALY. To apply this value to the Kenyan context, we use the benefit transfer methodology presented in Hammit and Robinson (2011), which takes the differences in real GDP per capita into account, as measured in purchasing power parity (PPP) and the elasticity of the willingness to pay for risk reduction with respect to income:

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

We used a 'snowball' sampling approach to identify experts to interview, with representatives of the ASL2050 Steering Committee suggesting names of renowned national experts, including two animal and two human health experts for each zoonotic diseases. These experts were then asked to recommend additional experts to interview, etc. When this snowball approach occasionally was interrupted, the ASL2050 National Focal points resumed the expert unveiling process. The final sample comprised 55 experts, including 36 animal health experts, 15 human health experts and 4 other experts including one health and zoonosis expert. The sample is biased towards animal health experts, as there are few human doctors with expertise in the selected zoonotic diseases. However, animal health experts were often able

<sup>2</sup> [http://www.who.int/healthinfo/global\\_burden\\_disease/metrics\\_daly/en/](http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/)

to answer human health questions as, being specialised in zoonotic diseases, they typically operate at the interface between animal and human health. The interviews were conducted in September and October 2017, the data were analyzed in November and December 2017 and the results were validated in collaboration with stakeholders in January 2018.

### 3. Livestock and public health monetary impact calculation: methodology

The monetary impact of the priority zoonotic diseases on society is 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

$$\begin{aligned} & \text{Livestock and Public Health USD Impact} \\ & = \\ & \text{Value of animals lost} \\ & + \\ & \text{Value of production decrease due to infected animals} \\ & + \\ & \text{Social cost of mortality in humans} \\ & + \\ & \text{Social cost of morbidity in humans} \end{aligned}$$

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

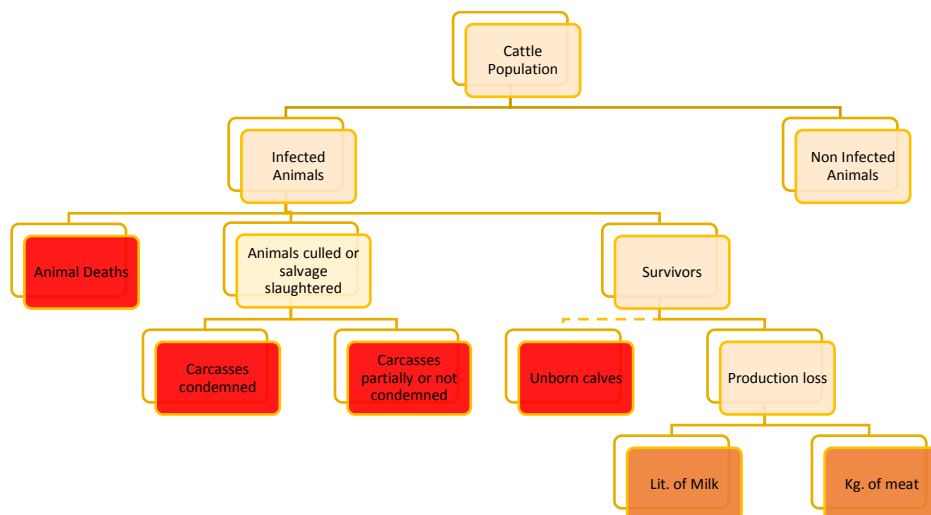
#### 3.1 Cattle

In cattle systems, an infected animal will either die, be culled or salvage slaughtered or survive being less productive during the disease. Both the value of the animals lost as well as the decreased production should be estimated to calculate the total loss due to disease occurrence. Figure 1 depicts a flowchart that highlights the different cattle-related variables the protocol data estimates, including the value of animals lost due to disease (in red) and the value of production loss in survivors (in dark orange). The cost of treating sick animals is not accounted for as data on farmers' expenses on veterinary goods and services by disease are not available, because the share of farmers with access to animal health services is usually small, and because their spending on veterinary services is typically negligible (CAHI, 2015; MAAIF, 2016). The value of animals lost is 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 carcasses partially or not condemned animals multiplied by the farm-gate price of an adult animal discounted by 25-30 percent;
- 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 is calculated as the sum of:

- 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 disease and not affected by fertility loss, multiplied by the average reduction in milk production in litres and by the market price of one litre of milk;
- The number of survivors multiplied by the average dressed weight loss and by the market price of one kg. of beef.



**Figure 1.** Cattle-related variables in the USD loss calculation

### **3.2 Poultry**

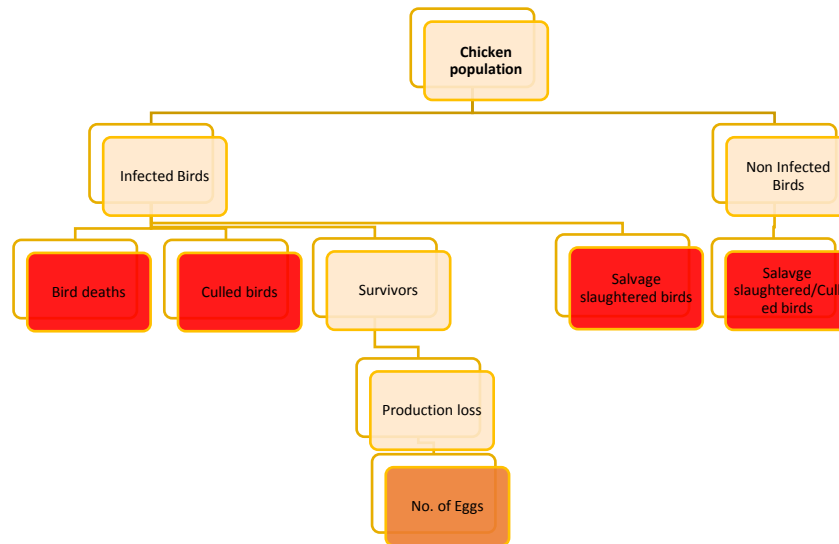
In poultry systems, birds affected by a disease may die, be culled or salvage slaughtered, or suffer from decrease in egg production. For some diseases the whole flock might be slaughtered as a precaution, therefore salvage slaughterery also includes non-infected birds. Furthermore, while no sale happens after culling, in the case of salvage slaughter the birds can still be consumed, though they very likely have not reached their full slaughter weight. Figure 2 depicts a flowchart highlighting the different poultry-related variables the protocol data estimates, including the value of animals lost due to disease (in red) as well as the value of production decrease in survivors (in dark orange). The cost of treating sick birds is not accounted for as data on farmers' expenses on veterinary goods and services by disease are not available, because the share of farmers with access to animal health services is usually small, and because their spending on veterinary services is typically negligible.

The value of birds lost is calculated as the sum of:

- the number of birds killed by the disease multiplied by the farm-gate price for a live chicken;
- the number of culled birds multiplied by the farm-gate price of a live chicken;
- the number of salvage slaughtered birds multiplied by the farm-gate price for a live chicken discounted by 40 % in intensive system and 63% in semi-intensive and free range systems. ;

The value of production decrease in surviving hens is calculated as:

- The number of surviving hens multiplied by the average reduction in the number of eggs produced and by the egg market price.

