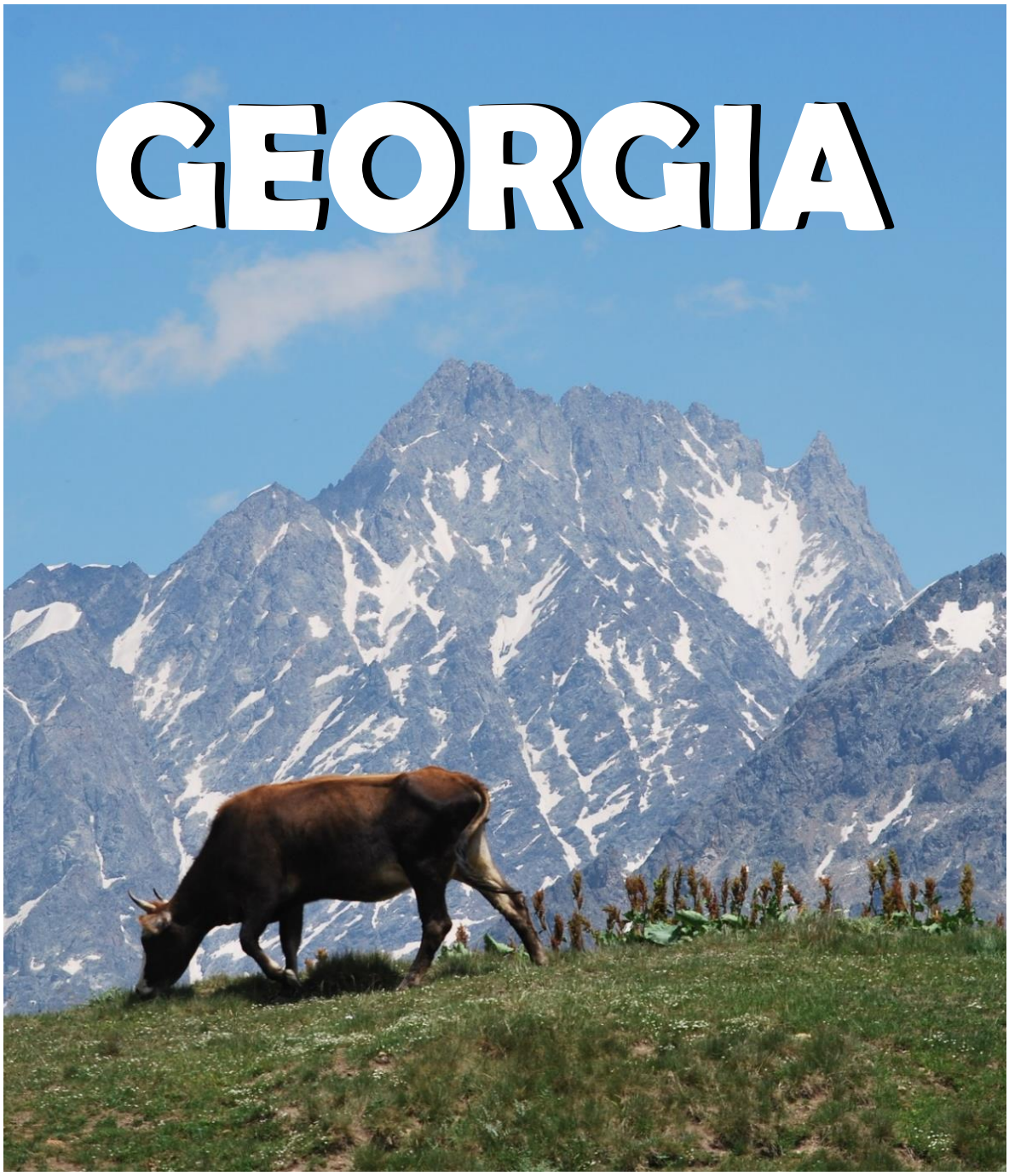
Food and Agriculture Organization of the United Nations

One Health cost–benefit analysis of control policies for the prevention of livestock brucellosis in



One Health cost–benefit analysis of control policies for the prevention of livestock brucellosis in Georgia

by
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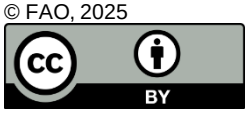


Contents

Abbreviations v
Executive summary vii
Background 1
Descriptive epidemiology of brucellosis in livestock and humans 2
Brucellosis in animals 2
Brucellosis in humans 6
Economic analysis of disease burden 10
Economic losses in livestock production 10
Economic losses for humans 13
Cost of brucellosis control programmes 17
Modelling the effects of alternative vaccination strategies 19
Analysed vaccination scenarios 19
Modelling immunity profiles in livestock and number of infected animals and humans 20
Cost–benefit analysis 24
Conclusions 29
Annexes 32
Bibliography 53

Figures

1 Bovine brucellosis in Georgia 4
2 Prevalence of brucellosis and density of large and small ruminants, 2011 5
3 Human brucellosis in Georgia 7
4 Distribution of human brucellosis in Georgia, 1970–2008 8
5 Distribution of Brucella melitensis and Brucella abortus isolates 9
6 Immunity profiles of different vaccination scenarios in small ruminants 20
7 Immunity profiles of different vaccination scenarios in large ruminants 21
8 Simulated number of infected cases in livestock and humans 23
9 Present value cash flow profiles of vaccination scenarios in small ruminants 25
10 Present value cash flow profiles of vaccination scenarios in large ruminants 27

Annex Figure 3.1 Annual predicted baseline disease occurrence in small ruminants with 95% confidence intervals 44
Annex Figure 3.2 Annual predicted baseline disease occurrence in large ruminants with 95% confidence intervals 44
Annex Figure 3.3 Annual predicted baseline disease occurrence in humans with 95% confidence intervals 45

Tables

1 Livestock gross margins per cattle, sheep and goats 11

2 Economic losses for humans 16

3 Cost–benefit analysis of present value monetary costs and benefits of vaccination scenarios in small ruminants (USD) 26

4 Cost–benefit analysis of present value monetary costs and benefits of vaccination scenarios in large ruminants (USD) 28

Table A1.1 Animal health-related information and parameters 32

Table A1.2 Human health-related information and parameters 34

Table A2.1 Immunity profile for continuous mass vaccinations in small ruminants (scenario A) 37

Table A2.2 Immunity profile for replacement stock vaccinations in small ruminants (scenario B) 38

Table A2.3 Immunity profile for interval mass vaccinations in small ruminants (scenario C) 39

Table A2.4 Immunity profile for mass vaccinations followed by replacements vaccinations in small ruminants (scenario D) 40

Table A2.5 Immunity profile for continuous mass vaccinations in large ruminants (scenario E) 41

Table A2.6 Immunity profile for replacement stock vaccinations in large ruminants (scenario F) 42

Table A2.7 Immunity profile for interval mass vaccinations in large ruminants (scenario G) 43

Table A4.1 Cash flow for scenario A: continuous mass vaccinations in small ruminants (USD) 46

Table A4.2 Cash flow for scenario B: replacement stock vaccinations in small ruminants (USD) 47

Table A4.3 Cash flow for scenario C: interval mass vaccinations in small ruminants (USD) 48

Table A4.4 Cash flow for scenario D: mass vaccination followed by replacement stock vaccinations in small ruminants (USD) 49

Table A4.5 Cash flow for scenario E: continuous mass vaccinations in large ruminants (USD) 50

Table A4.6 Cash flow for scenario F: replacement stock vaccinations in large ruminants (USD) 51

Table A4.7 Cash flow for scenario G: interval mass vaccinations in large ruminants (USD) 52

Abbreviations

BCR	benefit–cost ratio
CDC	United States Center for Disease Control
ELISA	enzyme-linked immunosorbent assay
FAO	Food and Agriculture Organization of the United Nations
GEOSTAT	National Statistics Office of Georgia
IFAD	International Fund for Agricultural Development
IPTM	Institute of Parasitology and Tropical Medicine
IRR	internal rate of return
NCDC	National Centre for Disease Control and Public Health of Georgia
NFA	National Food Authority
NPV	net present value
RBT	Rose Bengal test
TCP	Technical Cooperation Programme
WAHIS	World Animal Health Information System
WOAH	World Organisation for Animal Health
WHO	World Health Organization

Executive summary

1. An economic analysis was performed to assess the cost of brucellosis to households, to the public, and to the livestock production in Georgia. The burden of brucellosis on the human population was estimated from data on morbidity, duration of the disease, treatment as outpatient or inpatient, and lost income. Lost profit in animal production was estimated from the effect of abortion and reduced milk yield on gross margins of infected animals. The cost–benefit analysis focused on the net monetary gain associated only with vaccination strategies for brucellosis prevention and control. The effectiveness of proposed control measures was compared using spreadsheet models, estimating the number of vaccinated animals in the population over time, and the development of a mathematical model to estimate the number of infected animals over time according to vaccination scenarios.

2. The current annual losses from brucellosis in Georgia are estimated at USD 1.95 million. This includes:
   - USD 1.3 million from gross margin losses in animal production. Losses due to brucellosis are calculated at USD 90 per cow, USD 12 per sheep, and USD 20 per goat.
   - USD 362 000 from human health and productivity losses. The average human case costs USD 1 508, and this varies by case type. The majority of cases are outpatients, with medical costs of USD 1 116 per case; for uncomplicated or mildly complicated inpatients the cost is USD 2 006; and for complicated cases the cost is up to USD 3 328.
   - USD 282 000 for disease control (USD 203 000 for large ruminants, and USD 79 000 for small ruminants).

3. Current disease control consists of mass vaccination followed by replacement stock vaccinations. Nevertheless, due to shortcomings, its implementation resembles a replacement stock vaccination strategy. In Georgia, 250 000 small ruminants are vaccinated, and assuming an optimal seroconversion rate of 80 percent, the proportion of successfully immunized animals in the population is 22 percent. For large ruminants, the cumulative vaccination coverage for the 2016–2019 period is only 43 percent, so with a seroconversion rate of 80 percent, the proportion of successfully immunized animals would be 35 percent. The current benefits justify only 50 percent of the costs to control the disease, giving a negative return on investment.

4. To control brucellosis, the following programmes were compared:

Small ruminants

A) continuous mass vaccination of all small ruminants for four years;
B) replacement stock vaccination for eight years;
C) interval mass vaccination of all small ruminants at year one and three; and
D) one mass vaccination on year one, followed by replacement stock vaccinations.

Large ruminants

E) continuous mass vaccination of all large ruminants for four years;
F) replacement stock vaccination for ten years; and
G) interval mass vaccination of all large ruminants at year one and five.

The seven selected scenarios were thoroughly analysed, starting with the projected immunity they confer to the ruminant population, predicted effectiveness in reducing the disease burden, and comparison of costs and benefits and related indicators such as net present value, cost–benefit ratio, and internal rate of return. From an epidemiological point of view, the mass vaccination strategy is best at controlling the disease; however, due to large costs, this is economically unsuitable. On the other hand, replacement vaccination ranked third in terms of cost–benefit. Interval mass vaccination is equal to mass vaccination in controlling the disease, followed by replacement vaccination, which is the current model described in the strategy of the National Food Authority (NFA). However, although it is slightly inferior in reducing the disease burden, interval mass vaccination is effective in controlling the disease, and is the most profitable option economically.

5. The recommendation to optimize the current NFA strategy to control brucellosis in Georgia is to follow the interval mass vaccination strategy. The cost–benefit analysis indicates that the projected earnings generated by such a strategy exceeds the anticipated costs, with a net present value of USD 765 523 in small ruminants and an overall benefit–cost ratio (BCR) of USD 2.4 for the eight-year period, basically meaning that the government will get USD 2.4 in benefits for every dollar spent. For large ruminants, the same scenario has a net present value of USD 1 705 748 and a BCR of 2.0 for the ten-year period of implementation.

Background

Georgia is an agricultural country, with 50 percent of its 3.7 million inhabitants living in rural areas. Thus, the livestock sector is important for Georgian livelihoods. Official statistics show a population of 878 900 large ruminants and 869 500 small ruminants – distributed in 170 000 and 1 100 farms respectively. Most herds and flocks in Georgia are small backyard operations consisting of approximately five to ten cattle, 100 to 300 sheep, or five to ten goats. There are few commercial operations with acceptable biosecurity management systems; the majority of ruminants are reared in villages or nomadic flocks and herds. In the village husbandry system, backyard animals graze together with livestock from different villages in unfenced pastures. They have a common water source and are usually both small and large ruminants are housed in a barn together. In Georgia, there is a strong transhumance tradition, with animals moving to and from seasonal pastures. In winter and summer, animals from several owners are kept together. Sometimes, animals from different villages are kept together. There are also nomadic herds and flocks which may be herded long distances to seasonal pastures. They graze on pastures commonly used by local animals, with the possibility of direct contact between these two distinctive groups. The intermixing of animals from different locations increases the risk of spreading infectious diseases such as brucellosis.

It has been recognized that brucellosis is a serious problem in Georgia, for both livestock and humans. It is estimated that the prevalence in large ruminants could be between 1.2 and 6 percent, and in small ruminants between 1.4 and 2.2 percent. Nonetheless, the disease is not evenly distributed, and in some areas the prevalence is much higher. In humans, the annual average incidence rate is 4.6 cases per 100 000, with the majority of these cases in the eastern part of the country where there are more small ruminants. The Ministry of Health and Ministry of Agriculture are concerned by the hyperendemic situation of brucellosis in certain regions, so control measures such as vaccinations, testing and slaughter have been undertaken to reduce the disease burden in ruminant populations, and to prevent infection in humans. Although there are measures in place for brucellosis control, there is a need for programme evaluation and enhancement. Cost–benefit analysis has become a widely used technique in public policymaking due to the widespread interest in observing the tangible economic benefits of a given strategy. To assist the Georgian authorities, the Food and Agricultural Organization of United Nations (FAO), through its Technical Cooperation Programme (TCP), has commissioned the development of a cost–benefit analysis of the effectiveness of measures carried out to control brucellosis, and to propose recommendations for improvement and enhancement of these strategies.

Descriptive epidemiology of brucellosis in livestock and humans

Animal and human brucellosis cases are prevalent in many parts of Georgia, resulting in significant losses to livestock and causing debilitating disease to humans. Although the disease is recognized as an important health issue, there is a scarcity of data available on the disease burden on animals and humans. The following profiles of the disease in livestock and humans have been prepared by combining the basic data provided by the NFA and data collected from online databases. In addition, an extensive literature search was performed in English, Georgian and Russian languages. Relevant articles reporting on the presence, frequency, and control of brucellosis in humans and animals in Georgia have been evaluated, summarized, and necessary data extrapolated (see References and Annex 1).

Brucellosis in animals

Brucellosis in animals was first recorded in 1923/24 in Abkhazia. The period from 1965 to the late 1980s was characterized by the implementation of vaccinations, and test and slaughter of positive animals. At that time, USSR-produced vaccines (strain-19 and strain-82) were used in large ruminants, while the Rev-1 strain was used for small ruminants. However, coverage of vaccination was not high, no control of the vaccination procedure was made, the cold chain for the vaccine was not properly maintained, and the quality of the vaccine applied is unknown (NFA, 2016). Test and slaughter were based on the brucellin antigen, and brucellosis-positive animals were permanently marked with a stamp (those animals would then be sent to the abattoir). It is not known how the veterinary services at that time discriminated the vaccinated animals from the animals to be tested, and how efficient test and slaughter control measures were in a situation where all the applied vaccine strains would trigger positive results in diagnostic tests. The Soviet administration at that time stated that the ministries of health and agriculture of Georgia did not properly organize their work to protect human health and did not take the necessary measures to eliminate animal brucellosis. Therefore, outbreaks of brucellosis continued to occur, which to a certain extent resulted in an increase (see Figure 3) in the number of new human cases (MoA and MoH, USSR, 1977).

After Georgia won its independence, vaccination in general was discontinued. However, different reports state that it continued in high-risk zones in cattle with strain-19. These claims are reinforced by data from the World Organisation for Animal Health (WOAH) database Handistatus II, demonstrating that vaccinations were performed to a moderate degree. In 1996, there were 192 590 cattle vaccinated, while in 2003 and 2004 there were 116 350 and 125 313 heads vaccinated respectively (WOAH, 2016). Due to the absence of animal identification and because the vaccine titers interfered with serological monitoring vaccinations in 2005, the vaccinations were totally suspended.