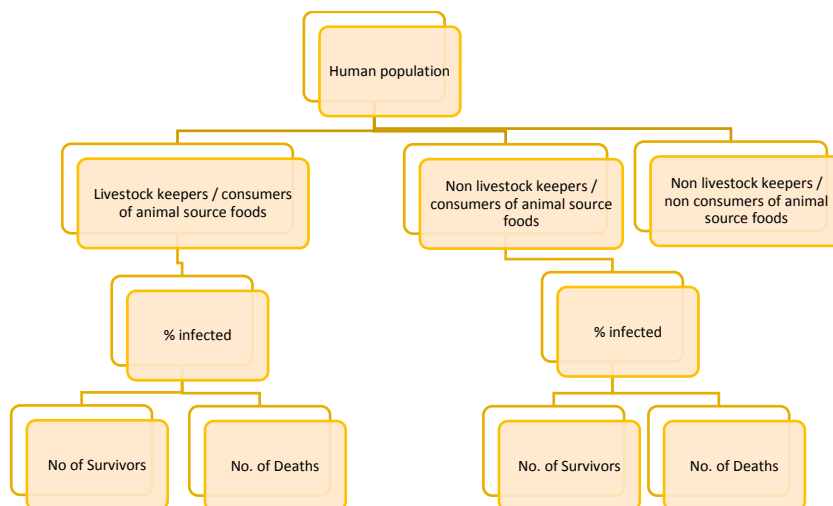


**Figure 2.** Poultry-related variables in the USD loss calculation

### 3.3. Humans

Zoonoses are transmitted from animals to humans through both direct and indirect contact, vectors and food consumption. Therefore different categories of people face different risks of contracting zoonotic diseases. To estimate the impact of morbidity and mortality of zoonoses in humans, the population at risk was split into three broad groups: (i) non-livestock keepers & non consumers of animal source foods; (ii) non-livestock keepers & consumers of animal source foods; (iii) livestock keepers & consumers of animal source foods<sup>3</sup>.

Figure 3 depicts a flowchart that highlights the different human-related variables the protocol data estimates, including the number of infected people, as well as survivors and deaths, by category of people. We assume there are no infections among non-livestock keepers and non-consumers of animal source foods.



**Figure 3.** Human related variables in the USD loss calculation

<sup>3</sup> Occupations at higher risk of infection also include 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 of them are already living in a livestock keeping households or are consumers of animal source foods.

The economic cost of the zoonotic disease is 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) and the DALY weight measuring the severity of the disease<sup>4</sup> and by the society's willingness to pay for one day 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 time of infection – and society's willingness to pay for one year of healthy life.

#### 4. Livestock and public health monetary impact calculation: results

##### 4.1. Data validation

The collected data was validated through a two-step process. First, a statistics summary was generated for the key variables to estimate. Second, for the variables with implausible values, the literature in question was looked at and protocol respondents were consulted to clean the data. Table 1 presents the reference population, prevalence and fatality rate data that were ultimately used to calculate the impact of the selected zoonoses on society.

**Table 1.** Key protocol-variables underpinning the USD loss calculation

	Total Population		
	Cattle 18 828 617	Humans 42 961 187	
		Cattle keepers	Consumers
<b>Brucellosis</b>			
Prevalence (cases/total pop)	6.4%	7.1%	0.5%
Fatality rate (deaths/cases)	1.6%	1.0%	0.4%
<b>Bovine TB</b>			
Prevalence (cases/total pop)	1.8%	0.06%	0.03%
Fatality rate (deaths/cases)	23%	8.5%	5.0%
	Total Population		
	Poultry 39 635 189	Humans 42 961 187	
		Poultry keepers	Consumers
<b>Salmonellosis</b>			
Prevalence (cases/total pop)	11%	0.1%	0.1%
Fatality rate (deaths/cases)	47%	10%	9%

#### 4.2. Results

##### 4.2.1 Brucellosis

##### Brucellosis of Cattle

Table 2 shows the value of animals lost and the value of production loss due to brucellosis of cattle by production system. This loss is based on data obtained through expert elicitation on selected key animal health indicators (variables described in figure 1). Brucellosis causes an estimated economic loss of 237.5 million USD Purchasing Power Parity (PPP) in cattle per year, which is equal to 8.1 percent of the cattle value added (GDP) and amounts to 22.55 percent of Ministry of Agriculture, Livestock and Fisheries (MALF) expenditure budget. About 65 percent loss is due to foregone production (Figure 4).

<sup>4</sup> A DALY 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

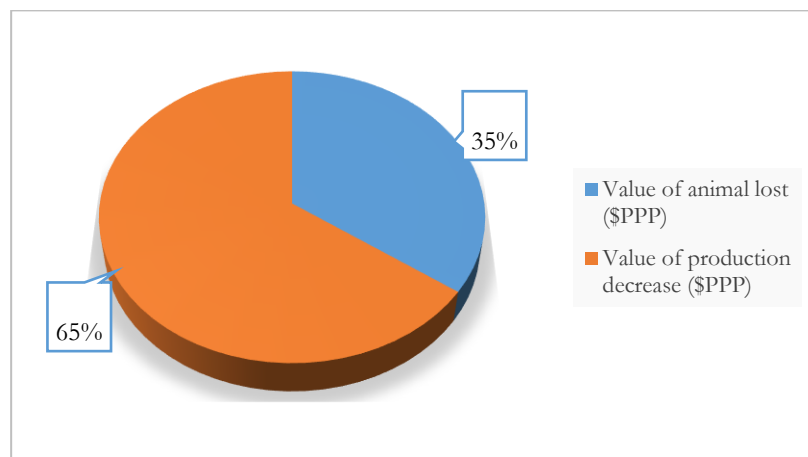


Total animal loss (understood as the value of the animals lost due to brucellosis plus foregone production) is mainly in extensive pastoralism (with over 105 million USD PPP it represents 44 percent of the losses) and semi-intensive systems (38 and 42 million USD PPP in beef and milk production systems respectively, each one contributing slightly over 15 percent to the total loss). This is due to a higher prevalence rate in the extensive pastoralism system as well as the lower investments in animal disease and control in comparison to intensive dairy, beef feedlots and ranching systems (Otieno, Hubbard and Ruto, 2012).

**Table 2.** Value of animals lost, and value of production lost due to brucellosis in beef and dairy production system

	<b>D – Int.</b>	<b>D - S.Int.</b>	<b>D – Ext.</b>	<b>B - Feedlot</b>	<b>B – S.Int.</b>	<b>B - Past.</b>	<b>B - Ranch</b>	<b>TOTAL</b>
Estimated prevalence	2.0%	5.2%	7.5%	4.2%	4.6%	8.8%	6.1%	6.4%
Value of animals lost due to the disease (million USD PPP)	8.4	8.7	4.1	0.2	19.9	33.5	7.9	82.7
Value of production lost due to the disease (million USD PPP)	13.1	29	13.3	0.2	21.6	71.6	6.2	154.8
<b>TOTAL (million USD PPP)</b>	<b>21.4</b>	<b>37.7</b>	<b>17.4</b>	<b>0.37</b>	<b>41.5</b>	<b>105</b>	<b>14.1</b>	<b>237.5</b>
<i>Animal losses as % cattle value added<sup>1</sup></i>								8.1 %
<i>Animal losses as % MALF budget.<sup>2</sup></i>								22.55 %

Note: D – Int. = Dairy - Intensive; D - S.Int = Dairy - Semi-Intensive; D – Ext. = Dairy - Extensive; B – Feedlot = Beef - Feedlot; B – S.Int = Beef - Semi-intensive; B - Past. = Beef - Extensive pastoralism; B – Ranch = Beef - Extensive ranching; MALF = Ministry of Agriculture, Livestock and Fisheries. Sources for (1) is Output at current prices (KNBS, 2016); and (2) GoK, 2018. National and County governments Budget allocation and expenditure (2015/16 and 2016/17): Agriculture, Health and Environment sectors. Office of the Controller of Budgets, Republic of Kenya, Ref: COB/GEN/002/Vol.1. Dated 12/02/2018. Values in PPP stands for international dollar purchasing power parity and the exchange rate is obtained from WB (2018).