In the early 1990s, small-scale surveys for cattle in high-risk areas were conducted every year to identify new foci, but no epidemiological information could be obtained from those surveys. In a 1996 WOAH report for Georgia, 816 cases distributed among 16 outbreaks were reported.[1]

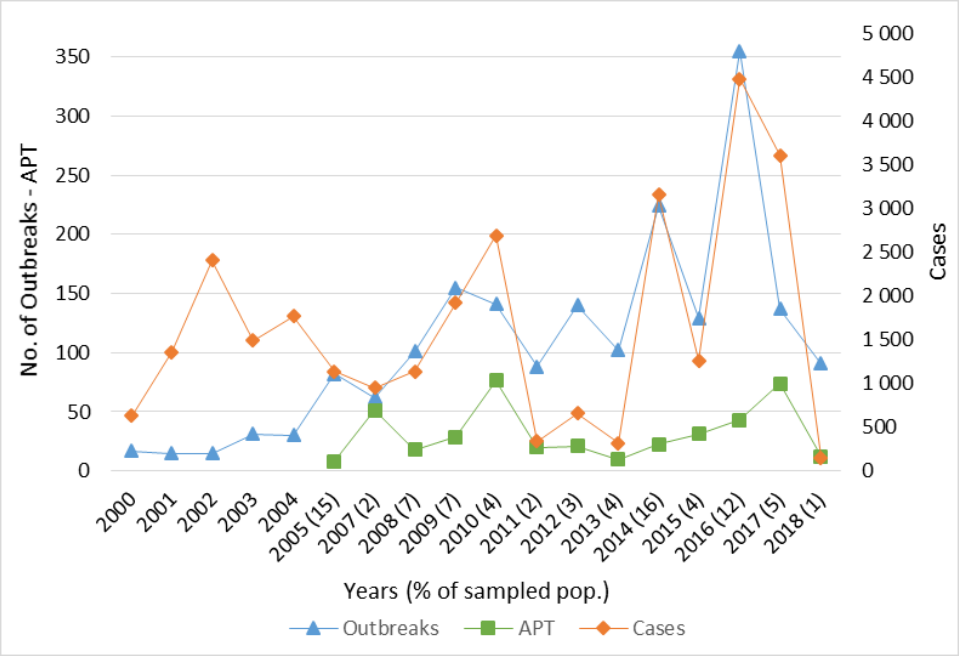
[1] It is assumed that the minor epidemiological unit in Georgia is the village, thus the outbreaks represent infected villages.

The standard protocol for testing animals is to conduct the Rose Bengal test (RBT) first on all samples. Those that are positive in the regional labs are forwarded to the central lab for additional testing. There, the RBT is conducted, as is the enzyme-linked immunosorbent assay (ELISA). Those samples that test positive on the ELISA are considered definitively positive. Although a polymerase chain reaction (PCR) is available in the central lab, it is rarely if ever used for brucellosis (Ragan, 2009).

Testing is performed mainly in cattle and only in high-risk areas, thus encompassing only a small fraction of the population. A total of 29 433 reactor animals were identified among 1 915 outbreaks between 2000 and 2018. The sampling information for the early 2000s is not available, but from 2005 to 2018, the proportion of sampled population ranged from as high as 15 percent in 2005 to a low of 1.3 percent in 2018, and with an annual average of around 6 percent. There is a good correlation between cases and outbreaks, and the average number of reactors per outbreak is around 11 cases. The annual incidence rate expressed as animals per thousand (APT) is on average 31 heads (or 3.1 percent), with spikes seen in 2010 and 2016 – with 76 and 74 APT.

Ironically, in the WOAH-World Animal Health Information System (WAHIS), all positive animals are declared slaughtered, which might lead one to conclude that 100 percent of infected animals are eliminated. Although the owners of brucellosis-positive animals are required to slaughter them, there is no economic incentive to slaughter all of them, since compensation for animals destroyed is not provided. When owners resist slaughtering, NFA veterinarians try to explain the importance of eliminating the animals, or in some cases revert to the local police. However, without the support of a fully functional animal identification and registration system (AIR) and a compensation scheme that redeems the full value of the animals, the test and slaughter strategy will fail to control the disease. Examples from other countries show that this strategy has been unsuccessful because there was no compensation, or it was carried out with partial marked value. On the other hand, without an AIR system, the test and slaughter strategy could backfire, as obviously farmers – in order to avoid slaughter of valuable reproducing animals – will sell them illegally, thus risking the further spread of the disease.

Figure 1. Bovine brucellosis in Georgia



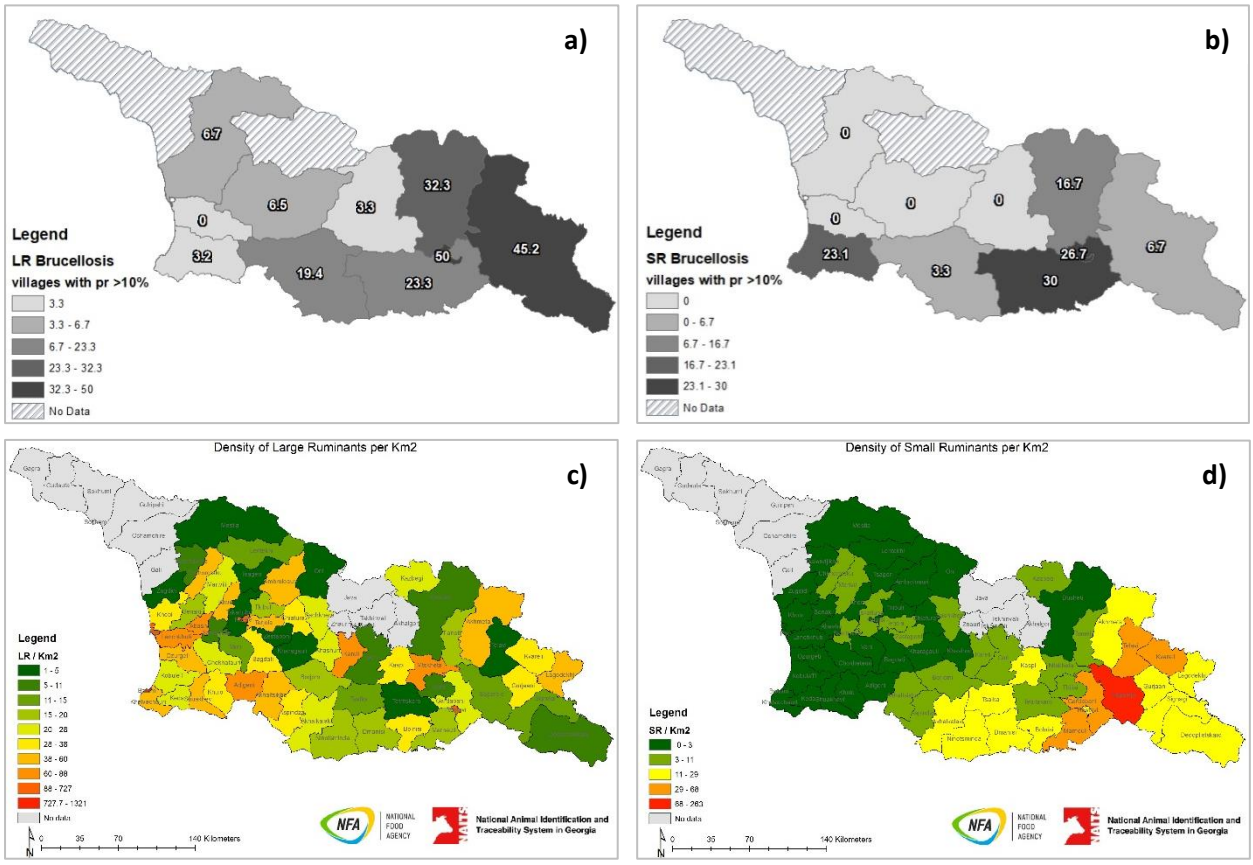
Note: Data from 2006 are missing.

Sources: data from 2000 to 2004 published in OIE Handistatus II (OIE, 2016), data from 2005 to 2018 published in WAHIS (WOAH, 2019).

There is virtually no programme-based testing in sheep and goats; only some limited testing is performed, mainly for trade purposes. There are concerns that the methods used to test small ruminants are not adequate, relying on antiquated Soviet standards – the cattle RBT method is used rather than the modified RBT that is used for small ruminants and recommended by the WOAH (Havas, 2011). According to WOAH–WAHIS data for Georgia, the level of sampling for these species for the period 2007–2012 was 5 504 animals, which is way too small to make any conclusions regarding actual prevalence in small ruminants. The fact that 119 samples were positive reveals a prevalence of 2.2 percent, which is indicative of a substantial spread in the population.

The above findings are primarily based on samples submitted for animals tested as part of the national plan, and should not be considered representative of the true prevalence. To address the lack of information, in 2011 the NFA implemented a serological survey based on a random probability-based sampling scheme aiming to detect hotspot areas. The estimated average proportion of villages with a prevalence level equal to or higher than 10 percent at national level was 16.5 percent (CI95%: 4.2, 28.4) in large ruminants and 8.1 percent (CI95%: 0.1, 16.1) in sheep and goats, but with pronounced differences by region.

Figure 2. Prevalence of brucellosis and density of large and small ruminants, 2011



Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.

Notes: (a) Regional distribution of the proportion of positive villages with a prevalence equal or higher than 10 percent in large ruminants in 2011; b) regional distribution of the proportion of positive villages with a prevalence equal or higher than 10 percent in large ruminants in 2011; c) density of large ruminants per square kilometre by municipality; d) density of small ruminants per square kilometre by municipality

Sources: *a. and b. NFA, 2016; c. and d. NFA Animal Identification and Registration data, 2018.* Regions where bovine brucellosis was detected at a high level were Kakheti, Tbilisi, Mtskheta-Mtianeti, Kvemo-Kartli, Samtskhe-Javakheti (East and South Georgia, see fig 2a).

All these regions are epidemiologically linked by seasonal movements of herds and flocks. Regions where sheep and goats brucellosis was detected at a high level are Kakheti, Tbilisi, Mtskheta-Mtianeti, Kvemo-Kartli, Samtskhe-Javakheti (East and South Georgia, see Figure 2, map b) (NFA, 2016). However, the survey was not able to estimate the animal-level prevalence, it only focused on detecting the disease in regions and epidemiological units with an occurrence equal to or higher than 10 percent. Therefore, in these species the disease prevalence and distribution are inadequately understood and likely underestimated.

Granular data from surveys conducted in 2014–2017 show that the animal incidence was low (<1 percent) in Samegrelo-Zemo-Svaneti, Adjara, Ratcha, Shida Kartli and Kakheti; medium or high (>2 percent) in Guria, Samtskhe-Javakheti, Mtskheta-Mtianeti and Kvemo Kartli; and very high (7.7 percent) in Tbilisi. Farm prevalence at country level was around 5 percent, with higher rates in Samtskhe-Javakheti (6.5 percent), Mtskheta-Mtianeti (9.6 percent) and Tbilisi (14.7 percent). With respect to village prevalence, the rate was high at country level (47 percent), meaning that almost five out of ten villages tested had positive reactors.

Village prevalence was high in Samtskhe-Javakheti (45 percent), Kvemo Kartli (57 percent) and Kakheti (42 percent), all with a high cattle population (see Figure 2, map b). It was

extremely high in Tbilisi (71 percent), were seven out of ten had positive reactors. Nonetheless, this data should be treated with caution, because the surveys were risk-based rather than population-based, meaning that at the population level the figures are expected to be lower.

It is assumed that the disease is related with the density of affected populations. However, the higher proportion of infected villages in large ruminants in Kakheti, Mtskheta-Mtianeti, Kvemo-Kartli and Tbilisi could suggest that apart from infection with *Brucella abortus*, the infection is amplified by spillovers of *Brucella melitensis* in cattle from small ruminants, which abound in these regions. The discrepancies are visible by comparing the proportion of infected villages with Guria, Samegrelo-Zemo Svaneti and Adjara, where cattle densities are quite high but small ruminants are few. The presence of *Brucella melitensis* in cattle has been documented in Georgia (NFA, 2016). Apart from test and slaughter, in 2016 the NFA enhanced disease control in cattle by starting the implementation of a vaccination campaign with the RB51 strain. The strategic action consisted of a mass vaccination of all eligible animals followed by vaccination of replacement stock. The mass vaccination schedule was to be implemented in Adjara, Kakheti and Tbilisi in 2016, in Samtskhe-Javakheti, Shida Kartli, Mtskheta-Mtianeti and Kvemo Kartli in 2017, and in Samegrelo-Zemo Svaneti, Guria, Ratcha-Lechkhumi and Imereti in 2018. The replacement stock vaccination was due to follow a year after mass vaccination according to the same schedule, and in 2019 only the replacement stock was to be vaccinated in all regions. The number of vaccinations expected was approximately 240 000 for 2016, 409 000 for 2017, 407 500 for 2018, and 99 000 for 2019. In reality, about 230 000 animals were vaccinated in 2016/17, and by 2018 total vaccinations amounted to around 450 000 heads. These figures demonstrate that the implementation of the strategy has been suboptimal, and the results achieved so far are not substantial to have a meaningful impact in reducing disease prevalence.

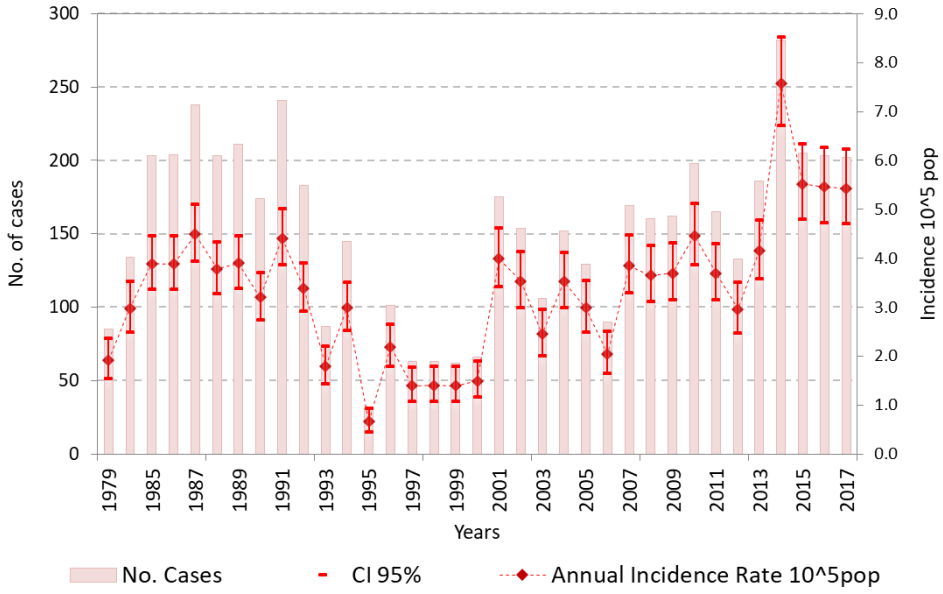
The strategy of the NFA seeks the prevention and control of brucellosis in sheep and goats by vaccinating with the Rev-1 strain, according to a similar schedule to that for cattle. It includes one round of mass vaccination followed by replacement stock vaccinations. The mass vaccination with Rev-1 strain of females up to three months of age, excluding pregnant females and males, was divided into two parts – in the first year for animals in the regions of Samtskhe-Javakheti, Shida Kartli, Mtskheta-Mtianeti, Kvemo Kartli, Kakheti, and Tbilisi, and in the second year in the regions of Samegrelo-Zemo Svaneti, Guria, Adjara, Ratcha-Lechkhumi, and Imereti. The campaign was originally planned to start in 2017, but it was postponed because veterinary services reassessed the strategy in order to minimize as much as possible side-effects from vaccination. In 2019, about 250 000 animals were vaccinated, which is half of what was expected.

Brucellosis in humans

The first case of brucellosis in humans in Georgia was described in 1921, and in 1923 culture isolation confirmed brucellosis presence. Currently, human brucellosis is one of the most prevalent zoonosis in Georgia. Most suspected brucellosis patients are referred to the Institute of Parasitology and Tropical Medicine (IPTM) in Tbilisi. Brucellosis case definition was based on the National Center for Disease Control (NCDC) and Public Health of Georgia definition, which was based on an updated United States Center for Disease Control 2001 case evaluation guidelines. It is estimated that annually, the IPTM tests about 400 clinical samples for serological evidence of brucellosis. According to the official statistics of the NCDC, in the

past ten years, on average about 190 confirmed cases of brucellosis are being recorded in the country annually, and the average incidence rate is 4.6 cases per 100 000 population. Long-term trends of the disease in humans shows fluctuating stability, with figures similar to those of the past ten years. In the late 1980s and early 1990s, there were 190 cases registered annually, but the incidence rate was smaller at 3.6 cases per 100 000 population. This discrepancy is explained by the decline in Georgia's population caused by emigration (by those in search of employment), and a sharp fall in the birth rate. There was a notable decrease in the late 1990s, but that was a statistical anomaly due to the functional disorder of the surveillance system linked to the turmoil the country was facing at the time (Figure 3). However, it is likely that the disease is underreported in Georgia due to the weaknesses of passive surveillance and the need to travel to Tbilisi for disease diagnosis and treatment.