**Figure 4.** Cattle production systems: value of production loss and animals lost (%) due to brucellosis

However, when estimating losses per case of brucellosis in cattle (Table 3), dairy systems register the highest loss per head. The total loss per case is obtained from dividing the losses of the animal value and the foregone losses by the number of animals affected. We found higher losses per case in dairy systems and intensive dairy systems, largely due to both higher value in the foregone production and higher value of the animals. Among beef systems, ranching (followed by feedlots) records the highest losses per case. Each case of brucellosis represents a loss of 22% of the farm-gate price of a healthy animal. This value is higher for dairy and lower for beef production systems.

**Table 3.** Estimates of losses by brucellosis case in cattle, as a percentage of the price of a health animal

	<b>D – Int.</b>	<b>D - S.Int.</b>	<b>D – Ext.</b>	<b>B - Feedlot</b>	<b>B – S.Int.</b>	<b>B - Past.</b>	<b>B - Ranch</b>	<b>TOTAL</b>
Value of animals lost per case (USD PPP)	225	77	110	101	80	47	170	84
Value of production lost per case (USD PPP)	352	257	356	105	86	100	133	147
<b>TOTAL loss per case (USD PPP)</b>	<b>577</b>	<b>334</b>	<b>466</b>	<b>206</b>	<b>166</b>	<b>147</b>	<b>303</b>	<b>231</b>
<i>Loss per case as a percentage of the farm-gate price of a healthy animal</i>	<i>36%</i>	<i>31%</i>	<i>29%</i>	<i>16%</i>	<i>17%</i>	<i>17%</i>	<i>19%</i>	<i>22%</i>

Note: D – Int. = Dairy - Intensive; D - S.Int = Dairy - Semi-Intensive; D – Ext. = Dairy - Extensive; B – Feedlot = Beef - Feedlot; B – S.Int = Beef - Semi-intensive; B - Past. = Beef - Extensive pastoralism; B – Ranch = Beef - Extensive ranching.

### Brucellosis in human beings

As described above, the social cost of the disease is estimated as the sum of the cost of mortality and cost of morbidity. The disease impact was estimated for two sub-groups of people: the cattle keepers, who are in contact with the animals and are also potentially consuming cattle source products, and individuals who are not livestock keepers but might be infected through consumption of animal source foods. Results are shown in Table 4 for both groups as well as the total population of reference. In 2016 in Kenya 12 004 people died of brucellosis (out of 1.27 million cases estimated), on average at age 25<sup>5</sup>. According to the World Bank, life expectancy in Kenya is 66.65 years, therefore 12 004 \* (66.65 – 25) years are estimated to be lost due to the brucellosis. About 96 percent of the fatalities are among livestock keepers. The total social cost of brucellosis is estimated to be 4.1 billion USD PPP (3.9 billion USD PPP billion among cattle keepers and 0.2 billion USD PPP among consumers).

To put these numbers in context, Table 4 also shows the results as a percentage of GDP and of the Ministry of Health budget. This comparison should be regarded with caution: the GDP and the government budget are annual values, whereas the social costs include the individual's life expectancy extending beyond one year. The total social cost of brucellosis, 4 billion USD PPP, is equivalent to 1.7 percent of the national GDP and close to 140% of a yearly budget for the Kenyan Ministry of Health.

**Table 4.** Brucellosis: cases, fatality, DALYs and social costs, 2016

	<b>Cattle keepers</b>	<b>Consumers</b>	<b>Total</b>
Number of cases (**)	1 154 417	121 501	1 275 917
Number of deaths (**)	11 544	460	12 004
Years of life lost due to mortality (YLL)	479 922	19 139	499 061
Years lost due to morbidity (YLD)	3 382	358	3 740
DALYs (YLL + YLD)	483 303	19 498	502 801
Willingness to pay for one year of healthy life (USD PPP)	8 091	8 091	8 091
<b>Total social cost (million USD PPP)</b>	<b>3 910</b>	<b>157.7</b>	<b>4 068</b>
<i>Total social cost (as % of Kenyan GDP)<sup>1</sup></i>			1.7%
<i>Total social cost (as % MoH budget)<sup>2</sup></i>			139.68%

Note. Source: ASL2050 Expert Data calculated. MoH: Ministry of Health. Sources for (1) is Output at current prices (KNS, 2016); and (2) GoK, 2018. National and County governments Budget allocation and expenditure (2015/16 and 2016/17): Agriculture, Health and Environment sectors. Office of the Controller of Budgets, Republic of Kenya, Ref: COB/GEN/002/Vol.1. Dated 12/02/2018. Values in PPP stands for international dollar purchasing power parity and the exchange rate is obtained from WB (2018).

<sup>5</sup> The age of infection is 25 years for consumers and slightly varies for cattle keepers in different production systems. Calculations are based on the specific average age when infected and for the different categories of people

### Cost of brucellosis of animals and humans

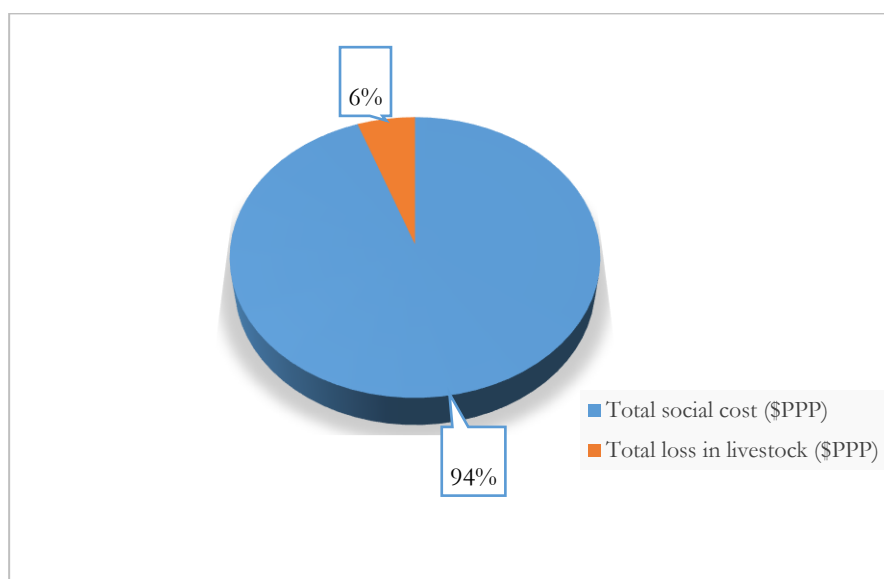
To compare the cost of brucellosis of animals and humans, we must address the fact that mortality costs calculates the “loss” of future years as described above, whereas all other estimates refer to losses encountered in 2016. Therefore, in the comparison below we account for the 12 004 deaths of people at the willingness to pay for a healthy life in 2016 in Kenya i.e. 8 091 dollars.

Table 5 presents the social cost of brucellosis for livestock keepers versus the cost associated to reduced animal production and animal deaths. It shows that the social cost is much higher than animal-related losses. Figure 5 shows the relative weight of total costs in humans and animals, which confirms that brucellosis has major negative externalities on public health, as about 94 percent of its costs are associated to morbidity and mortality in humans. The highest losses are in semi intensive beef and dairy production systems.

**Table 5.** Cost of brucellosis of animals and humans by production system

	<b>D – Int.</b>	<b>D - S.Int</b>	<b>D – Ext</b>	<b>B - Feedlot</b>	<b>B – S.Int</b>	<b>B - Past.</b>	<b>B - Ranch</b>	<b>TOTAL</b>
Animal losses (million USD PPP)	21.4	37.7	17.4	0.4	41.5	05.1	4.1	237.5
Livestock keepers (million USD PPP)	472.3	1 181.7	68.6	0.2	1 361.1	823.3	3	3 910.2
Consumers (million USD PPP)								157.7
<b>Total (million USD PPP)</b>								<b>4 305.5</b>

Note: D – Int. = Dairy - Intensive; D - S.Int = Dairy - Semi-Intensive; D – Ext. = Dairy - Extensive; B – Feedlot = Beef - Feedlot; B – S.Int = Beef - Semi-intensive; B - Past. = Beef - Extensive pastoralism; B – Ranch = Beef - Extensive ranching.



**Figure 5.** USD cost (percent) of brucellosis in cattle and humans

### **4.2.2 Bovine Tuberculosis (TB)**

#### Bovine TB in Cattle

Table 6 shows the value of animals lost and the value of production lost due to bovine TB by production system. This loss is estimated using data obtained through expert elicitation on selected animal health indicators (variables described in figure 1). The animal loss per year due to bovine TB amounts to 175.6 million USD PPP in Kenya, which represents 6 percent of the cattle value added (GDP). The majority of losses (84 percent) is due to animal deaths, with the remaining due to foregone production (Figure 6).

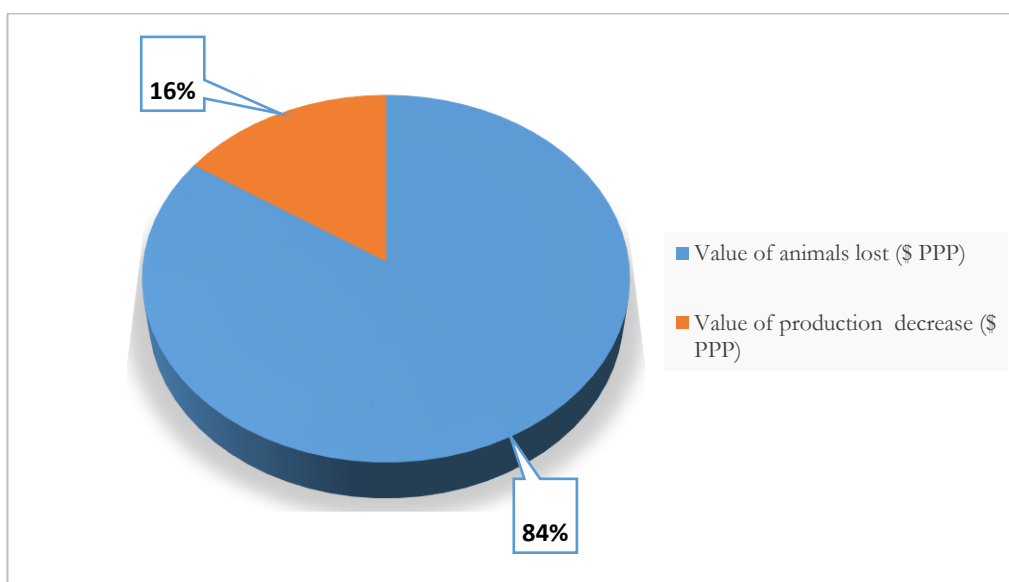
The results indicate a high mortality rate for bovine TB (23 percent), which contributes to the high value of animal losses.

Extensive pastoralism (beef production) records both the highest animal loss and foregone production, it is followed by intensive dairy and semi intensive systems. This is expected as these systems (ext. pastoralism, beef and dairy semi-intensive and dairy intensive) have larger animal population and higher estimated TB prevalence

**Table 6.** Value of animals lost and the value of production lost due to Bovine TB by beef and dairy production system

	<b>D – Int.</b>	<b>D - S.Int</b>	<b>D – Ext</b>	<b>B - Feedlot</b>	<b>B – S.Int</b>	<b>B - Past.</b>	<b>B - Ranch</b>	<b>TOTAL</b>
Estimated prevalence	2.2%	1.8%	0.8%	0.5%	0.7%	2.5%	1.2%	1.8%
Value of animals lost due to the disease (million USD PPP)	21.4	14.6	2.9	0.1	21.2	82.9	5.1	148.2
Value of production lost due to the disease (million USD PPP)	7.8	5.2	0.9	0.03	1.2	11.2	1.1	27.4
<b>TOTAL (million USD PPP)</b>	<b>29.2</b>	<b>19.7</b>	<b>3.8</b>	<b>0.1</b>	<b>22.5</b>	<b>94.1</b>	<b>6.2</b>	<b>175.6</b>
<i>Animal losses as % Cattle GDP<sup>1</sup></i>								<i>6.0%</i>
<i>Animal losses as % MALF budget expenditure<sup>2</sup></i>								<i>16.8%</i>

Note: D – Int. = Dairy - Intensive; D - S.Int = Dairy - Semi-Intensive; D – Ext. = Dairy - Extensive; B – Feedlot = Beef - Feedlot; B – S.Int = Beef - Semi-intensive; B - Past. = Beef - Extensive pastoralism; B – Ranch = Beef - Extensive ranching; MALF = Ministry of Agriculture, Livestock and Fisheries. Sources for (1) are Output at current prices (KNS, 2016); and (2) GoK, 2018. National and County governments Budget allocation and expenditure (2015/16 and 2016/17); Agriculture, Health and Environment sectors. Office of the Controller of Budgets, Republic of Kenya, Ref: COB/GEN/002/Vol.1. Dated 12/02/2018, Values in PPP stands for international dollar purchasing power parity and the exchange rate is obtained from WB (2018).



**Figure 6** Cattle production systems: value of production loss and animals lost (%) due to Bovine TB

Table 7 shows losses per case, including the value of animal lost and foregone production. The highest loss per case is in the dairy extensive system (963 USD PPP) and the lowest is in the beef extensive pastoralism system (470 USD PPP). The average loss expressed as a percentage of the farm gate price of a healthy animal is 53 percent. It is higher in the dairy extensive and beef semi-intensive systems and lower in beef feedlots and ranching systems.