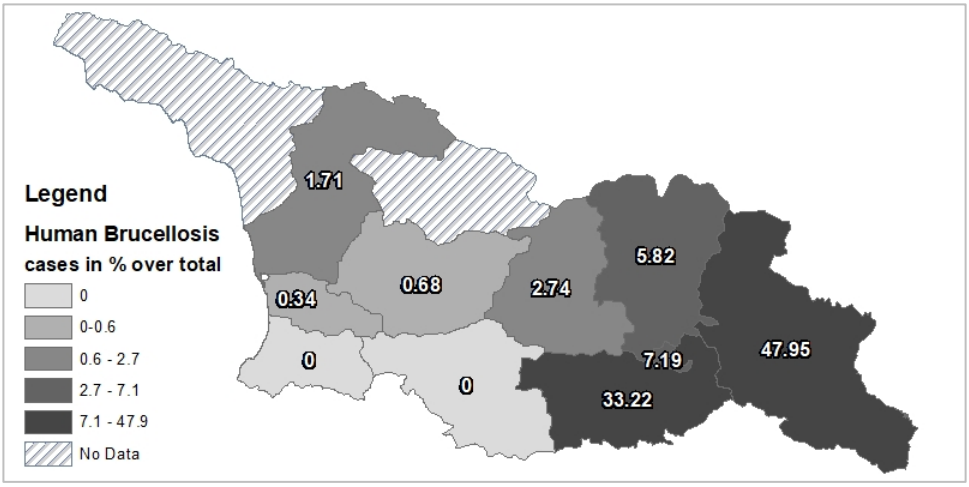
Figure 3. Human brucellosis in Georgia



Source: NCDC**.** 2019**.** Annual brucellosis incidence data for Georgia. Tbilisi, Georgia.

Despite the surveillance limitations, the incidence data from the NCDC highlights the uneven distribution of human brucellosis in Georgia. The vast majority of human cases occur in the eastern and southeastern provinces of Kakheti and Kvemo Kartli. The geographical disease distribution has been historically consistent over time. During the 1930s, a large-scale survey was implemented to estimate the prevalence of brucellosis. Although there are no incidence data for that period, it is important to emphasize that the disease was mainly present in eastern Gorgia, especially in Kakheti region. Indeed, brucellosis was almost never found in western Georgia until the 1950s. In the 1950s and 1960s, more than 98 percent of cases were reported in the eastern part of the country, 94 percent during 1976–1990 and 97 percent during 1991–2004 (Sidamonidze, 2015). During the 1970s, Kvemo Kartli region had the highest prevalence, while Kakheti has had the highest prevalence since the late 1980s until the present day.

Figure 4. Distribution of human brucellosis in Georgia, 1970–2008



Note: Refer to the disclaimer on page *ii* for the names and boundaries used in this map.

Note: Cases aggregated samples from 1970–1973, 1988–1989, and 2004–2008.

Source: Akhvlediani et al. 2010. The changing pattern of human brucellosis: Clinical manifestations, epidemiology, and treatment outcomes over three decades in Georgia. BMC Infectious Diseases (BioMed Central), 10(346).

The high prevalence of the disease in the eastern part of the country might be explained by the prevalence of the disease in small ruminants. Since the data on small ruminants are not reliable, it is assumed that with high density there is a higher exposure risk. The disease in humans is mostly related to areas where these species have higher densities, as depicted in Figure 2 map d. Apart from the descriptive comparisons of Figure 3 and Figure 2 map d, there are various scientific papers supporting the link with small ruminants. Based on a medical chart review study, in about 40.4 percent of patient records contact with sheep was noted, while 35 percent had contact with both sheep and cattle (Akhvlediani *et al.*, 2010). Another similar study demonstrated that major risk factors for acquiring brucellosis were animal-related work (odd ratio [OR] 77.8), non-animal related work (OR 12.7), being unemployed or a pensioner (OR 13.1), sheep ownership (OR 19.3), making dairy products (OR 12.4), living in eastern Georgia (OR 278.1), and being aged over 44 years (OR 9.3) (Havas *et al.*, 2013). A more recent study reports that the majority of participants in the study owned cattle (58 percent), sheep (42 percent), and goats (22 percent). Approximately 37 percent of participants had direct contact with sick or aborted livestock within four months prior to disease onset. In this study, the occupational risk for brucellosis was similar among participants – 41 percent worked on a farm, 44 percent sheared sheep, 51 percent skinned animals, and 49 percent assisted cattle or small ruminants in delivery (Akhvlediani *et al.*, 2017).

Figure 5. Distribution of *Brucella* melitensis and *Brucella* abortus isolates

Note: Refer to the disclaimer on page *ii* for the names and boundaries used in this map.

Source*:* Sidamonidze, 2018, Study of Brucella strains separated in Georgia by molecular typing and phylogenetic analysis. Tbilisi.

In relation to the *Brucella spp* species, both *Brucella abortus* and *Brucella melitensis* were isolated in humans by the NCDC. The most prevalent species isolated was *Brucella melitensis* – in about 80 percent of cases which were geographically confined in eastern Georgia. *Brucella abortus,* even though it was less present, has a wider distribution and was detected also in the western part of the country. This further emphasizes the crucial role that small ruminants have in the disease epidemiology and geographical distribution in humans (NFA, 2016; Sidamonidze, 2018).

Economic analysis of disease burden

In order to assess the true potential benefits of improvement in disease prevention, it is necessary to assess the avoidable losses, as opposed to total costs from disease. Data requirements for the economic assessment of disease control can be classified under the following headings:

- disease occurrence;
- effects of the disease on production;
- effects of disease beyond production, like on human health;
- costs of control measures; and
- expected benefits of control measures.

Much of the required information was not readily available and was estimated based on extensive literature research; or when sources were not found, expert opinion was used instead. The subsequent economic analysis is therefore only as reliable as the data and technical expertise available (a full list of indicators, their values and sources are given in Annex 1). The focus is on estimating the baseline losses, which will be further used for the comparison of alternatives resulting primarily in the ranking of the control options.
The analysis considers human health and livelihoods, and animal production and health perspectives. Baseline disease data on the reported cumulative incidence of human and animal brucellosis were provided by the NCDC and the NFA. Meetings and online communications were held with NFA staff, NCDC staff and with international veterinary and livestock specialists to assess costs and effects of human and animal brucellosis.

Economic losses in livestock production

In animals, brucellosis mainly affects reproduction and fertility, reduces the survival of newborns, and reduces milk yield. Mortality in adult animals is insignificant. Reduced production arises due to sterility, decreased milk production and the cost of culling and replacing animals. Gross margins for average cattle, sheep and goats were calculated, as well as decreased gross margins for brucellosis-infected animals, according to literature data on Georgia livestock production or expert opinion. Increased feeding costs or increased labour due to impediments to free animal movement were not considered.
Brucellosis causes appreciable economic losses to the livestock industry in infected areas, resulting from abortions, sterility, decreased milk production, and veterinary care costs. In sheep and goats, economic losses are due to decreased breeding efficacy and reduced milk production. It is generally recognized that the most damaging aspect of small ruminant brucellosis stems from the adverse effects of the spread of infection with *Brucella melitensis* to cattle and to humans. *Brucella melitensis* is highly virulent and causes higher abortion rates in cattle, and much more severe human disease than *Brucella abortus,* the usual agent affecting cattle.
In goats, the infection may vary in duration from very short periods of slight infection which is rapidly eliminated (especially in vaccinated animals), to persistence for years, where excretion of the organism in the milk may continue for two or more lactations. The situation in sheep is very different, though this varies according to the susceptibility of the breed.
Gross margin is a measure of farm profit calculated as the value of output minus the value of variable costs. The aim here is to compare the change in gross margin for a livestock farm

without the disease and the economic disadvantages caused by the disease. In other words, this is expressed by the forgone profits, which is the difference between earnings actually achieved and earnings that could have been achieved with the absence of brucellosis. Foregone profits represent the investment capital that the farmer spent on investment fees. The assumption is that if the farm had been not affected by brucellosis, it would have generated a better return.

To calculate the gross margin, a set of indicators comprising reproduction parameters like flock or heard structure, offspring born, and mortality figures for each affected species, quantities of milk production and farm related costs such as feeding and pasture renting, labour and veterinary expenditures are used (see Table 1 and for a full list of indicators, see Table 5 in Annex 1). Farm profit has been calculated for meat and milk products as those are directly affected by brucellosis. Production data have been extrapolated from literature, while the selling prices of goods are taken from the official statistical yearbook (GEOSTAT, 2019). Farm gross output per cow is USD 950, USD 85 per sheep, and USD 122 per goat, while total variable costs amount to USD 495 for cattle and USD 25 for sheep and goats.[2] Based on these figures, the gross margin is USD 455, USD 59 and USD 97 for cow, ewe and doe respectively.

Table 1. Livestock gross margins per cattle, sheep and goats

	USD/kg	Kg live weight (lw)	cattle	USD/kg	Kg lw	sheep	USD/kg	Kg lw	goat
Reproduction parameters:									
Young stock born %			0.87			0.95			1.5
Young stock mortality [up to 2y cattle] %			0.05			0.15			0.15
Raised young stock %			0.83			0.81			1.28
Adult mortality %			0.03			0.05			0.05
Culled dams per year %			0.15			0.2			0.2
Surplus young stock %			0.65			0.56			1.03
Selling age young stock (months)			5			3			3
Selling of young stock USD	4.83	100	483	5.13	18	92	5.13	13	67
Culled dams USD	4.32	250	1 080	4.23	30	127	4.23	35	148
Return from livestock sale USD			474			77			98
Milk parameters:									
Milk prod. litres (excl. young cons.) USD	0.32		1 486	0.32		48	0.32		150
Unmilked ewes and does %						0.25			0.25
Unmilked fem 4th + 5th lactation %						0.25			0.25
Return from milk production USD			476			7.7			24
Gross output, USD			**950**			**85**			**122**
Variable costs:									
Veterinary costs, USD			30.8			3.1			3.1

[2] Apart from feeding, labour and veterinary costs, other costs include fees for renting pastures, cost of salt, and costs of transportation for animal movement.

Feeding and other variable costs USD	274	12.1	12.1
Labour costs* USD	190	9.9	9.9
Total costs USD	**494.8**	**25.1**	**25.1**
Gross margin (GM) USD	**455**	**59**	**97**
GM decrease due to brucellosis	20%	20%	20%
GM decrease in USD	91	11.9	19.4
Estimated total no. of cases per year No. (prevalence: 1.5% SR; 1.4% LR)	12 500	11 971	1029
Foregone profit USD	**USD 1 137 474**	**USD 142 169**	**USD 19 920**
Total lost earnings due to brucellosis for cattle, sheep and goats:			**USD 1 299 562**

Note: Labour costs include the monthly wage of shepherds for 170 small ruminants (this is part-time work), a cost USD 10 per animal. Labour needs per cow and year are calculated at 190 days with an opportunity cost for family labour at USD 1/hour.

Source: Author's own elaboration.

It is estimated based on expert opinion that due to brucellosis, gross margins decreased by 20 percent due to infected cattle, sheep and goats. This includes abortions, reduced milk production, possible culling, and prolonged antibiotic treatment. Seropositive animals have higher rates of abortion, stillbirth, infertility and calf mortality, as well as reduced growth and longer calving intervals. If the placenta is retained in aborting dams, increased use of antibiotic treatments helps reducing subsequent complications. Often, infected females will abort only once, although they may remain infected their entire life. Aborting cows kept for milking may produce 20 to 25 percent less milk for that season, while seropositive non-aborting cows may produce 10 percent below the potential. Less than 5 percent of cows may abort where seroprevalence is below 5 percent. In small ruminants, the abortion rate could range from 20 to 60 percent depending on the level of infection in the flock.

The estimate of a 20 percent gross margin reduction corresponds to 15 percent of expected births being late abortions, with the same percentage of reduced milk production per lactation per cow, ewe and doe, respectively, and plus 20 percent veterinary expenses per cow, or plus 20 percent per ewe and doe. There is also a 5 percent increase in mortality in young stock factored in. In reality, there will also be early abortions with subsequent zero milk production, which means there are more abortions than the 15 percent. However, no data were found on the rate of abortion for infected dams, and on the ratio of early to late abortions. The farmer suffers loss of income due to abortion, the consequent loss of milk production, and a prolonged fattening time of lambs for meat production due to the birth of premature animals and low fertility rates.

Losses due to brucellosis are calculated at USD 90 per cow, USD 12 per sheep and USD 20 per goat. At national level – factoring in the assumed population-based prevalence of brucellosis – the losses are quite substantial. The greater part of the economic burden is borne by large ruminants, with a total loss of earnings amounting to USD 1.13 million, and to a lesser extent by losses in small ruminants, of USD 160 000. Therefore, in total, each year Georgia loses USD 1.3 million in expected profits from the livestock sector due to brucellosis.

Apart from the farm level gross margins and forgone profit, there are some further economic implications caused by the disease, of which decision makers should be aware. On the macroeconomic level, there are in addition to the losses experienced in infected herds other indirect effects which are difficult to assess. Such instances are trade effects, as the disease

may have an effect on the availability of export markets to a country. An estimate of costs could be made by assuming that after an initial loss of exports, an alternative market offering lower prices can be found. Secondary effects are effects arising upstream or downstream, like in processing and marketing of the affected production process, as the dependent industries are hampered in expanding. These effects are difficult to evaluate and can be reflected in the prices of the products directly affected. They could be quantified by calculating the value added in case of a brucellosis-free environment at every stage of the processing industry affected. Indirect and secondary effects could not be calculated and therefore are not included in this study; however, if brucellosis is controlled appropriately, the benefits of such effects could be substantial.

Economic losses for humans

Global data indicate that in humans, the symptoms of brucellosis include extreme weakness, joint and muscle pain, headache, undulant fever, hepatomegaly, splenomegaly, and night sweats. Mortality is reported to be negligible as brucellosis has a low mortality rate (5 percent of untreated cases), with rare deaths caused by complications such as endocarditis or meningitis. Neurological disease can take the form of meningitis, encephalitis, peripheral neuropathy, brain or epidural abscesses, radiculoneuropathies or meningovascular syndromes. Subclinical infections are relatively common. Acute brucellosis during the first two trimesters of pregnancy has been reported to lead to spontaneous abortion on up to 40 percent of cases if untreated, while untreated disease may be associated with intrauterine foetal death in only 2 percent of cases, with onset in the third trimester. Patients who have brucellosis develop relapses, despite treatment with several antibiotic regimens. If untreated, the disease can persist in specific organs or tissue, or become chronic. The duration of the disease can vary from a few weeks to many months or even years.
For the purpose of the present analysis, human health parameters and related costs – such as duration of treatment and hospital and outpatient treatment – were derived from different literature sources (see Table 6 in Annex 1).

This includes:

- disease severity and proportion of patients with complications;
- inpatient days – number of days in hospital;
- cost of hospital day;
- proportion of hospitalization;
- outpatient visits;
- out of pocket contributed for health care (visits, transport, stay in hospital, food in hospital);
- diagnostic tests and drugs; and
- lost earnings over months.

A study conducted in Georgia reported that fever was recorded in 94.3 percent, sweating in 75.8 percent, chills in 77.7 percent, fatigue in 77.3 percent, osteoarticular and neuromuscular pain in 88 percent, hepatomegaly in 34 percent, and splenomegaly in 16.3 percent of the investigated patients. Polylymphadenopathy was rare and observed only in 8.8 percent of cases. Anaemia was detected in 45.8 percent of cases. Leukopenia was present in 7.54 percent of cases, thrombocytopenia in 26 percent and pancytopenia in 5.2 percent of the patients. Additionally, a slight increase in liver enzyme levels was observed in 35.4 percent of the cases. The most frequent complication of brucellosis was sacroileitis (inflammation of the

joint between the sacrum at the base of the spine), which was observed in 13 percent of the patients, while epididymoorchitis was detected in only 9 percent of cases. Both of these complications were associated with delayed diagnosis for more than one month, which was observed in about 20 percent of cases (Kokaia *et al.*, 2014). Another study showed that 19 percent of patients suffered from further complications such as epididymoorchitis, cystitis, pyelonephritis and acute ileitis (Akhvlediani *et al.*, 2017). The severity of the disease has financial implications related to the diagnosis, duration and type of treatment, and the inability to work. The share of different case types has been calculated as 71 percent outpatients, 19 percent uncomplicated or mildly complicated, and 10 percent complicated cases.

Most suspected brucellosis patients are referred to the IPTM in Tbilisi. In Georgia, about 29 percent of cases are hospitalized and the remainder treated as outpatients at clinics (Kokaia *et al.*, 2014). The hospitalization period is on average 18 days, ranging from eight days to 27 days. According to treatment protocols, outpatients have to attend healthcare centres every 17 days during the 42 days of treatment. For the losses of inpatient care per hospital day, no official data could be obtained and the price including salaries, administration and maintenance was taken as USD 50 per day from a similar study in Georgia (Komakhidze *et al.*, 2015), while the price of an outpatient visit is USD 10.3 per visit based on the different price lists of private clinics.

A recent study demonstrated that 63 percent of patients sought care in other medical facilities before going to the IPTM, and a number of them visited up to three other medical facilities first. In total, 28 percent of participants were previously diagnosed with clinical suspicion of brucellosis before coming to the IPTM (Akhvlediani *et al.*, 2017). Such a practice demonstrates that there are substantial costs related to travel going to clinics or to the IPTM, although these out-of-pocket costs could not be estimated. An NCDC report has stated that out-of-pocket payments constitute the highest share of private expenditure, which could reach up to 57 percent (NCDC, 2017). Nonetheless, the report does not give any details on cost breakdowns, so to account for such expenditures, USD 5 has been added to each case categorized as other expenditures.

Diagnosis of brucellosis in Georgia is based on the slide and tube agglutination tests and confirmation is performed by the Wright agglutination test at a titer ≥1/200 and by enzyme-linked immunosorbent assay (ELISA) to detect Brucella-specific IgM and IgG antibodies. Since clinical manifestations of brucellosis are not specific (pathognomonic), several other tests are run on the suspected cases which mostly – but not exclusively – include urinalysis, complete blood count, C-reactive protein, erythrocyte sedimentation rate, and blood glucose. The cost of these tests is USD 49, calculated from a comparative estimation from the price lists of diagnostic centres in Georgia. In addition, complicated cases undergo more advanced diagnostic techniques which could include abdominal ultrasound, cardiac ultrasound, X rays, chest X rays, articulations, magnetic resonance imaging, CT scan head, CT scan pulmonary and CT scan abdominal. The cost of these diagnostic procedures is USD 151. Again, prices have been taken from an average of different price lists and where only two-thirds of the collective cost was used since not all complicated cases would need the full range of examinations.

Antibiotics such as tetracycline, rifampicin and the aminoglycosides streptomycin and gentamicin are effective against *Brucella* bacteria. However, the use of more than one antibiotic is needed for several weeks, due to the fact that bacteria incubate within cells. Antibiotic treatment with doxycycline plus rifampin, or doxycycline in combination with other medications, for six weeks, is sufficient in most cases. More prolonged regimens may be required for patients with complications such as hepatitis, splenitis, meningoencephalitis,

endocarditis, or osteomyelitis. For uncomplicated acute brucellosis, combinations of oral antibiotics are usually sufficient, or even preferred, as they are simpler to use in the outpatient setting. Acute, complicated brucellosis (for example skeletal disease, or endocarditis) often requires long-term triple-drug therapy for effective cure. For skeletal disease, six to eight weeks of antibiotics may be necessary for cure. Persisting musculoskeletal complaints may be present in patients with chronic infection and sacroiliitis. Meningoencephalitis and endocarditis should receive at least 90 days of therapy and may require over six months. Endocarditis typically responds poorly to antibiotics alone, and generally requires surgical excision of the affected valve. Necrotizing orchitis and other suppurative complications of brucellosis require surgery or drainage. For this study, the cost for frontline antibiotics doxycycline and rifampicin is USD 38 for a full 42-day course for outpatients and non-complicated inpatients; and for complicated inpatients it is USD 82, which would be a prolonged treatment of up to 90 days plus the triple therapy with added streptomycin. These prices are based on lists of the AVERSI pharmaceutical group in Georgia (AVERSI, 2019).

A high occupational risk of infection with *Brucella* species is associated with specific work places where employees are working in direct contact with infected animals or their products. This includes certain workers at higher risk, such as farmers (33 percent of cases), shepherds with 27 percent, butchers with 2 percent, veterinarians with 1 percent, and other professions comprising 37 percent of cases (Sidamonidze *et al.*, 2015). As the disease has a strong relation with occupation it is expected that it affects more individuals at working age. A study revealed that 86 percent of cases in Georgia involve people over 18 years old (other studies estimate up to 90 percent of cases). It is worth mentioning that the former study had a better age group distribution and therefore used as a parameter for the calculations (Havas, 2012; Akhvlediani *et al.*, 2010; Sidamonidze *et al.*, 2015). The calculation assumes a sick leave of three months for uncomplicated cases, and five months for complicated cases, assuming one month for the period until the patient starts a correct medical approach, and four months on average after starting a correct medical approach. Averted productivity losses due to better health are calculated. Productivity is valued based on an average daily wage of USD 18 per person, extrapolated from the average wage per person per month of USD 384.96 for 21 working days a month (GEOSTAT, 2019). It is known that cases of brucellosis in humans are underdiagnosed and underreported. In general, official statistics notify only acute cases, and for example mild cases caused by *Brucella abortus* might not be reported. There is some underreporting for various reasons, including weak surveillance, social stigma, and long travel distances for diagnosis and treatments. The overall economic burden of the disease for humans has been calculated for the number of officially reported cases, together with an estimated 20 percent of underreported cases.

Table 2. Economic losses for humans

	USD/day	Outpatient		Uncomplicated		Complicated	
		days	USD	days	USD	days	USD
Doxycycline, 100 mg orally twice daily	0.65	42	27	42	27	90	58
Streptomycin intra muscular 1g daily	0.28	0	0	0	0	14	4
Rifampicin 600 mg orally once daily	0.26	42	11	42	11	76	20
Total for drugs			***38***		***38***		***82***
Hospital bed including doctor + admin costs	50	0	0	18	900	27	1 350
Outpatient visit every 17 days	10	3.5	36	2.5	26	4	41
Diagnostic, laboratory test, others*			49		49		200
Total medical cost USD			**123**		**1 012**		**1 673**
Lost earnings age 18+	18	55	993	55	993	92	1 656
Total per one case			***1 116***		***2 006***		***3 328***
Breakdown of cases **			71%		19%		10%
Total proportional by case type			792		387		338
Total per average human case USD							**1 508**
Number of cases per year (average 2013 to 2017)							200
Number of unreported cases 20%							40
Total per year for all human cases USD							**361 958**

Notes: * In addition for complicated cases, X ray, CT scan, MRI, ultrasound, etc.
** Hospitalized patients 29 percent and from them is taken the ratio 35 percent versus 65 percent complicated and other hospital cases.

Source: Author's own elaboration.

As shown in Table 2, the economic cost of hospitalization and lost earnings are high. The total annual human costs caused by the disease in Georgia is USD 362 000. The average human case cost is estimated at USD 1 508 and varies by case type, the majority of which are outpatients with a cost of USD 1 116, uncomplicated or mildly complicated inpatients with a cost of USD 2 006, and complicated cases of up to USD 3 328. These figures are comparable with those of other countries at a similar stage of economic development and with similar issues with brucellosis. A study conducted in 2007 in Albania showed that the average human brucellosis case cost was USD 1 090, while the total human health cost was USD 1.3 million – Albania had at least six times more cases than Georgia at that time. In neighbouring Armenia, an FAO study in 2014 showed that a human case of brucellosis cost USD 950, and that the total cost to human health was USD 175 000. In more developed European countries, the costs are much higher, as indicated by a study in Spain carried out to evaluate economic loss due to human brucellosis. The direct cost for a patient, including hospitalization for 13 days, was USD 2 500, plus a mean absence from work of 102 days, giving an overall cost of USD 8 000 per patient.

While the effects of brucellosis on human production or output in terms of lost income and the costs of treatments can be quantified, the costs of mortality, abortion and human suffering are difficult to evaluate. In addition to direct losses, indirect losses may exist where the fear of contracting a disease limits human activity. These effects were not estimated and are not included in the analysis.

Cost of brucellosis control programmes

The costs of livestock brucellosis control programmes were calculated only for vaccination strategies in large ruminants and small ruminants based on data provided by the NFA. The calculations consider vaccine purchase costs, service fees for vaccinating animals, and visiting farms and transport. In addition to these costs for small ruminants, also calculated are costs for post-vaccination technical monitoring to estimate the seroconversion ratio as a consequence of the vaccination. When smooth vaccines are applied, an antibody response to the antigen challenge is expected. The antibodies induced by the vaccination are detectable three to four weeks after the vaccination using a diagnostic test such as RBT, complement fixation test (CFT) or iELISA. The calculation is based on an assumption that 3 percent of vaccinated animals will be tested to estimate the seroconversion ratio. However, in reality, proper sample size estimations will be needed to account for clustering and stratification.

For large ruminants, post-vaccination monitoring is not as straight forward as for small ruminants, since measuring the serological response of rough vaccines like the RB51 strain is quite difficult. This strain lacks the main cell wall antigens that determine the response, therefore serological tests are not capable of detecting the efficacy of the vaccine. The control on efficiency could rely on alternative tests detecting cytosol-induced antibodies or by allergic tests. Vaccine quality control can be the only control used for assessing vaccination efficacy in large ruminants.

The test and slaughter programme in cattle was not fully evaluated since there is no compensation policy in place and therefore only the testing costs are included. There are some concerns that the slaughtered positive animals have a lower market value, but this loss of income could not be quantified. On the other hand, there is a risk of misinterpreting the positive cases of test and slaughter, since in field conditions a booster-like effect in augmenting antibody response might be prevalent, leading to positivity of diagnostic tests for vaccinated animals. The RB51 strain does not produce detectable antibodies by conventional serological tests, even though vaccinated cattle exposed to other *Brucella* strains like *Brucella abortus* strain 2308, and *Brucella suis* bv.1, can produce antibodies (Poester *et al.*, 2006; Olsen and Hannager, 2010). Similarly, it could be speculated that the same phenomena apply if cattle are exposed to wild *Brucella abortus* strains and *Brucella melitensis* from small ruminants – protection conferred by RB51 against *Brucella melitensis* infection in cattle is unknown. Therefore, it would be advisable to isolate and type the strains in the early phases of the control strategy.

The costs of transporting the vaccine from the capital to the district were not calculated, as there is in any case some transport between the headquarters and the regional veterinary inspectors.

The cost of items for brucellosis control actions in large ruminants include:

- vaccine purchase at USD 0.75 per dose;
- vaccination service fee at USD 0.17 per animal;
- costs such as gloves, needles, thermos box, transport, etc, USD 0.12 per animal;
- farm visit fee at USD 0.34 per farm; and
- testing (USD 1.20/test and USD 0.15 consumables), USD 1.44 per animal.

During the 2016–2019 period, about 450 000 bovines were vaccinated. The number of farms is not reported but taking into account that the average herd is 5.2 animals, the estimate of

number of farms visited is about 86 500. For the 2016–2018 period, about 165 000 tests were carried out. Therefore the total cost of bovine brucellosis control was USD 735 000 – USD 497 410 for vaccinations and USD 237 600 for testing. The average annual cost for 2016–2019 is about USD 203 500.[3]

The cost of items for brucellosis control actions in small ruminants include:

- vaccine purchase at USD 0.15 per dose;
- vaccination service fee at USD 0.07 per animal;
- costs such as gloves, needles, thermos box, transport, etc, USD 0.05 per animal;
- farm visit fee at USD 0.34 per farm; and
- testing (USD 1.20/test, USD 0.02 travel and USD 0.15 consumables), USD 1.37 per animal.

The vaccination of small ruminants started in 2019; so far about 250 000 animals have been vaccinated. The number of farms visited is not known, but by assuming a mean flock of 100 animals, that equates to 2 500 farms (the number of farms could be higher, as goat flocks are quite small). The total cost of the brucellosis control campaign for 2019 is USD 78 625 – USD 68 350 for vaccinations and USD 10 275 for post-vaccination monitoring (no data are available if post-vaccination monitoring has taken place, and if so at what percentage of the population).

[3] The testing average is based on 2016–2018 for 2019, there is no indication of the amount of testing performed.

Modelling the effects of alternative vaccination strategies

Brucellosis control strategies are based on two types of interventions, through modification of host immunity by vaccinating the ruminant populations, and by testing and removing the infected animals from the population. The general guidelines state that in an endemic disease situation in the ruminant population where progress with a test and slaughter programme is not observed, mass vaccination is recommended. In the event of moderate herd prevalence (for example less than 5 percent), a programme combining vaccination of young replacement with test and slaughter in adults is recommended. However, when there are important risk factors that cannot be controlled – like movement under conditions of transhumance – vaccination is recommended, even when the prevalence is lower. This is in line with the current Georgian policy, but it should be emphasized that implementation has not been properly carried out, mainly due to budgetary shortcomings, and the poor understanding of decision-makers. Therefore, to gain better understanding of brucellosis transmission between animal species and humans, it is necessary to assess the effectiveness, and costs and benefits, of different vaccination scenarios in livestock in order to better inform decision-makers and ensure proper financial plaining. To this end, a mathematical model was developed and used to encompass the general lack of detailed epidemiological data, to estimate future projections of disease trends, and to estimate the performance of different vaccination options in a situation where the current strategy is not properly implemented in the field. The modelling approach is based on:

- selection of alternative vaccination scenarios;
- modelling the conferred immunity; and
- modelling the effect of vaccination strategies on disease burden in animals and humans.

Vaccination is often the first step in the control of infectious disease. On its own, however, it cannot achieve the full eradication of brucellosis. So at a later stage when the prevalence of the disease will be very low or even close to zero, an exclusive test and slaughter policy should lead to the eradication of the disease and gaining officially free status. To ensure success, such an eradication programme requires proper organization of the veterinary services and laboratories, good cooperation with the stakeholders, as well as movement control, individual identification, a well-organized national database, and an adequate budget.

Analysed vaccination scenarios

For the purpose of this study, seven vaccination models (four in small ruminants and three in large ruminants) are calculated, with variations of coverage and effectiveness, as follows:

Small ruminants

A) continuous mass vaccination of all small ruminants for four years;
B) replacement stock vaccination for eight years;
C) interval mass vaccination of all small ruminants at year one and three; and
D) one mass vaccination on year one followed by replacement stock vaccinations.

Large ruminants

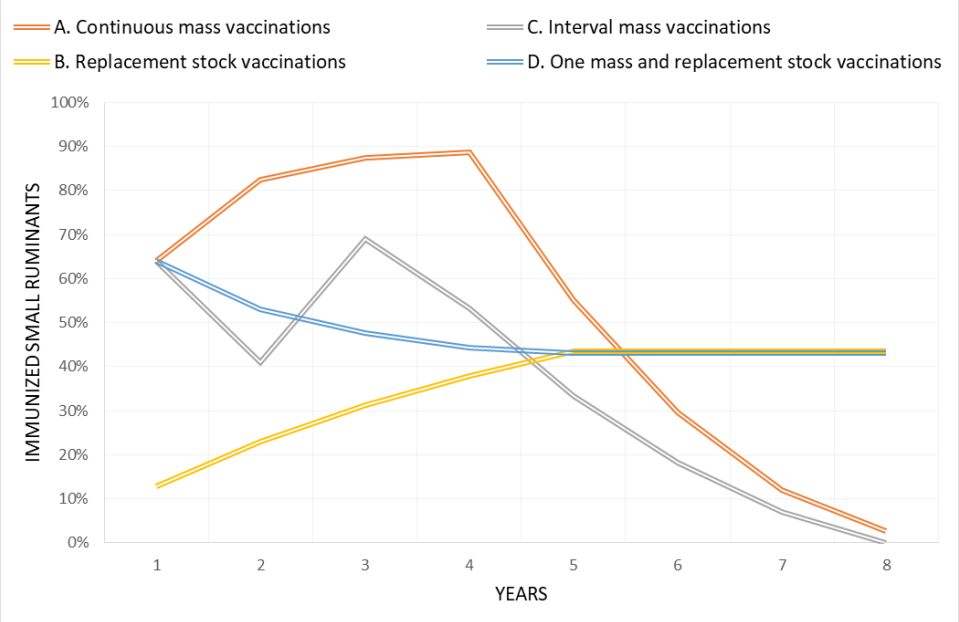
E) continuous mass vaccination of all large ruminants for four years;
F) replacement stock vaccinations for ten years; and
G) interval mass vaccination of all large ruminants at year one and five.

The proposed models are not exhaustive since in reality many variations can be implemented at different times, levels of coverage, and seroconversion, thus leading to endless combination, so the selected models are to be taken as alternative interventions used for economic acceptability and enhancement of current strategic actions.

Modelling immunity profiles in livestock and number of infected animals and humans

To assess the impact of different brucellosis vaccination scenarios, it is necessary to develop models with the number of effectively protected animals in the population, which means knowing the vaccination coverage, animals vaccinated compared to total number of animals, and seroconversion rate, and animals successfully vaccinated with the appropriate serological reaction compared to total number of vaccinated animals. Effective vaccination is achieved when two requirements are fulfilled: vaccination coverage is over 80 percent of the eligible animals, and the seroconversion ratio is 80 percent or greater. The part of the model for vaccinated animals is presented in Annex 2, and is calculated according to the optimal vaccination rate of 80 percent, seroconversion rate of 80 percent, and the rate of animals losing protection by 20 percent for small ruminants, and 10 percent for large ruminants (Roth *et al.*, 2003). The calculation is made separately for each age cohort, and each age cohort is culled at the end of their productive life, which is after five years for small ruminants (assuming that these species are kept for breeding until a maximum of six years of age on average). For large animals, the average life was taken as ten years – some animals live longer and others shorter, but the model works with an average.