**Table 7.** Estimated losses due to bovine TB per case in cattle

	D – Int.	D - S.Int	D – Ext	B - Feedlot	B – S.Int	B - Past.	B - Ranch	TOTAL
Value of animals lost per case (USD PPP)	514	374	734	396	528	414	571	467
Value of production lost per case (USD PPP)	187	133	229	134	31	56	125	78
<b>TOTAL loss per case (USD PPP)</b>	<b>701</b>	<b>507</b>	<b>963</b>	<b>529</b>	<b>559</b>	<b>470</b>	<b>696</b>	<b>545</b>
<i>Loss per case as a percentage of the farm-gate price of a healthy animal</i>	44%	47%	60%	41%	58%	55%	43%	53%

Note: D – Int. = Dairy - Intensive; D - S.Int = Dairy - Semi-Intensive; D – Ext. = Dairy - Extensive; B – Feedlot = Beef - Feedlot; B – S.Int = Beef - Semi-intensive; B - Past. = Beef - Extensive pastoralism; B – Ranch = Beef - Extensive ranching.

### Bovine TB in Human Beings

As described above, the social cost of the disease is estimated as the sum of the cost of mortality and cost of morbidity. Results are shown in Table 8 for the cattle keepers, consumers and the reference population. In 2016, 1 168 people died of Bovine TB out of 9 689 cases, at an average age of 31.25 years<sup>6</sup>. About 70 percent of the fatalities occurred among livestock keepers. According to the World Bank, life expectancy is 66.65 years, meaning we account for 1 168 deaths \* (66.65-31.25) years of life lost all together, i.e. a total of 41 590 years.

To put these numbers into context, Table 8 shows these results as a percentage of GDP and of the budget expenditures of the Ministry of Health. This comparison should be regarded with caution: the GDP and budget are annual values, whereas mortality costs include the individual's life expectancy, which extends beyond one year. The social total cost of bovine TB, 336.5 million USD PPP, is equivalent to 0.1 percent of the national GDP and close to 12 percent of the yearly budget for the Kenyan Ministry of Health.

**Table 8.** Bovine TB: cases, fatality, DALYs and social cost, 2016

	Cattle keepers	Consumers	Total
Number of cases (**)	9 689	6 894	16 582
Number of deaths (**)	824	345	1 168
Years of life lost due to mortality (YLL)	28 121	12 631	40 752
Years lost due to morbidity (YLD)	482	356	839
DALYs (YLL + YLD)	28 603	12 987	41 590
Willingness to pay for 1 year of healthy life (USD PPP)	8 091	8 091	8 091
<b>Total social costs (million USD PPP)</b>	<b>231.4</b>	<b>105.1</b>	<b>336.5</b>
<i>Total social cost (as % of Kenya GDP)<sup>1</sup></i>			0.1%
<i>Total social cost (as % MoH budget expenditures)<sup>2</sup></i>			11.55%

Note: (\*\*) source: ASL2050 Expert Data calculated. MoH: Ministry of Health. Sources for (1) is Output at current prices (KNS, 2016); and (2) GoK, 2018. National and County governments Budget allocation and expenditure (2015/16 and 2016/17): Agriculture, Health and Environment sectors. Office of the Controller of Budgets, Republic of Kenya, Ref: COB/GEN/002/Vol.1. Dated 12/02/2018, and Values in PPP stands for international dollar purchasing power parity and the exchange rate is obtained from WB (2018).

### Cost of Bovine TB in animals and humans

Table 9 compares the cost of Bovine TB in animals and humans, including details by production system when available. The total annual loss in livestock is estimated to be 175.6 million USD PPP, while the social cost in humans is 336.5 million USD PPP. The social cost of Bovine TB is much higher than the

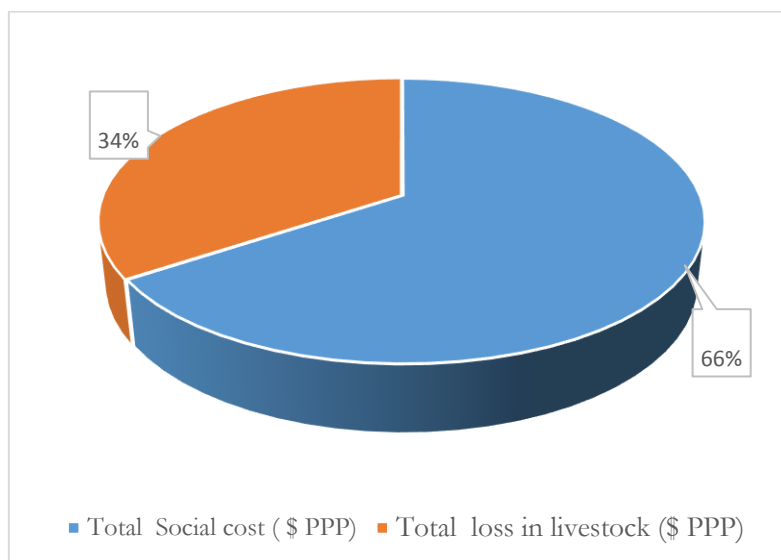
<sup>6</sup> The average is calculated considering the different average age of infection for cattle keepers (33 years) and for consumers (30 years).

value of animal loss across the production systems, with morbidity and mortality in humans contributing to about 66 percent of all Bovine TB cost for society (Figure 7).

**Table 9.** Cost of Bovine TB in animals and humans

	<b>D – Int.</b>	<b>D - S.Int</b>	<b>D – Ext</b>	<b>B - Feedlot</b>	<b>B – S.Int</b>	<b>B - Past.</b>	<b>B - Ranch</b>	<b>TOTAL</b>
Animal losses (million USD PPP)	29.2	19.7	3.8	0.1	22.5	94.1	6.2	175.6
Livestock keepers (million USD PPP)								231.4
Consumers (million USD PPP)								105.1
<b>Total (million USD PPP)</b>								<b>512.1</b>

Note: D – Int. = Dairy - Intensive; D - S.Int = Dairy - Semi-Intensive; D – Ext. = Dairy - Extensive; B – Feedlot = Beef - Feedlot; B – S.Int = Beef - Semi-intensive; B - Past. = Beef - Extensive pastoralism; B – Ranch = Beef - Extensive ranching.



**Figure 7.** USD cost (percent) of bovine tuberculosis in cattle and humans

#### 4.2.3 Salmonellosis

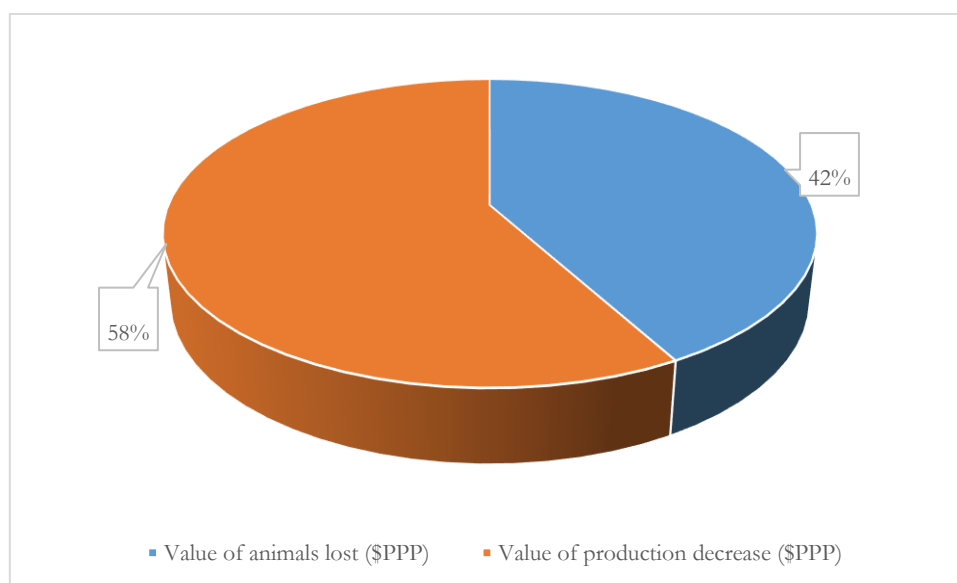
##### Salmonellosis in Poultry

Table 10 shows the value of animals lost and production loss by poultry production system. The animal loss per year due to salmonellosis amounts to 44.1 million USD PPP, which represents about 17 percent of the poultry value added, equivalent to approximately 4 percent of the annual budget of the Ministry of Agriculture, Livestock and Fisheries. The prevalence of the disease is higher in the free-range system (14 percent) than in the other production systems, aggregate losses are higher in the semi-intensive system. About 58 percent of the loss is due to reduced production and productivity, with 42 percent due to loss of birds (Figure 8).

**Table 10.** Value of animals lost, and the value of production lost due to Salmonellosis in poultry systems

	<b>Intensi ve</b>	<b>Semi- Intensive</b>	<b>Free- range</b>	<b>TOTAL</b>
Estimated prevalence	9%	9%	14%	11%
Value of animals lost due to the disease (million USD PPP)	4.1	6.9	7.5	18.5
Value of production lost due to the disease (million USD PPP)	4	11.9	9.7	25.6
<b>TOTAL (million USD PPP)</b>	<b>8.1</b>	<b>18.9</b>	<b>17.2</b>	<b>44.1</b>
<i>Animal losses as % Poultry GDP<sup>1</sup></i>				16.9%
<i>Animal losses as % MALF budget expenditure<sup>2</sup></i>				4.22%

Note: MALF = Ministry of Agriculture, Livestock and Fisheries. Sources for (1) are Output at current prices (KNBS, 2016); and (2) GoK, 2018. National and County governments Budget allocation and expenditure (2015/16 and 2016/17): Agriculture, Health and Environment sectors. Office of the Controller of Budgets, Republic of Kenya, Ref: COB/GEN/002/Vol.1. Dated 12/02/2018. Values in PPP stands for international dollar purchasing power parity and the exchange rate is obtained from WB (2018).



**Figure 8.** Poultry production systems: value of production loss and birds lost (%) due to salmonellosis

Table 11 shows losses due to salmonellosis per case. A case of salmonellosis costs on average 11 USD PPP. The cost is higher in semi extensive and intensive systems (17 and 11 USD PPP per case) than in free-range systems (7 USD PPP per case). This is explained by the fact that birds are more productive in the former than in the latter systems.

As a percentage of the price of a live bird, a salmonellosis case in poultry represents a loss equivalent to the 121 percent of its farm-gate price (Table 11). This value is higher for semi-intensive and intensive systems and lower for free-range systems. The loss per case can be higher than the price of a bird as the average value of foregone production is higher than the average value of an animal.

**Table 11.** Estimated losses due to salmonellosis in poultry production systems

	<b>Intensive</b>	<b>Semi- Intensive</b>	<b>Free- range</b>	<b>TOTAL</b>
Value of animals lost per case (USD PPP)	5	6	3	5
Value of production lost per case (USD PPP)	5	11	4	6
<b>TOTAL loss per case (USD PPP)</b>	<b>11</b>	<b>17</b>	<b>7</b>	<b>11</b>
<i>Loss per case as a percentage of the farm-gate price of a healthy animal</i>	145%	163%	77%	121%

## Salmonellosis in Human Beings

Table 12 presents values of the social cost of salmonellosis in humans, estimated as the sum of the cost of mortality and morbidity. In 2016, 3 871 people died of salmonellosis out of 38 945 cases, on average at age 27.50<sup>7</sup>. According to the World Bank, life expectancy in Kenya is 66.65 years, meaning that 3 871 deaths \* (66.65-27.50) years of life lost all together were estimated. The social cost of salmonellosis is thus estimated to be 1 061.2 million USD PPP, with 78 percent of all losses among poultry keepers (823.5 million USD PPP vs 237.7 million USD PPP among consumers).

To put these numbers in context, Table 12 shows the cost of salmonellosis in humans as a percentage of the GDP and of the annual budget of the Ministry of Health. This comparison should be regarded with caution: the domestic output and the budget are annual values, whereas mortality costs include the individual's life expectancy, which is more than one year. The social total cost of salmonellosis is equal to 0.4 percent of the Kenyan GDP and 36.4 percent of the annual budget of the Ministry of Health.

**Table 12.** Salmonellosis from poultry: cases, fatality, DALYs and social cost in humans, 2016

	Poultry keepers	Consumers	Total
Number of cases (**)	30 426	8 518	38 945
Number of deaths (**)	3 121	750	3 871
Years of life lost due to mortality (YLL)	101 720	29 343	131 063
Years lost due to morbidity (YLD)	63	34	96
DALYs (YLL + YLD)	101 783	29 377	131 160
Willingness to pay for one year of healthy live (USD PPP)	8 091	8 091	8 091
<b>Total social cost (million USD PPP)</b>	<b>823.5</b>	<b>237.7</b>	<b>1 061.2</b>
<i>Total social cost (as % of Kenyan GDP)<sup>1</sup></i>			<i>0.4%</i>
<i>Total social cost (as % MoH budget expenditure)<sup>2</sup></i>			<i>36.44%</i>

Note: Source: ASL2050 Expert Data calculated. MoH: Ministry of Health. Sources for (1) is Output at current prices (KNS, 2016); and (2) GoK, 2018. National and County governments Budget allocation and expenditure (2015/16 and 2016/17): Agriculture, Health and Environment sectors. Office of the Controller of Budgets, Republic of Kenya, Ref: COB/GEN/002/Vol.1. Dated 12/02/2018. Values in PPP stands for international dollar purchasing power parity and the exchange rate is obtained from WB (2018).