Figure 6. Immunity profiles of different vaccination scenarios in small ruminants



Source: Author's own elaboration.

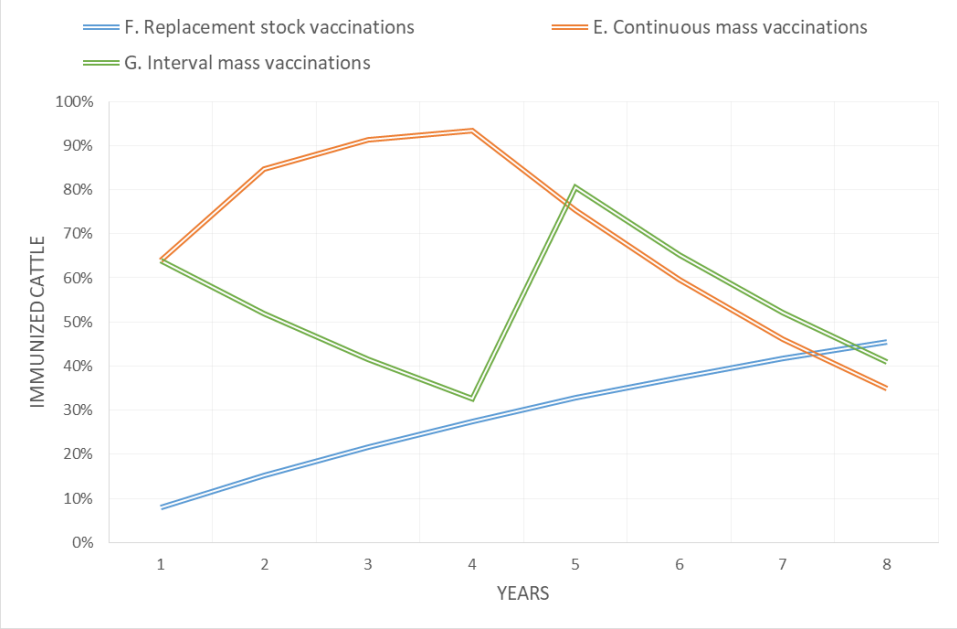
From the immunity profiles in Figure 6, it can be seen that continuous mass vaccination (scenario A) quickly boosts herd immunity, reaching up to 89 percent of the flock by the fourth

year, and then drops to 10 percent by the seventh year. On the other hand, replacement stock vaccination (scenario B) is rather slow in building herd immunity, and stagnates at 43 percent by the fifth year. Interval mass vaccinations (scenario C) start with 64 percent coverage of immunized animals, drops to 41 percent by the second year, and rises to 69 percent through the booster mass vaccination of the third year, before falling gradually to 0 percent by the eighth year. One mass vaccination followed by replacement stock vaccination (scenario D) starts with 64 percent and equals scenario B by the fifth year (constant at 43 percent).

Ranking the scenarios by their average annual proportion of immunized animals, the best is scenario A with an average of 53 percent, followed by scenario D with 48 percent, and scenarios C and B with 36 percent and 35 percent respectively. In Greece, a decrease in human brucellosis was observed when the vaccination of animals was less than 30 percent (Minas *et al.*, 2004); therefore, it can be concluded that all scenarios can potentially control the disease.

Similar patterns are seen in the scenarios developed for large ruminants. There is a higher proportion of immunized large ruminants compared with small ruminants, even though the scenarios are similar. This is more evident in the results achieved by scenario E, with a peak of 93 percent, and G, with a peak of 80 percent. In fact, large ruminants live twice as long as small ruminants, and therefore herd immunity is higher because the vaccinated animals remain in the herd for longer. However, this is not evident for scenario F because the replacement rate is smaller and the period shown in Figure 7 does not cover the entire life span of bovines, but if followed the proportion of immunized animals will rise to 52 percent by the tenth year. The ranking of scenarios is E, G and F, with an average annual proportion of immunized animals of 69 percent, 54 percent, and 29 percent respectively.

Figure 7. Immunity profiles of different vaccination scenarios in large ruminants



Source: Author's own elaboration.

Taking into account that the NFA brucellosis strategy envisions mass vaccinations during the initial stages of the strategy, the results achieved in the field so far are discouraging. There

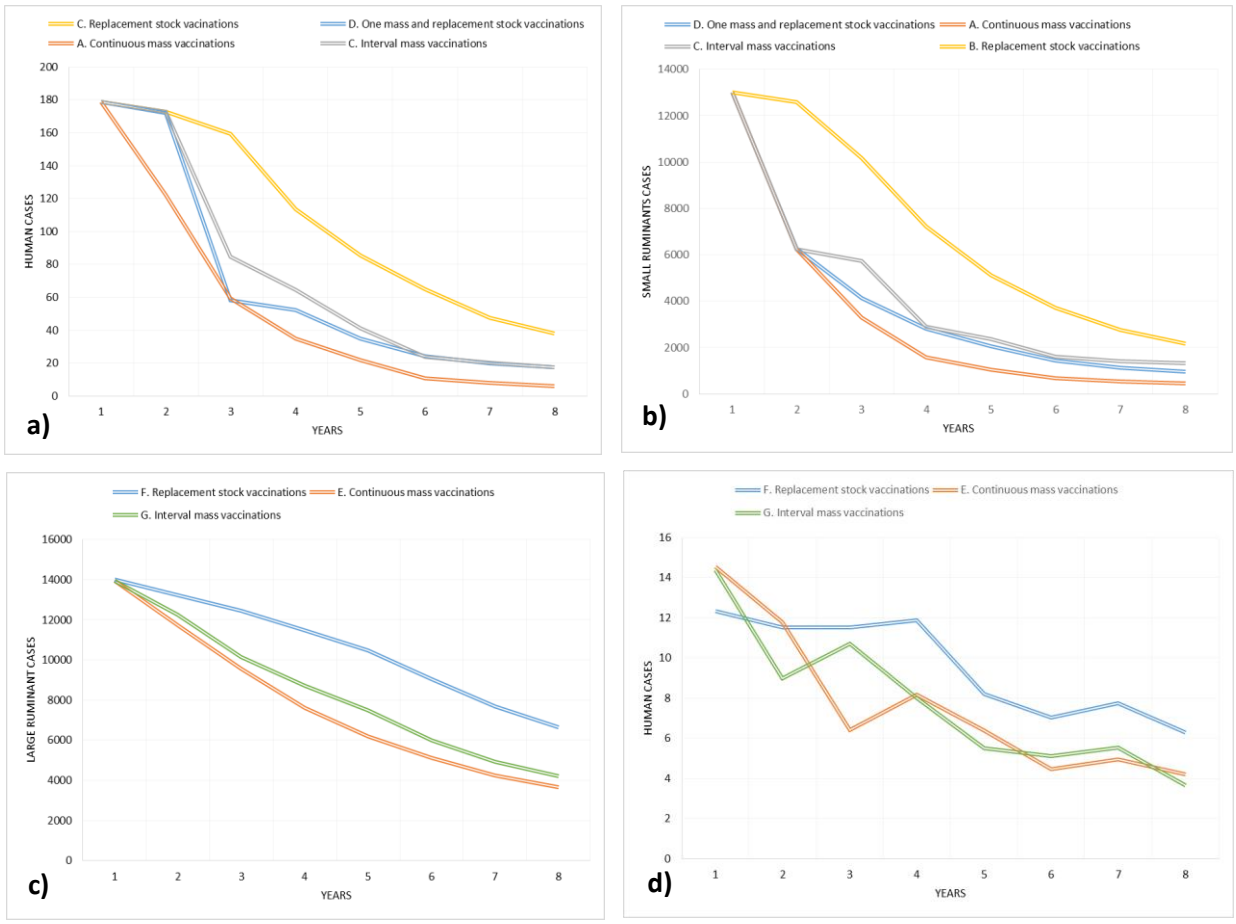
are 250 000 vaccinated small ruminants in Georgia currently, and assuming an optimal seroconversion rate of 80 percent, it means that the proportion of successfully immunized animals in the population is 22 percent. This is comparable with the proportion of protected animals achieved in the second year (23 percent) by scenario B (replacement stock vaccinations). In large ruminants, the cumulative vaccination coverage during the 2016–2019 period has reached only 43 percent of the population. With a seroconversion rate of 80 percent, the proportion of successfully immunized animals would be 35 percent. Again, this figure is more comparable with replacement stock vaccinations (33 percent fifth year of scenario F) than with the two other scenarios. Based on such figures, the replacement stock scenarios B and F will be taken as baselines for comparison and evaluation of costs and benefits.

The development of infected animals and human populations is based on a dynamic model of livestock-to-human brucellosis transmission developed for a similar study in Mongolia (Zinsstag *et al.*, 2005; Roth *et al.*, 2003).[4] The model was adapted to the Georgian situation by using demographic and prevalence data from livestock and annually reported human brucellosis cases, as described in this report. Births and deaths are included in the model to follow the estimated growth trends in human and animal populations. This compartmental model considers transmission in steps of one year between small ruminants, between large ruminants, and from livestock species to humans. To make the model more realistic, a random function for positive ruminants was introduced as a uniform distribution at 0.2–0.8 for small ruminants and 0.1–0.85 for large ruminants. Simultaneously fitted sheep–human and cattle–human contact rates were adjusted to have a contribution of small ruminant-derived human brucellosis of 80 percent to account for the dominance of *Brucella melitensis* in human brucellosis as indicated by strain isolations in Georgia. The vaccination effect was fitted by using as inputs the immunity profiles of chosen scenarios for small and large ruminants. The model is limited in spatial domain and does not consider geographical differences of the disease prevalence. Model building was done using a trial version of Stella Architect software v1.5 (www.iseesystems.com).

The model fitted the susceptible livestock and human populations quite well, with a total population at the end of the eight years of 4.1 million humans, 1.1 million bovines and 1 million small ruminants. In order to compare disease control optional scenarios, a baseline was estimated without disease control. The positive sheep and cattle, and annually estimated human brucellosis cases, with their respective 95 percent confidence limits, are presented in Annex 3. The total number of predicted brucellosis cases for a period of eight years is 103 000 (with an annual average of 12 800) for small ruminants, and 112 000 cases (with an annual average of 12 400) for large ruminants. In humans, the total number is 1 937 cases, with an annual average of 175 cases. In general, the trends show that there is stability for large ruminants, with more fluctuation for small ruminants. Long-term projections show a rising pattern peaking in the 11th year in small ruminants with about 20 600 cases, and in the 13th year in large ruminants with 14 800 cases. There is a similar pattern between small ruminants and humans due to their stricter relationship. In humans, the growth rate in the first period is stable and human brucellosis peaks – in parallel with small ruminants – in the 11th year, with 280 cases.

[4] For a comprehensive and detailed methodology the reader is advised to review the paper, A model of animal–human brucellosis transmission in Mongolia.

Figure 8. Simulated number of infected cases in livestock and humans



Notes: a) Infected cases in small ruminants by vaccination scenario; b) infected human cases derived from small ruminants by vaccination scenario; c) infected cases in large ruminants by vaccination scenario; and, d) infected human cases derived from large ruminants by vaccination scenario.

Source: Author's own elaboration.

It is clear that apart from replacement stock vaccinations, the other scenarios showed a rapid decrease in positive cases after eight years. The difference is caused by the fact that for scenarios with mass vaccinations, herd immunity is built up quite fast and this protects more susceptible animals, while in the replacement stock scenario, immunity rises gradually and therefore infections continue to occur. Scenario A, continuous mass vaccination, will reduce the burden of the disease by 74 percent compared to the total number of cases in the baseline scenario without intervention (see Annex 3). Scenario B, replacement stock, will reduce the number of cases by 45 percent; scenario C, interval mass vaccination, by 66 percent, and scenario D, one mass and replacement stock vaccination, by 69 percent. In simulations of infected human cases derived from small ruminants (Figure 8, b), the patterns are similar to those of small ruminants, although infected animals stay in the flock and continue to infect humans for at least four years until they are removed. The most marked reduction of disease burden is achieved by scenario A, with 77 percent, followed by scenario D with 71 percent, and scenarios C and B with 69 percent and 56 percent respectively.

In large ruminants, the order of efficacy of scenarios is similar: the continuous mass vaccination scenario E with a reduction of 45 percent; interval mass vaccination scenario G

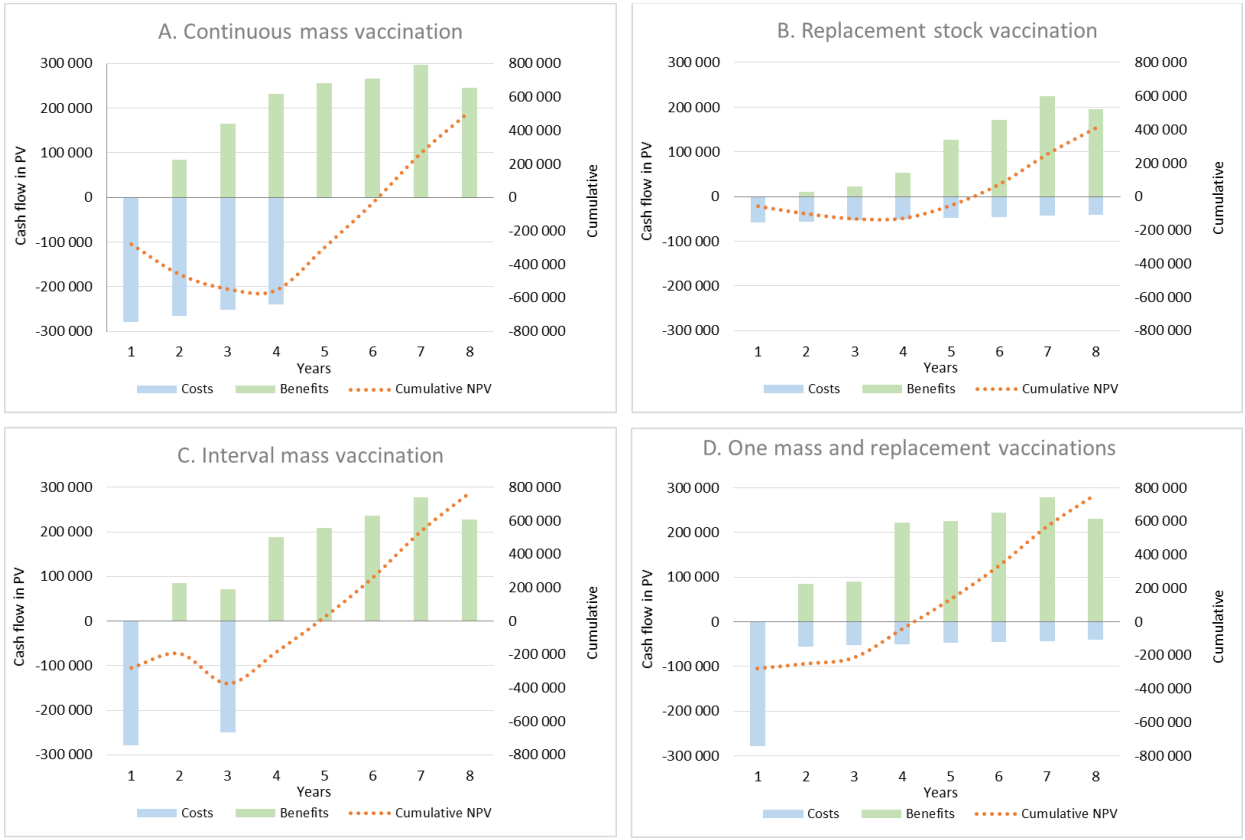
with 40 percent; and replacement stock vaccination scenario F with 24 percent. In humans, the reduction of disease burden is almost insignificant, with a maximum of 4 percent and barely distinguishable differences between scenarios.
According to the current strategy implementation (corresponding to scenario B for small ruminants and scenario F for large ruminants, without the contribution of test and slaughter as its effect is not possible to calculate), it can be said that in small ruminants, the decrease of the disease burden is 3 percent, in large ruminants' 10 percent, and in humans from both large and small ruminants about 7 percent, which is about 12 averted human cases.