## Cost of Salmonellosis in animals and humans in 2016

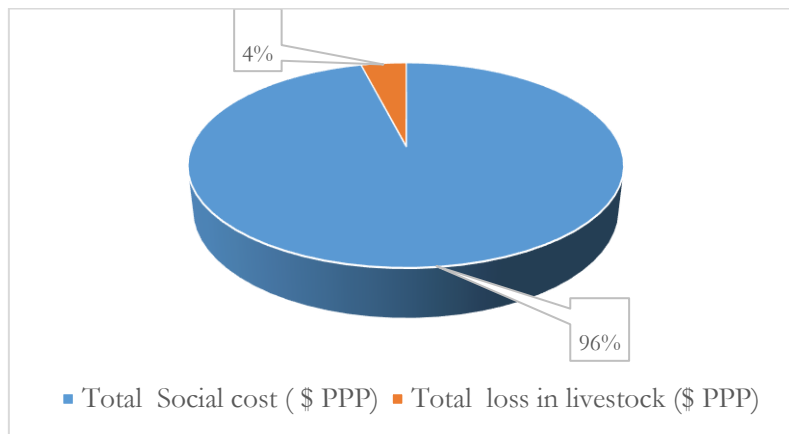
Table 13 compares the cost of salmonellosis in birds and humans, and by poultry keeper in the different production systems. Total costs of salmonellosis amount to 1 061.2 million USD PPP. Figure 9 shows the shares of losses between social and chicken losses. The results show that social cost is the majority (96 percent in front of 4 percent of animals' costs), especially in the free-range system.

**Table 13.** Cost of salmonellosis in poultry and humans

	Intensive	Semi-Intensive	Free-range	Total
Animal losses (million USD PPP)	8.1	18.9	17.2	44.1
Livestock keepers losses (million USD PPP)	5.9	70.2	747.4	823.5
Consumers losses (million USD PPP)				237.7
<b>Total (million USD PPP)</b>				<b>1 061.2</b>

<sup>7</sup> The average age of infection varies between population groups. For poultry keepers in intensive, semi-intensive and free-range systems it is 21.75, 20.5 and 35 years, respectively. For consumers, the average age of infection is 27.5 years.





**Figure 9.** USD cost (percent) of salmonellosis in chicken and humans

### 4.3. Discussion

Prevalence and fatality estimates of brucellosis, bovine TB and salmonellosis are generally within previously reported numbers, when available. Otherwise, they represent a first estimation to substantiate with additional evidence. For brucellosis, experts reported brucellosis prevalence for cattle in Kenya to be 6.4 percent (see Table 1). This data is in line with previously reported rates ranging between 2 and 25 percent (OIE, 2013) with intensive systems having generally lower incidences. Osoro *et al.* (2015) report 15.5 to 46.5 percent prevalence rates in extensive systems and 2.4 percent in intensive systems. Generally, prevalence of brucellosis in cattle is highly variable and is highest in pastoral production system (Kadohira *et al.*, 1997). Although experts estimated fatality rate in cattle to be 1.6 percent, there is not much information in literature and official reports on the disease causing mortalities in cattle in Kenya. Despite being severely debilitating and disabling, brucellosis is rarely fatal (Morris, 2013).

In human cases, the data reported in Table 1 show a significant difference in the prevalence of brucellosis among livestock keepers and consumers, 7.1 and 0.5 percent respectively. Integrated Disease Surveillance and Response (IDSR) reports of Ministry of Health found a 0.23 percent prevalence in Kenya, which is in line with our findings for consumers (GoK, 2016a).

Animal health experts determined that the bovine TB prevalence and fatality in Kenya are 1.8 and 23 percent respectively. Studies on bovine TB prevalence in cattle in the country reported prevalence between 1 and 2.2 percent, largely relying upon secondary data analysis performed during routine abattoir meat inspection (Gathogo, Kuria and Ombui, 2012; Fèvre *et al.*, 2017). In Uganda, other studies showed that the prevalence was significantly higher in the agro-pastoral zone (8.3 percent) than in the pastoral zone (4.33 percent) (Bernard *et al.*, 2005), while in Ethiopia the pooled prevalence estimate of bovine tuberculosis is 5.8 percent and *Mycobacterium bovis* is widely found across major livestock producing regions (Sibhat *et al.*, 2017).

Bovine tuberculosis in humans is not easy to diagnose, even “health-care workers have few diagnostic tools to differentiate *M. bovis* from *M. tuberculosis* in humans, which means that the true burden of the disease in humans is unknown and may be underestimated” (WHO, 2018, pp. 82). Experts estimated a 0.06 percent bovine TB prevalence rate for cattle keepers, and 0.03 percent in consumers. Although there is no official data on the prevalence of *Mycobacterium bovis* in humans in Kenya, some studies have reported rates ranging between 6.9 and 9.6 percent (Bernard *et al.*, 2005). According to Kenya TB prevalence survey of 2016, prevalence rate for human TB in Kenya is 558/100 000 (0.06 percent) (GoK 2016 b), which is line with the estimates in this brief. The role of *Mycobacterium bovis* is however unknown.

Prevalence of Non-Typhoidal Salmonella (NTS) serovars circulating in poultry farms and poultry products are unknown. In Kenya, experts evaluate salmonella prevalence and fatality rates in poultry to be 11 and 24 percent, respectively. A study attempting to determine salmonellosis prevalence has reported 3.6 percent in birds and 5.9 percent in eggs across Kenya (Nyabundi *et al.*, 2017). Similar studies show salmonellosis contamination rates for chicken in Ethiopia vary from 0.8-11 percent (Aragaw *et al.*, 2010) while in Tanzania they vary from 6.3 -18.4 percent (Mdegela *et al.*, 2000). Estimates from experts' data also show that the prevalence rate for Salmonellosis in poultry is 14 percent which is higher in the free-range system and 9 percent in the intensive systems. Similarly, a study in Ethiopia found that there was a higher prevalence of salmonella in the indigenous chicken 71.4 percent compared to the grade chicken 28.6 percent (Endris *et al.*, 2013). This is coherent with the description of poultry production systems from FAO (2017b), in which the free-range systems' birds are left to freely scavenge and where sanitary measures are limited.

In humans, NTS is a major global health concern, with an estimated 93.8 million human cases and 155 000 deaths each year (Nyabundi *et al.*, 2017). In Kenya, the number of cases reported by MoH through the integrated Disease Surveillance and Response (IDSR) in 2016 is 675 695 cases of both typhi and non-typhi salmonellosis. Some studies have reported incidences of 568/100 000 and 51/100 000 NTS in rural and urban centres respectively (Tabu *et al.*, 2012). The implementation of the expert elicitation protocol allowed to obtain prevalence and fatality rates for poultry keepers and consumers, salmonellosis prevalence in humans is estimated at 0.1 percent and fatality rate in the range of 9 to 10 percent (see Table 1).

Overall, experts' estimates appear consistent with the available evidence, which substantiates the results presented in this brief. The results teaches several lessons: The first one is that, in livestock, economic losses due to animal death and foregone production vary widely depending on the disease. For example, about 65 percent of animal losses due to brucellosis are explained by reduced production, while in the case of bovine TB this percentage is 16 percent. The second lesson is that zoonotic diseases can have a major impact on public health, as measured in monetary terms. The total social cost of brucellosis and bovine tuberculosis and of Non-typhoidal Salmonella is estimated to be around 6 billion USD PPP, which corresponds to 3.9 percent of the national GDP. The third and possibly most important lesson, is that the cost of these three zoonotic diseases for society is largely accounting for morbidity and mortality in humans, rather than for reduction in animal production and productivity. This lesson is of paramount relevance for the design of any "One Health" policy, which facilitates improving public health by tackling zoonotic diseases at their source.