Cost–benefit analysis

The objective of the study is to compare the costs of current vaccination actions with different vaccination strategies. The economic evaluation included the impact on human health costs and income loss, and impact on livestock production. Benefits in monetary terms were computed for both sectors. For the livestock sector, the avoidance of losses in animal products (if the disease is controlled) is a benefit; and for the public health sector, avoiding medical costs and loss of income are benefits.
A cost–benefit analysis is an objective process intended to show the economic merit of vaccination options. Costs and benefits are projected over the relevant time period and the population affected. In examining and comparing different policies, the timing of expenditures and benefits over the years has to be emphasized. Treatments and prophylaxis typically involve costs over a number of years. In all cases, the present values of the costs and benefits (the sum of the discounted costs and benefits) need to be compared, not the simple sum of costs. To compare costs and benefits that occur in different years, it is necessary to convert their value into a present value. This has been done by using a technique known as discounting. The discount rate to use in cost–benefit analysis is often a source of considerable uncertainty. However, for practical purposes, the real rate of interest can be used (Rushton, 2009). The most recent value of the real rate of interest for Georgia, as per 2018, is 7.2 (World Bank, 2019).
Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The NPV is used in capital budgeting and investment planning to analyse the profitability of a vaccination scenario. A positive NPV indicates that the projected earnings generated by implementing a specific vaccination scenario – in present US dollars – exceeds the anticipated costs, also in present dollars. It is assumed that an investment in a vaccination scenario with a positive NPV will be profitable, and an investment in a scenario with a negative NPV will result in a net loss.
A benefit–cost ratio (BCR) is an indicator used in cost–benefit analysis that attempts to summarize the overall value for money of a vaccination scenario. A BCR is the ratio of the benefits of a vaccination scenario, expressed in monetary terms in present value, relative to its costs, also expressed in monetary terms. This indicator takes into account the amount of monetary gain realized by performing a vaccination scenario versus the amount it costs to execute the scenario. As a decision criterion, the higher the BCR the better the investment in a vaccination scenario.
The internal rate of return (IRR) is calculated from cash flows. The IRR is a capital budgeting method used to decide whether it is worth making a long-term investment in a specific vaccination scenario. The IRR is the annualized effective compounded return rate which can

be earned on the invested capital (that is, the yield on the investment). A vaccination scenario is a good investment proposition if its IRR is greater than the rate of return that could be earned by alternative investments (investing in other projects, buying bonds, even putting the money in a bank account). Thus, the IRR should be compared to an alternative cost of capital including an appropriate risk premium; in this case it should be bigger than the real rate of interest. Mathematically, the IRR is defined as any discount rate that results in a net present value of zero of a series of cash flows.

Figure 9. Present value cash flow profiles of vaccination scenarios in small ruminants



Source: Author's own elaboration.

Figure 9 shows the cash flow profiles for each vaccination scenario. For scenario A, continuous mass vaccination, there is a large cash sink with high expenditure during half of the period, which is prolonging the payout period until the breakeven point (the point where total costs and total benefits are equal) at the end of the sixth year; then the payback period lasts for two years. On the other hand, the benefits are quite considerable, with a good growth rate after the second year that peaks at USD 300 000 by the seventh year. In the replacement stock vaccination scenario B, the investments are distributed almost evenly throughout the entire period. The benefits in the beginning are low, but as time passes continue to grow, even though in general they are comparably modest. The cash sink is the smallest in the group, with a relatively long period of pay-out due to low benefits at the beginning of the period, and reaching breakeven point by the fifth year.

Scenario C, interval mass vaccination, has large costs for only two years and the payout period is until the fifth year. Scenario D, one mass and replacement vaccinations, has a large cost at the beginning related to the mass vaccination campaigns, and then almost evenly distributed

costs for replacement stock vaccinations. The benefits are quite substantial, with the fourth year comparable to those of scenario A. Expenditure is initially high, but it recovers quickly in the fifth year due to the positive relationship between costs and benefits, with the latter abundant in comparison to costs. Detailed figures of cost and benefits, and cash flows, are presented in Annex 4.

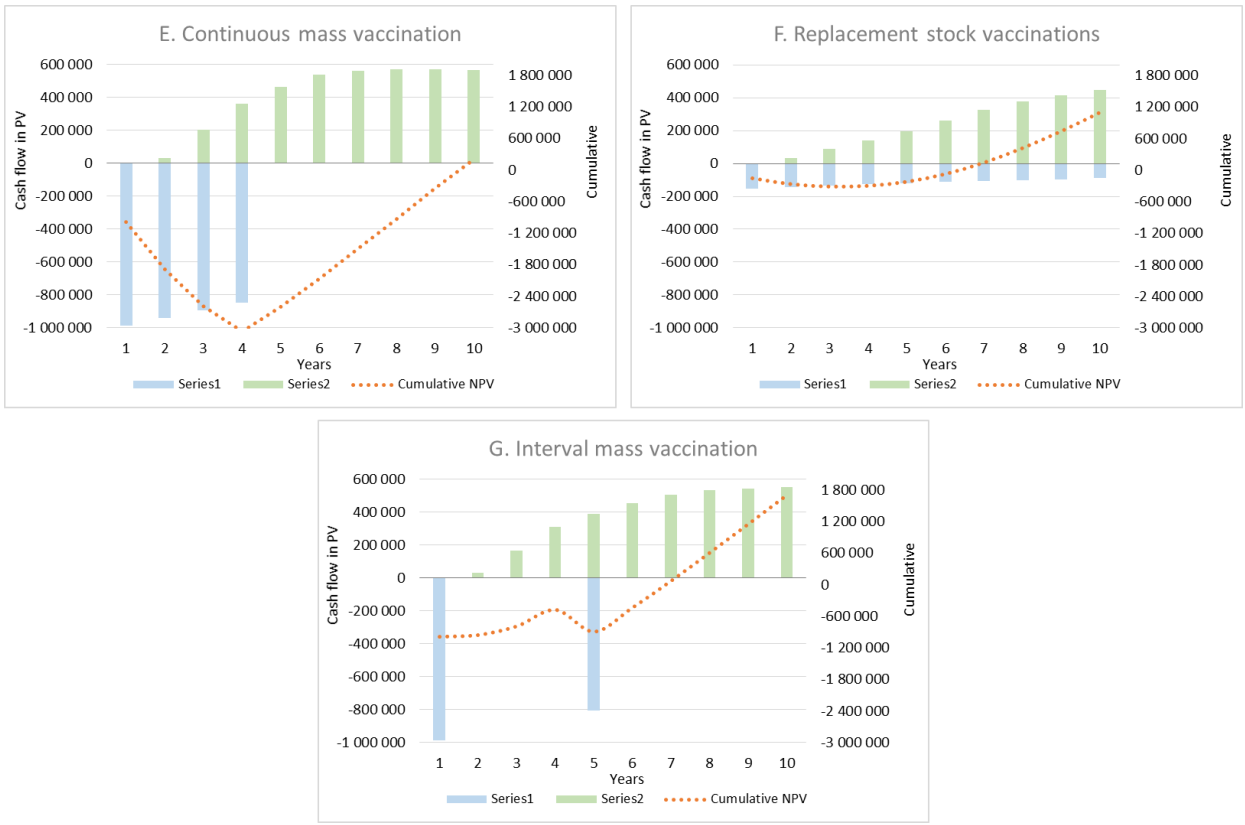
Table 3. Cost–benefit analysis of present value monetary costs and benefits of vaccination scenarios in small ruminants (USD)

	Scenario A	Scenario B	Scenario C	Scenario D
Present value of benefits	1 545 347	800 129	1 294 484	1 375 428
Present value of costs	1 035 070	395 296	528 961	615 331
Benefit–cost ratio	1.5	2	2.4	2.2
Net present value	510 277	404 833	765 523	760 097
Internal rate of return	23%	42%	39%	44%

Source: Author's own elaboration.

All presented vaccination scenarios would be economically viable choices if they were independent. In reality, however, they are mutually exclusive, therefore the government needs to decide on one of the scenarios to invest in. By comparing scenarios, it is evident from Table 3 that NPV and IRR provide conflicting results. This difference occurs because of the different cash flow patterns in the scenarios. In the case of scenario A, continuous mass vaccination, and scenario B, replacement stock vaccination, they could be discarded versus scenario C and scenario D, because both scenarios A and B have a smaller NPV and BCR, and scenario A also has a smaller IRR. While both scenario B and scenario D have a higher IRR than scenario C, the latter outperforms them in terms of BCR and NPV, meaning that the benefits are 2.4 times more than the costs, and the profitability generated by this scenario is at least USD 5 500 more than the competitor scenario D, and almost double compared with scenario C. In the calculation of costs and benefits, there is an assumption that cash flows will be reinvested at the same discount rate at which they are discounted. In the NPV calculation, the implicit assumption for a reinvestment rate is 7.2 percent. In IRR, the implicit reinvestment rate assumption is of 39 percent or 44 percent, for scenarios C and D, respectively. The reinvestment rate of 39 percent or 44 percent in IRR is quite unrealistic compared to NPV. This makes the NPV results superior to the IRR results. In this case, scenario C – interval mass vaccination – should be chosen.

Figure 10. Present value cash flow profiles of vaccination scenarios in large ruminants



Source: Author's own elaboration.

In large ruminants, the calculations are carried out for a period of ten years, to account for at least an entire generation. All scenarios are economically viable investments, with the continuous mass vaccination scenario E just barely passing the economical threshold of profitability. In this scenario, the costs are staggering, causing a large cash sink and pushing back the payback period until the last year. The benefits are also substantial, but because of the large costs, the profitability is marginal. For scenario F, replacement stock vaccination, the annual costs are minor compared with the other scenarios, although they are distributed through the whole period. Still, they amount to about two-thirds of the costs of continuous mass vaccination. The benefits are comparatively smaller, but the cumulative cash flow in present value becomes highly profitable after the sixth year. The benefits in scenario G, interval mass vaccination, are average compared with the two other scenarios. The costs are quite high in the first year and less marked in the fifth year due to discounting. The breakeven point of this scenario is reached after the seventh year, and the profitability is considerable thereafter.

Scenario E is the best scenario to control the disease in epidemiological terms and has the largest share of benefits compared to the other two. However, its costs are high and reduce the profitability, thus its scores lower cost–benefit indicators. A similar conflicting situation regarding the cost–benefit indicators in scenarios F and G arises, like with small ruminants. The same arguments are valid here also, therefore scenario G is a better investment.

Table 4. Cost–benefit analysis of present value monetary costs and benefits of vaccination scenarios in large ruminants (USD)

	Scenario E	Scenario F	Scenario G
Present value of benefits	3 877 169	2 284 145	3 499 576
Present value of costs	3 666 916	1 185 148	1 793 828
Benefit–cost ratio	1.1	1.9	2.0
Net present value	210 254	1 098 997	1 705 748
Internal rate of return	9%	37%	26%

Source: Author's own elaboration.

Considering that the current control strategy implementation resembles scenario B in small ruminants and scenario F in large ruminants, it can be said based on the results of the cost–benefit analysis that there are no visible benefits as yet. For large ruminants, the total costs are USD 735 010, while the total benefits up to the fifth year of scenario F total USD 568 938. This leads to a BCR equal to 0.8,[5] meaning that costs outweigh the benefits. This is in line with the current analysis since for scenario F the breakeven point between costs and benefits occurs in the sixth year. So if the strategy is followed at the current pace, it is expected to see some benefits after two years. In small ruminants, the current costs are USD 78 625, and the benefits for the second year of scenario B amount to USD 11 551, thus again resulting in a negative BCR of 0.15. Again, if the strategy is implemented unchanged, it is expected to have some tangible benefits after three years, as the breakeven point of scenario B occurs in the fifth year.

[5] This is a crude BCR because figures are not discounted; therefore it is not comparable with the other estimates of BCR in this report.

Conclusions

Economic losses stemming from brucellosis usually occur due to abortion in the affected animal population; diminished milk production and contamination of milk; culling of infected animals; endangering animal exports; human brucellosis causing reduced work capacity through sickness of the affected employees; treatment costs of affected people; government costs on research and eradication schemes; and loss of financial investments. The current annual losses due to the disease in Georgia amount to USD 1.95 million, where USD 1.3 million are from gross margin losses in animal production, USD 362 000 from human health and productivity losses, USD 203 000 for disease control in large ruminants, and USD 79 000 for disease control in small ruminants.

Such figures call for action to invest more in brucellosis control, as current action benefits are justifying only 50 percent of the costs to control the disease in ruminant populations. Investment returns in animal health are usually slow since the positive effect of any vaccination scenario is mostly after four and more years of the operation, as the animals survive five to ten years depending on species and on farmer culling practice. In human health, the benefit of any vaccination scenario is not immediate but considerably delayed, as the infected animals survive and infect new humans. Because the benefits of vaccination take longer to appear, when accounting for the time value of money, the overall value of the programme is reduced. This makes the benefit–cost ratio less favourable compared to programmes where the benefits are seen earlier. As a result, the calculated return on investment is also lower. The time factor plays an important role in cost–benefit analysis. However, other benefits may be considered which were not taken into account in the economic analysis, such as the quality of human life, human suffering, and influence on markets.

Any strategy can only be suitably implemented if the government provides the necessary budget. Up until now, this seems to be difficult, as the current strategy is not being implemented as originally intended. The strategic document of the NFA consists, at least for small ruminants, of mass vaccination followed by replacement stock vaccinations. Nevertheless, due to shortcomings, its implementation is on a par with replacement stock vaccination. Replacement stock vaccination scenarios, from an economic standpoint, are valid choices if implemented correctly. However, a more effective programme to control the disease through interval mass vaccinations has been shown to be a better economic option. The analysis supports the idea that switching from the current strategy to interval mass vaccination should substantially increase the scale of benefits.

In choosing the optimal course of action, technical considerations should also be taken into account. From the modelling, the best strategy to reduce the disease burden is mass vaccination. Indeed, in many countries without well-organized veterinary services and limited economic resources, the mass vaccination programme is the only feasible alternative to be applied and maintained, independent of the level of prevalence. In general, is advisable to mass vaccinate for at least one entire generation of the production life of livestock. In accordance with this rule of thumb, in the current analysis the mass vaccination has been programmed for four years in small ruminants. The same model was maintained in large ruminants, since including more than four years of mass vaccination in this species would be counterproductive in terms of profitability. However, such a strategy has huge costs in implementation, and in the cost–benefit analysis it was considered less suitable in large and small ruminants. Regarding the replacement stock strategy, it is the least effective strategy to reduce the incidence in both livestock and humans. However, due to the practical difficulties

of getting full vaccine coverage of the whole population, this strategy has failed to control brucellosis even in favourable conditions in developed countries. From an economic perspective, it ranks as the third option for investment.

The mass vaccination followed by replacement vaccination is the second-best strategy in both economic cost-benefit, and in controlling the disease. For this scenario, the ideal follow-up procedure is vaccinating exclusively 100 percent of replacement stock every year, usually for five to ten years, following the first mass vaccination campaign. In the typical husbandry conditions of small ruminants, owners can keep young replacements all through the year according to pasture resources and market prices. This practical problem, coupled with the difficulty of localizing all flocks during transhumance, results in several veterinary visits within a year to achieve the vaccination coverage of these young replacements (the same applies for the scenario with only replacements vaccinations). This problem can result in a failure of adequate vaccination coverage for the whole replacement population, and keep the disease present. Decision makers should be mindful that such an approach may risk incurring substantial uncalculated extra costs for little extra benefit in disease control effectiveness.

It is important to compare the mass vaccination and replacements vaccinations with interval mass vaccinations, which is very slightly less effective in controlling the disease, but it is the best in terms of economic profitability. As demonstrated by the analysis, interval mass vaccination is a better investment option but it is preferable to mass vaccination because it has less problematic implementation and therefore avoids the drawback of multiple visits in the field. Following the first mass vaccination the following year, only the replacement stock would be new and susceptible to the disease, but because of herd immunity, transmission to this section of the unvaccinated population – already at low risk as they are not pregnant – is much smaller (Blasco and Molina-Flores, 2011). In the third year, around 40 percent of the entire national flock would be unprotected and contain a high proportion of animals at risk which are pregnant and lactating, and therefore another mass vaccination is implemented to boost the immunity of the entire small ruminant population. To avoid any shortcomings, it is recommended that such mass vaccinations be performed during the pre-breeding period, late lambing season and during lactation, as this is the best window of opportunity to perform a whole-flock vaccination programme with the minimum of vaccine-induced side-effects. Similar reasoning is applied to large ruminants, although actions should be adjusted according to the husbandry profile of bovines.

From the analysis, it is evident that by investing more in controlling the disease in large ruminants, the economic benefits will be higher and outnumber those for small ruminants. However, it is worth mentioning that there are some differences in the benefits for large and small ruminants. The differences derive from the human health-related costs which for small ruminants are higher, as the disease in humans is mainly caused by *Brucella melitensis*. Human health benefits account for more than 50 percent of all benefits in small ruminants, and only 7 to 11 percent for large ruminants. Therefore, if funds are not available to properly control the disease in both ruminant types, control of the disease in small ruminants should be prioritized to avoid inestimable losses in public health.

As the vaccination campaign improves human health through interventions in the veterinary sector, the allocation of costs of the intervention among different sectors has to be decided. Although the benefit side can be assigned easily to breeders (benefits from livestock production), patients (reduced expense and coping costs), and the public health sector (avoidance of hospitalization and drugs), the costs cannot be assigned wholly to the agriculture or health sectors.

Finally, policymakers and decision-makers will need to balance the above technical criteria – which are intangible in terms of costs and benefits, and in terms of the scale of impact on NFA structures in implementing such vaccination scenarios – with the costs and gains that are expected to accrue.