## **5. 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 study the value of losses due to morbidity and mortality in animals and humans due to three zoonotic diseases in Kenya were assessed.

The livestock production complexity increases and the associated value chains have led to changes in the food systems, which carry new challenges from zoonotic diseases, their impact, and the costs of surveillance, control and prevention. Direct losses in 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 negative impact. Animals' morbidity and mortality due to zoonotic diseases also carry other losses related to the wider social, cultural and economic value of animals and their health and welfare to people. In Kenya, cattle and poultry are a main source of livelihoods, income and employment, they provide nutritious food and other non-tradable benefits, such as insurance and savings.

Kenya is particularly vulnerable to the zoonotic diseases' impacts due to the very close relationship and interaction between livestock and humans and also because more the largest share of households in the country keep livestock. It is imperative that evaluating the impact of zoonoses to facilitate decision-making receives more attention and importance, because of the imminent changes in the size and form of livestock production. Currently it is difficult to get data to measure zoonoses impact. We experimented with a new methodology, including the implementation of an expert elicitation protocol and the assessment in monetary terms of zoonotic diseases on society. Results suggest zoonotic impacts diseases are high, both from a livestock and human health perspective. This supports the significance of adopting a genuinely true "One Health" approach when designing and implementing livestock sector policies and strategies. Kenya may consider refining the expert elicitation protocol and expand it to other diseases to provide an improved information base for decision makers.

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## APPENDIX

### A1. DATA SOURCES

- **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 impact of the priority diseases in the countries. More than 250 experts were interviewed in 6 countries. 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:** Nationally representative household survey data implemented by the countries' National Statistical Offices allow 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.

### A2. EQUATIONS

We determine 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)

$$\begin{aligned} &= \\ &\text{Value of animals lost (I)} \\ &+ \\ &\text{Loss from salvage slaughter and culling (II)} \\ &+ \\ &\text{Loss from production decrease (III)} \\ &+ \\ &\text{Social cost of human mortality (IV.1)} \\ &+ \\ &\text{Social Cost of human morbidity (IV.2)} \end{aligned}$$

#### (I) Value of animals lost

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

$$\begin{aligned} &\text{Value of animals lost} \\ &= \\ &\text{Number of animals died due to disease (I.1)} \\ &\quad * \\ &\quad \text{Animal farmgate price (I.2)} \\ &+ \\ &\text{Number of carcasses condemned (I.3)} \\ &\quad * \\ &\quad \text{Animal farmgate price (I.2)} \end{aligned}$$

$$\begin{aligned}
 &+ \\
 &\text{Number of unborn calves (I.5)} \\
 & * \\
 &\text{Calf farmgate price (I.6)}
 \end{aligned}$$

**I.1 Number of animals died due to the disease:** 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 and per 1 000 000 birds for HPAI.

**I.2 Adult animal farmgate price:** To attach a monetary value to the number of animals lost, country data on the adult animal farmgate price was used.

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

**I.4 Number of unborn calves:** 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:

$$\begin{aligned}
 &\text{Number of unborn calves (I.4)} \\
 &= \\
 &\text{Number of survivors (Protocol: cases-deaths)} \\
 & * \\
 &\text{Share of adult cows (Country data and literature)} \\
 & * \\
 &\text{Calving rate (Country data and literature)} \\
 & * \\
 &\text{Fertility loss (Protocol)}
 \end{aligned}$$

## **(II) Salvage slaughter and culling**

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 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.

$$\begin{aligned}
 &\text{Loss from salvage slaughter and culling (cattle)} \\
 &= \\
 &(\text{Number of salvage slaughter} + \text{Number of animals culled} - \text{Number of carcasses condemned}) \text{ (II.1)} \\
 & * \\
 &(\text{Animal farmgate price (I.2)} - \text{Salvage value (II.2)})
 \end{aligned}$$

**II.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.

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



### **(III.) Loss from production decrease**

The animals 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:

$$\begin{aligned} & \text{Loss of production decrease (cattle)} \\ & = \\ & \text{Loss of meat production (III.1)} \\ & + \\ & \text{Loss of milk production (III.2)} \end{aligned}$$

#### **(III.1) Loss of meat production**

$$\begin{aligned} & \text{Loss of meat production} \\ & = \\ & \text{Number of survivors (cases-deaths, Protocol)} \\ & * \\ & \text{Weight loss in kilograms per head (Protocol)} \\ & * \\ & \text{Dressing percentage (Country data and literature)} \\ & * \\ & \text{Price of beef per kg (Country data, FAOSTAT)} \end{aligned}$$

#### **(III.2) Loss of milk production**

$$\begin{aligned} & \text{Loss of milk production} \\ & = \\ & \text{Loss from foregone lactation period (III.2.1)} \\ & + \\ & \text{Loss from milk productivity decrease (III.2.2)} \end{aligned}$$

##### **III.2.1 Loss from forgone lactation period:**

$$\begin{aligned} & \text{Loss from foregone lactation period} \\ & = \\ & \text{Number of unborn calves (see I.5 above)} \\ & * \\ & \text{Average litres per lactation (Country data by production system)} \end{aligned}$$

##### **III.2.2 Loss from milk productivity decrease:**

$$\begin{aligned} & \text{Loss from productivity decrease} \\ & = \\ & \text{Number of cows affected by productivity decrease (II.2.1)} \\ & * \\ & \text{Milk loss in litres per lactation period (Protocol)} \end{aligned}$$

*II.2.1 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):

$$\begin{aligned} & \text{Number of survivors (cases-deaths from Protocol)} \\ & * \\ & \text{Share of adult cows (Country data and literature)} \\ & * \\ & \text{Calving rate (Country data and literature)} \end{aligned}$$

(1-Fertility loss) (Protocol)

Variables:

**Number of livestock keepers by production system:** We estimate the number of people who are posed 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 and poultry. 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 and poultry products using the Global Consumption Database of the World Bank.<sup>8</sup>

**VI.1 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.

$$\begin{aligned} & \text{DALY} \\ & = \\ & \text{Number of deaths (Protocol)} \\ & * \\ & (\text{Average life expectancy (World Bank)} - \text{Average age of infection (Protocol)}) \\ & + \\ & \text{Number of survivors (Protocol)} \\ & * \\ & \text{Duration of disease (Protocol)} \\ & * \\ & \text{DALY weight (WHO)} \end{aligned}$$

**IV.2 Willingness to pay for a DALY**

To attach a monetary value to a DALY, we need to determine the willingness to pay 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. This value is then converted into country context using a benefit transfer methodology. This methodology considers 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).

$$\begin{aligned} & \text{Willingness to pay for a healthy life year} \\ & = \\ & \text{Willingness to pay for a healthy life year in the United States (PPP) (see below)} \\ & * \\ & (\text{GDP per capita in PPP of country} / \text{GDP per capita in PPP of US})^{\text{elasticity}} \\ & = \\ & \text{Willingness to pay for a healthy life in the United States (PPP)} \\ & = \\ & \text{Value of Statistical Life (US Department of Transport)} \\ & / \\ & \sum_{t=0..T} (1 + \text{discount rate})^t \end{aligned}$$

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<sup>8</sup> <http://datatopics.worldbank.org/consumption/detail>