Annex 1. Indicators and parameters used to calculate losses

A conversion rate of USD 1 = GEL 2.92 as per 10 August 2019 was used in all calculations.

Table A1.1 Animal health-related information and parameters

Species	Indicator	Unit	Value	Reference	Source article
Cattle	Adult mortality	%	0.03	Expert opinion	
Cattle	Culled dams live weight (lw) cattle	kg	250	IFAD, 2019	Dairy Modernization and Market Access Programme
Cattle	Feeding and other variable costs, cattle	USD	273.97	AYEG, 2015	Milk and dairy production
Cattle	Labour needs per cow and year in days	day	190	EGF, 2004	Land use systems in grassland dominated regions
Cattle	Meat cattle	USD	4.32	Geostat, 2019	
Cattle	Milk production (excluding consumption) cow	L	1486	Geostat, 2019	
Cattle	Opportunity costs of family labour/h	USD	2.19	Geostat, 2019	Average monthly nominal earnings GEL 1124
Cattle	Selling age young stock, months	Mo	3	Expert opinion	
Cattle	Selling of youngstock lw	kg	100	Expert opinion	
Cattle	Selling of youngstock price	USD	4.83	Media outlet	In a report it was stated that calf meat cost GEL 1.5 more than the cattle one
Cattle	Veterinary costs (drugs 20 gel, AI GEL 60, service GEL 10) USD cattle	USD	30.82	AYEG, 2015	Milk and dairy production
Cattle	Youngstock born cow	%	0.87	Geostat, 2019	
Cattle	Youngstock mortality (up to 2 years for cattle)	%	5	IFAD, 2018	Dairy Modernization and Market Access Programme
Goat	Adult mortality	%	0.05	Expert opinion	
Goat	Culled dams lw	kg	35	FAO, 2014	Sustainable goat breeding and goat farming in central and eastern European countries
Goat	Meat goat	USD	4.23	Geostat, 2019	
Goat	Meat sheep	USD	4.23	Geostat, 2019	
Goat	Milk production (excl. young's consum.) goat	L	150	FAO, 2014	Sustainable goat breeding and goat farming in central and eastern European countries
Goat	Selling age youngstock, months goat	Mo	2	FAO, 2014	Sustainable goat breeding and goat farming in central and eastern European countries
Goat	Selling of young stock lw	kg	13	Expert opinion	

Species	Indicator	Unit	Value	Reference	Source article
Goat	Selling of young stock price	USD	5	Media	In a Georgian media outlet it was mentioned that the price for yang stock is GEL 15
Goat	Young stock born goat	%	1.5	FAO, 2014	Sustainable goat breeding and goat farming in central and eastern European countries
Goat	Young stock mortality	%	0.15	Kochlamazashvili, 2014	Value chain analysis of the Georgian sheep sector
Sheep	Adult mortality	%	0.05	Expert opinion	
Sheep	Culled dams * lw sheep	kg	30	SlowFood, 2019	https://www.fondazioneslowfood.com/en/ark-of-taste-slow-food/tusheti-sheep/
Sheep	Feeding and other costs (feeding, pasture, movement, salt)	USD	12.15	MOLI, 2016	Milk and meat sector study
Sheep	Milk production (excluding consumption)	L	48	Gonashvili, 2013	Perspectives on Sheep Farming & The Sheep Market System in Georgia
Sheep	Selling age young stock, months	Mo	2–3	Expert opinion	
Sheep	Selling of young stock lw	kg	30	MOLI, 2016	Milk and meat sector study
Sheep	Selling of youngstock price	USD	5	Media	In a Georgian media outlet was mentioned that the price for SR yang stock is 15 GEL
Sheep	Shepherd (USD 170/month per 170 dams, not full year)	USD	9.93	MOLI, 2016	Milk and meat sector study
Sheep	Veterinary costs	USD	3.08	MOLI, 2016	Milk and meat sector study
Sheep	Youngstock born	%	0.95	Geostat, 2019	
Sheep	Youngstock mortality	%	0.15	Kochlamazashvili, 2014	Value Chain Analysis of the Georgian Sheep Sector
Large and small ruminants	Milk price/L	USD	0.32	Geostat, 2019	

Source: Author's own elaboration.

Table A1.2 Human health-related information and parameters

All items marked in bold have been used in the estimations; items marked with an asterisk (*) have been summarized, and two-thirds of the collective prices has been used since not all complicated cases would need the full range of examinations.

Items	Indicator	USD	GEL	Reference	Article/web
Hospital bed including doctor/other staff		16.70	48.76	WHO-CHOICE, 2011	https://www.who.int/choice/cost-effectiveness/inputs/health_service/en/
Hospital bed including doctor/other staff		57.30	167.32	WHO-CHOICE, 2011 (modified by current GDP)	https://www.who.int/choice/cost-effectiveness/inputs/health_service/en/
Hospital bed including doctor/other staff		**50**	146	Komakhidze, 2015	Cost-effectiveness of pneumococcal conjugate vaccination in Georgia
Outpatient visit		6.68	19.51	WHO-CHOICE, 2011 (modified by current GDP)	https://www.who.int/choice/cost-effectiveness/en/
Outpatient visit		3.95	11.53	WHO-CHOICE, 2011	https://www.who.int/choice/cost-effectiveness/en/
Outpatient visit		**10.27**	30.00	Family doctor price internal standard.	https://www.city24.ge/img/files/4.pdf
Average monthly nominal earnings		**384.96**	1124.10	GEOSTAT, 2018	http://georgiatoday.ge/news/17650/Geostat%3A-Average-Salary-in-2018-Was-GEL-1-068.3
Doxycycline 100 10 mg tab package		**3.25**	9.5	AVERSI, 2019	https://www.aversi.ge/ka/aversi/act/drugDet/?MatID=63896
Rifampicin 0.15 g 20 tab package		**1.30**	3.8	AVERSI, 2019	https://www.aversi.ge/ka/aversi/act/drugDet/?MatID=10691
Streptomycin 1 g flacon		**0.28**	0.82	AVERSI, 2019	https://www.aversi.ge/en/aversi/act/genDet/?FarmID=10500
Complete blood count (CBC)		**5.48**	16	MediMedi, 2019	http://medimedi.ge/medimedi.php?id=6&lang=geo
Urinalysis		**3.77**	11	MediMedi, 2019	http://medimedi.ge/medimedi.php?id=6&lang=geo
C-reactive protein (CRP)		**4.45**	13	MediMedi, 2019	http://medimedi.ge/medimedi.php?id=6&lang=geo
Erythrocyte sedimentation rate (ESR)		**3.77**	11	MediMedi, 2019	http://medimedi.ge/medimedi.php?id=6&lang=geo
Blood glucose		**3.77**	11	MediMedi, 2019	http://medimedi.ge/medimedi.php?id=6&lang=geo

Items	Indicator	USD	GEL	Reference	Article/web
Agglutination test for brucellosis (SAT)		**6.85**	20	NCDC, 2019	https://www.ncdc.ge/Pages/User/LetterContent.aspx?ID=6f82d46b-91d4-479c-97c3-e0f7d6f27e07
Wright test (SAT)		9.59	28	NEOLAB, 2019	http://neolab.ge/laboratoriuli-gamokvlevebi/
Brucella IgM, ELISA		**10.27**	30	NCDC, 2019	https://www.ncdc.ge/Pages/User/LetterContent.aspx?ID=6f82d46b-91d4-479c-97c3-e0f7d6f27e07
Brucella IgM		9.59	28	NEOLAB, 2019	http://neolab.ge/laboratoriuli-gamokvlevebi/
Brucella IgG, ELISA		**10.27**	30	NCDC, 2019	https://www.ncdc.ge/Pages/User/LetterContent.aspx?ID=6f82d46b-91d4-479c-97c3-e0f7d6f27e07
Brucella IgG		9.59	28	NEOLAB, 2019	http://neolab.ge/laboratoriuli-gamokvlevebi/
Abdominal ultrasound*		17.12	50	INITIO, 20019	https://initio.ge/ka/ultrasonografia
Cardiac ultrasound*		17.12	50	INITIO, 20019	https://initio.ge/ka/ultrasonografia
X ray, chest*		20.55	60	INITIO, 20019	https://initio.ge/ka/rentgeni
X ray, articulations*		13.70	40	INITIO, 20019	https://initio.ge/ka/rentgeni
MRI*		94.18	275	MINCLINIC, 2019	http://www.minclinic.ru/stranicy/stranicy_ge/stoimost%27_le4enija_ge.html
CT scan head*		65.07	190	MINCLINIC, 2019	http://www.minclinic.ru/stranicy/stranicy_ge/stoimost'_le4enija_ge.html
CT scan pulmonary*		71.92	210	MINCLINIC, 2019	http://www.minclinic.ru/stranicy/stranicy_ge/stoimost'_le4enija_ge.html
CT scan abdominal*		71.92	210	MINCLINIC, 2019	http://www.minclinic.ru/stranicy/stranicy_ge/stoimost'_le4enija_ge.html
Outpatient visit every 17 days	**17 days**				Expert opinion bases on interviews with doctors in Albania
Hospitalization length (8–27) days	**18 days**			Akhvlediani, 2017	Epidemiological and Clinical Features of Brucellosis in the Country of Georgia

Items	Indicator	USD	GEL	Reference	Article/web
Rate of patients which are hospitalized	**29%**			Kokaia, 2014	Human brucellosis in Georgia: Clinical and laboratory manifestations
Rate of patients with relapse	**8%**			Akhvlediani, 2010	The changing pattern of human brucellosis: clinical manifestations, epidemiology, and treatment outcomes over three decades in Georgia
Rate of patients with complications	**27%**			Akhvlediani, 2010	The changing pattern of human brucellosis: clinical manifestations, epidemiology, and treatment outcomes over three decades in Georgia
Proportion of cases of working age => 18 years	**86%**			Havas, 2013	Risk factors associated with human brucellosis in the country of Georgia: a case-control study

Source: Author's own elaboration.

Annex 2. Flock/herd model simulations to estimate immunity profiles

Table A2.1 Immunity profile for continuous mass vaccinations in small ruminants (scenario A)

Flock model simulating immunized animals (100 ewe flock; mortality not considered)

YEARS	1	2	3	4	5	6	7	8
Vaccination coverage	**0.80**	**0.80**	**0.80**	**0.80**				
Seroconversion	**0.80**	**0.80**	**0.80**	**0.80**				
Ewe cohort age 2 years	20	20	20	20	20 culled			
Successfully immunized	13	17	19	20	16			
Not protected	7	3	1	0	4			
Ewe cohort age 3 years	20	20	20	20 culled				
Successfully immunized	13	17	19	20				
Not protected	7	3	1	0				
Ewe cohort age 4 years	20	20	20 culled					
Successfully immunized	13	17	19					
Not protected	7	3	1					
Ewe cohort age 5 years	20	20 culled						
Successfully immunized	13	17						
Not protected	7	3						
Ewe cohort age 6 years	20 culled							
Successfully immunized	13							
Not protected	7							
Remonts		20	20	20	20	20 culled		
Successfully immunized		13	17	19	15	11		
Not protected		7	3	1	5	9		
Remonts			20	20	20	20	20 culled	
Successfully immunized			13	17	14	10	7	
Not protected			7	3	6	10	13	
Remonts				20	20	20	20	20
Successfully immunized				13	10	8	5	3
Not protected				7	10	12	15	17
Proportion of immunized	**64%**	**82%**	**87%**	**89%**	**55%**	**30%**	**12%**	**3%**

Source: Author's own elaboration.

Table A2.2 Immunity profile for replacement stock vaccinations in small ruminants (scenario B)

Flock model simulating immunized animals (100 ewe flock; mortality not considered)

YEARS	1	2	3	4	5	6	7	8
Vaccination coverage	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**
Seroconversion	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**
Remonts								20
Successfully immunized								13
Not protected								7
Remonts							20	20
Successfully immunized							13	10
Not protected							7	10
Remonts						20	20	20
Successfully immunized						13	10	8
Not protected						7	10	12
Remonts					20	20	20	20
Successfully immunized					12.8	10.2	8.2	6.6
Not protected					7.2	9.8	11.8	13.4
Remonts	20	20	20	20	20			
Successfully immunized	13	10	8	7	5			
Not protected	7	10	12	13	15			
Remonts		20	20	20	20	20 culled		
Successfully immunized		13	10	8	7	5		
Not protected		7	10	12	13	15		
Remonts			20	20	20	20	20 culled	
Successfully immunized			13	10	8	7	5	
Not protected			7	10	12	13	15	
Remonts				20	20	20	20	20
Successfully immunized				13	10	8	7	5
Not protected				7	10	12	13	15
Proportion of immunized	**13%**	**23%**	**31%**	**38%**	**43%**	**43%**	**43%**	**43%**

Source: Author's own elaboration.

Table A2.3 Immunity profile for interval mass vaccinations in small ruminants (scenario C)

Flock model simulating immunized animals (100 ewe flock; mortality not considered)

YEARS	1	2	3	4	5	6	7	8
Vaccination coverage	**80%**		**80%**					
Seroconversion	**80%**		**80%**					
Ewe cohort age 2 years	20	20	20	20	20 culled			
Successfully immunized	13	10	14	12	9			
Not protected	7	10	6	8				
Ewe cohort age 3 years	20	20	20	20 culled				
Successfully immunized	13	10	14	12				
Not protected	7	10	6	8				
Ewe cohort age 4 years	20	20	20 culled					
Successfully immunized	13	10	14					
Not protected	7	10	6					
Ewe cohort age 5 years	20	20 culled						
Successfully immunized	13	10						
Not protected	7	10						
Ewe cohort age 6 years	20 culled							
Successfully immunized	13							
Not protected	7							
Remonts		20	20	20	20	20 culled		
Successfully immunized		0	13	13	10	8		
Not protected		20	7	7	10	12		
Remonts			20	20	20	20	20 culled	
Successfully immunized			13	17	14	10	7	
Not protected			7	3	6	10	13	
Proportion of immunized	**64%**	**41%**	**69%**	**53%**	**33%**	**18%**	**7%**	**0%**

Source: Author's own elaboration.

Table A2.4 Immunity profile for mass vaccinations followed by replacements vaccinations in small ruminants (scenario D)

Flock model simulating immunized animals (100 ewe flock; mortality not considered)

YEARS	1	2	3	4	5	6	7	8
Vaccination coverage	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**
Seroconversion	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**
Ewe cohort age 2 years	20	20	20	20	20 culled			
Successfully immunized	13	10	8	7	5			
Not protected	7	10	12	13	15			
Ewe cohort age 3 years	20	20	20	20 culled				
Successfully immunized	13	10	8	7				
Not protected	7	10	12	13				
Ewe cohort age 4 years	20	20	20 culled					
Successfully immunized	13	10	8					
Not protected	7	10	12					
Ewe cohort age 5 years	20	20 culled						
Successfully immunized	13	10						
Not protected	7	10						
Ewe cohort age 6 years	20 culled							
Successfully immunized	13							
Not protected	7							
Remonts		20	20	20	20	20 culled		
Successfully immunized		13	10	8	7	5		
Not protected		7	10	12	13	15		
Remonts			20	20	20	20	20 culled	
Successfully immunized			13	10	8	7	5	
Not protected			7	10	12	13	15	
Remonts				20	20	20	20	20
Successfully immunized				13	10	8	7	5
Not protected				7	10	12	13	15
Remonts					20	20	20	20
Successfully immunized					13	10	8	7
Not protected					7	10	12	13
Remonts						20	20	20
Successfully immunized						13	10	8
Not protected						7	10	12
Remonts							20	20
Successfully immunized							13	10
Not protected							7	10
Remonts								20
Successfully immunized								13
Not protected								7
Proportion of immunized	**64%**	**54%**	**48%**	**44%**	**43%**	**43%**	**43%**	**43%**

Source: Author's own elaboration.

Table A2.5 Immunity profile for continuous mass vaccinations in large ruminants (scenario E)

Herd model simulating immunized animals (100 cow herd; mortality not considered

YEARS	1	2	3	4	5	6	7	8	9	10
Vaccination coverage	**80%**	**80%**	**80%**	**80%**						
Seroconversion	**80%**	**80%**	**80%**	**80%**						
Cattle cohort age 1 years	10	10	10	10	10	10	10	10	11	12
Successfully immunized	6	9	10	10	9	8	7	6	6	5
Not protected	4	1	0	0	1	2	3	4	5	7
Cattle cohort age 2 years	10	10	10	10	10	10	10	10	11	culled
Successfully immunized	6	9	10	10	9	8	7	6	6	
Not protected	4	1	0	0	1	2	3	4	5	
Cattle cohort age 3 years	10	10	10	10	10	10	10	10	culled	
Successfully immunized	6	9	10	10	9	8	7	6		
Not protected	4	1	0	0	1	2	3	4		
Cattle cohort age 4 years	10	10	10	10	10	10	10	culled		
Successfully immunized	6	9	10	10	9	8	7			
Not protected	4	1	0	0	1	2	3			
Cattle cohort age 5 years	10	10	10	10	10	10	culled			
Successfully immunized	6	9	10	10	9	8				
Not protected	4	1	0	0	1	2				
Cattle cohort age 6 years	10	10	10	10	10	culled				
Successfully immunized	6	9	10	10	9					
Not protected	4	1	0	0	1					
Cattle cohort age 7 years	10	10	10	10	culled					
Successfully immunized	6	9	10	10						
Not protected	4	1	0	0						
Cattle cohort age 8 years	10	10	10	culled						
Successfully immunized	6	9	10							
Not protected	4	1	0							
Cattle cohort age 9 years	10	10	culled							
Successfully immunized	6	9								
Not protected	4	1								
Cattle cohort age 10 years	10	culled								
Successfully immunized	6									
Not protected	4									
Remonts		10	10	10	10	10	10	10	11	12
Successfully immunized		6	9	10	9	8	7	6	5	5
Not protected		4	1	0	1	2	3	4	6	7
Remonts			10	10	10	10	10	10	11	12
Successfully immunized			6	9	8	7	6	5	5	4
Not protected			4	1	2	3	4	5	6	8
Remonts				10	10	10	10	10	11	12
Successfully immunized				6	6	5	5	4	4	3
Not protected				4	4	5	5	6	7	9
Proportion of immunized	**64%**	**85%**	**91%**	**93%**	**75%**	**60%**	**46%**	**35%**	**25%**	**17%**

Source: Author's own elaboration.

Table A2.6 Immunity profile for replacement stock vaccinations in large ruminants (scenario F)

Herd model simulating immunized animals (100 cow herd; mortality not considered)

YEARS	1	2	3	4	5	6	7	8	9	10
Vaccination coverage	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Seroconversion	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**	**80%**
Remonts	10	10	10	10	10	10	10	10	10	10
Successfully immunized	8.00	7.20	6.48	5.83	5.25	4.72	4.25	3.83	3.44	3.10
Not protected	2.00	2.80	3.52	4.17	4.75	5.28	5.75	6.17	6.56	6.90
Remonts		10	10	10	10	10	10	10	10	10
Successfully immunized		8.00	7.20	6.48	5.83	5.25	4.72	4.25	3.83	3.44
Not protected		2.00	2.80	3.52	4.17	4.75	5.28	5.75	6.17	6.56
Remonts			10	10	10	10	10	10	10	10
Successfully immunized			8.00	7.20	6.48	5.83	5.25	4.72	4.25	3.83
Not protected			2.00	2.80	3.52	4.17	4.75	5.28	5.75	6.17
Remonts				10	10	10	10	10	10	10
Successfully immunized				8.00	7.20	6.48	5.83	5.25	4.72	4.25
Not protected				2.00	2.80	3.52	4.17	4.75	5.28	5.75
Remonts					10	10	10	10	10	10
Successfully immunized					8.00	7.20	6.48	5.83	5.25	4.72
Not protected					2.00	2.80	3.52	4.17	4.75	5.28
Remonts						10	10	10	10	10
Successfully immunized						8.00	7.20	6.48	5.83	5.25
Not protected						2.00	2.80	3.52	4.17	4.75
Remonts							10	10	10	10
Successfully immunized							8.00	7.20	6.48	5.83
Not protected							2.00	2.80	3.52	4.17
Remonts								10	10	10
Successfully immunized								8.00	7.20	6.48
Not protected								2.00	2.80	3.52
Remonts									10	10
Successfully immunized									8.00	7.20
Not protected									2.00	2.80
Remonts										10
Successfully immunized										8.00
Not protected										2.00
Proportion of immunized	**8%**	**15%**	**22%**	**28%**	**33%**	**37%**	**42%**	**46%**	**49%**	**52%**

Note: The overage in this scenario has been increased to 100 percent to account for the current strategy.
Source: Author's own elaboration.

Table A2.7 Immunity profile for interval mass vaccinations in large ruminants (scenario G)

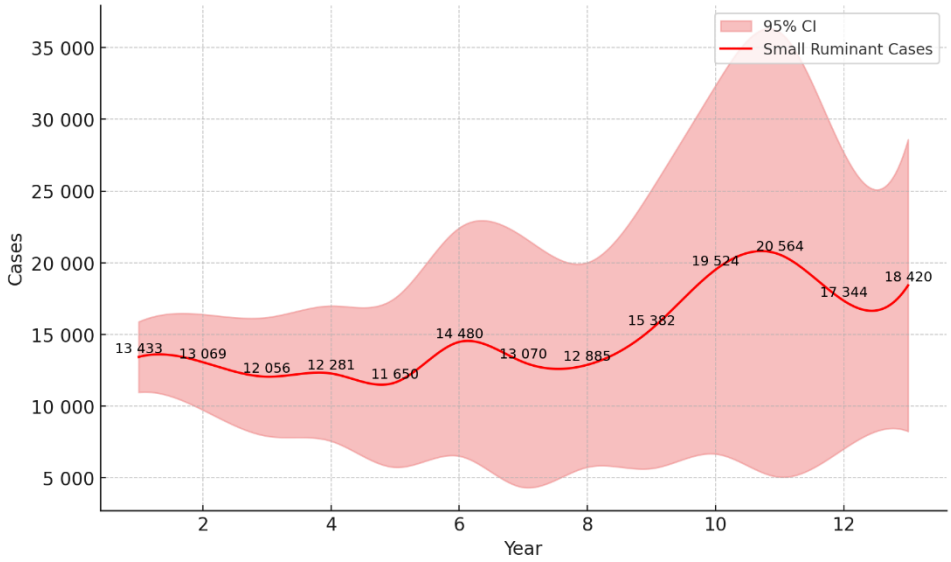
Herd model simulating immunized animals (100 cow herd; mortality not considered)

YEARS	1	2	3	4	5	6	7	8	9	10
Vaccination coverage	**0.80**				**0.80**					
Seroconversion	**0.80**				**0.80**					
Cattle cohort age 1 years	10	10	10	10	10	10	10	10	11	12
Successfully immunized	6	6	5	5	8	7	7	6	5	5
Not protected	4	4	5	5	2	3	3	4	6	7
Cattle cohort age 2 years	10	10	10	10	10	10	10	10	11	culled
Successfully immunized	6	6	5	5	8	7	7	6	5	
Not protected	4	4	5	5	2	3	3	4	6	
Cattle cohort age 3 years	10	10	10	10	10	10	10	10	culled	
Successfully immunized	6	6	5	5	8	7	7	6		
Not protected	4	4	5	5	2	3	3	4		
Cattle cohort age 4 years	10	10	10	10	10	10	10	culled		
Successfully immunized	6	6	5	5	8	7	7			
Not protected	4	4	5	5	2	3	3			
Cattle cohort age 5 years	10	10	10	10	10	10	culled			
Successfully immunized	6	6	5	5	8	7				
Not protected	4	4	5	5	2	3				
Cattle cohort age 6 years	10	10	10	10	10	culled				
Successfully immunized	6	6	5	5	8					
Not protected	4	4	5	5	2					
Cattle cohort age 7 years	10	10	10	10	culled					
Successfully immunized	6	6	5	5						
Not protected	4	4	5	5						
Cattle cohort age 8 years	10	10	10	culled						
Successfully immunized	6	6	5							
Not protected	4	4	5							
Cattle cohort age 9 years	10	10	culled							
Successfully immunized	6	6								
Not protected	4	4								
Cattle cohort age 10 years	10	culled								
Successfully immunized	6									
Not protected	4									
Remonts		10	10	10	10	10	10	10	10	10
Successfully immunized		0	0	0	6	6	5	5	4	4
Not protected		10	10	10	4	4	5	5	6	6
Remonts			10	10	10	10	10	10	10	10
Successfully immunized			0	0	6	6	5	5	4	4
Not protected			10	10	4	4	5	5	6	6
Remonts				10	10	10	10	10	10	10
Successfully immunized				0	6	6	5	5	4	4
Not protected				10	4	4	5	5	6	6
Remonts					10	10	10	10	10	10
Successfully immunized					6	6	5	5	4	4
Not protected					4	4	5	5	6	6
Proportion of immunized	**64%**	**52%**	**41%**	**33%**	**80%**	**65%**	**52%**	**41%**	**32%**	**24%**

Source: Author's own elaboration.

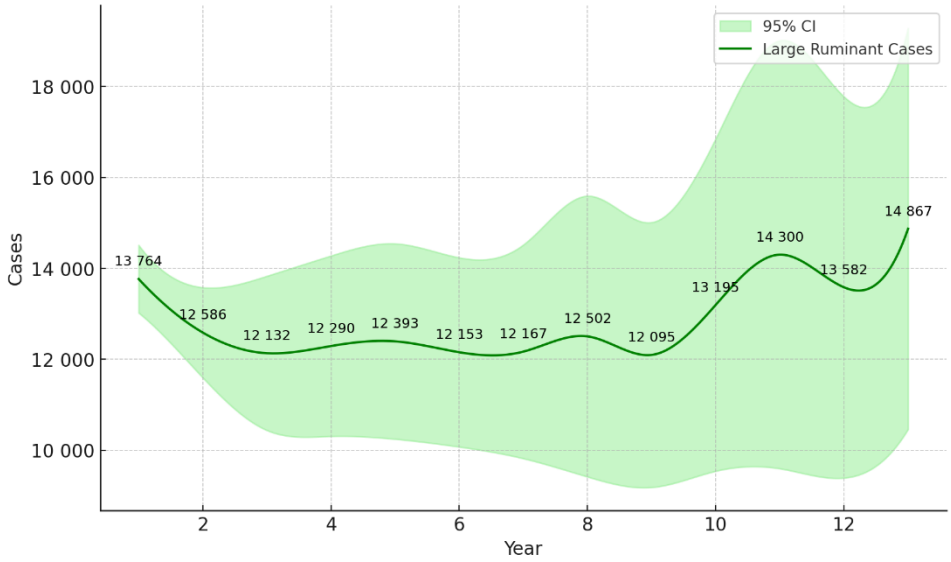
Annex 3. Baseline disease occurrence profiles

Figure A3. 1 Annual predicted baseline disease occurrence in small ruminants with 95% confidence intervals



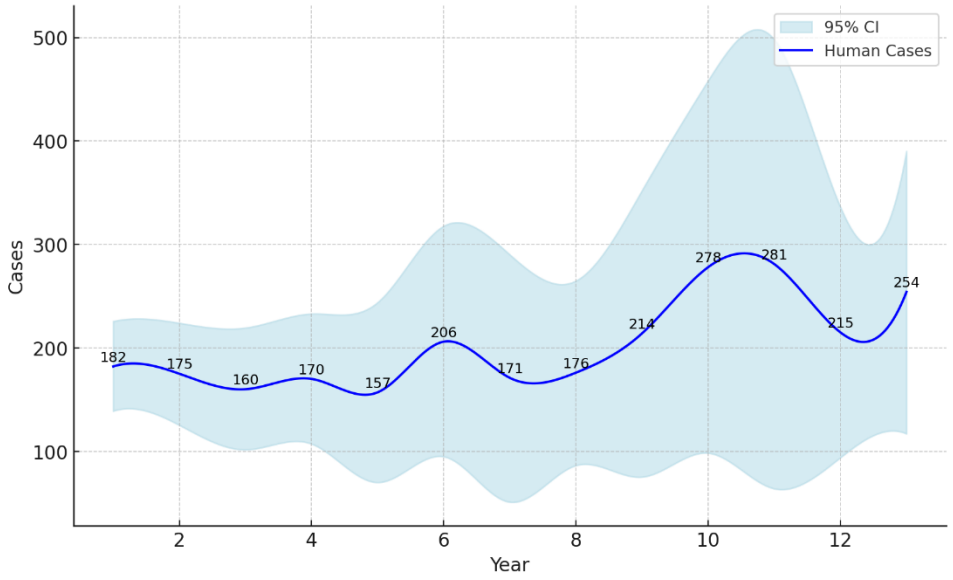
Note: CI stands for confidence interval.
Source: Author's own elaboration.

Figure A3.2 Annual predicted baseline disease occurrence in large ruminants with 95% confidence intervals



Source: Author's own elaboration.

Figure A3.3 Annual predicted baseline disease occurrence in humans with 95% confidence intervals



Source: Author's own elaboration.

Annex 4. Cash flow tables for vaccination scenarios

Table A4.1 Cash flow for scenario A: continuous mass vaccinations in small ruminants (USD)

YEARS	1	2	3	4	5	6	7	8	Total
Actions:									
no. of animals to be vaccinated	884 500	901 140	918 658	936 673	0	0	0	0	3 640 971
no. of farms to be visited	11 000	11 000	11 000	11 000	0	0	0	0	44 000
Inflows:									
from reduced human health costs	0	5 614	79 238	152 334	203 882	203 542	294 558	245 011	1 184 180
from reduced losses in animals	0	85 374	109 463	133 894	132 569	172 541	156 820	155 348	946 009
Total benefits by year	0	90 988	188 702	286 228	336 451	376 084	451 378	400 359	**2 130 188**
Present value of benefits by year	0	84 877	164 205	232 342	254 767	265 650	297 421	246 086	**1 545 347**
Outflows:									
cost of Rev1 vaccine	132 675	135 171	137 799	140 501	0	0	0	0	546 146
cost of aplication	60 582	61 722	62 922	64 156	0	0	0	0	249 382
cost of visit per farm	3 767	3 767	3 767	3 767	0	0	0	0	15 068
other costs (consumables, etc)	45 437	46 291	47 191	48 117	0	0	0	0	187 036
post-vaccination serosurvey	36 349	37 033	37 753	38 493	0	0	0	0	149 629
Total cost by year	278 810	283 985	289 432	295 034	0	0	0	0	**-1 147 261**
Present value of costsby year	278 810	264 911	251 859	239 490	0	0	0	0	**-1 035 070**
Cash flows:									
Net cash flow	-278 810	-192 997	-100 730	-8 806	336 451	376 084	451 378	400 359	
Net Present Value by year	-278 810	-180 034	-87 654	-7 148	254 767	265 650	297 421	246 086	
Cumulative cash flow	-278 810	-471 807	-572 537	-581 344	-244893	131 191	582 569	982 928	
Cumulative NPV	-278 810	-458 845	-546 498	-553 647	-298 880	-33 230	264 191	510 277	
Cost-Benefit indicators:									
Net Present Value								**510 277**	
Benefit Cost Ratio								**1.5**	
Internal Rate of Return for cash flow						5%	17%	**23%**	

Source: Author's own elaboration.

Table A4.2 Cash flow for scenario B: replacement stock vaccinations in small ruminants (USD)

YEARS	1	2	3	4	5	6	7	8	Total
Actions:									
no. of animals to be vaccinated	176 900	180 228	183 732	187 335	190 976	194 666	198 484	202 383	1 514 703
no. of farms to be visited	11 000	11 000	11 000	11 000	11 000	11 000	11 000	11 000	88 000
Inflows:									
from reduced human health costs	0	5 614	2 714	1 740	85 223	107 572	213 135	185 368	601 367
from reduced losses in animals	0	5 937	23 424	63 287	81 796	134 490	128 824	133 970	571 728
Total benefits	0	11 551	26 138	65 027	167 019	242 062	341 959	319 339	**1 173 095**
Present value of benefits	0	10 776	22 745	52 785	126 470	170 983	225 323	196 285	**805 366**
Outflows:									
cost of Rev1 vaccine	26 535	27 034	27 560	28 100	28 646	29 200	29 773	30 357	227 205
cost of aplication	12 116	12 344	12 584	12 831	13 081	13 333	13 595	13 862	103 747
cost of visit per farm	3 767	3 767	3 767	3 767	3 767	3 767	3 767	3 767	30 137
other costs (consumables, etc)	9 087	9 258	9 438	9 623	9 810	10 000	10 196	10 396	77 810
post-vaccination serosurvey	7 270	7 407	7 551	7 699	7 848	8 000	8 157	8 317	62 248
Total cost	58 776	59 811	60 900	62 020	63 153	64 300	65 488	66 700	**-501 147**
Present value costs	58 776	55 793	52 994	50 344	47 820	45 419	43 151	40 998	**-395 296**
Cash flows:									
Net cash flow	-58 776	-48 259	-34 762	3 006	103 866	177 761	276 472	252 639	
Net Present Value by year	-58 776	-45 018	-30 249	2 440	78 649	125 564	182 172	155 288	
Cumulative cash flow	-58 776	-107 035	-141 797	-138 791	-34 925	142 837	419 309	671 947	
Cumulative NPV	-58 776	-103 794	-134 043	-131 603	-52 954	72 610	254 782	410 070	
Cost-Benefit indicators:									
Net Present Value								**410 070**	
Benefit Cost Ratio								**2.0**	
Internal Rate of Return for cash flow						20%	36%	**43%**	

Source: Author's own elaboration.

Table A4.3 Cash flow for scenario C: interval mass vaccinations in small ruminants (USD)

YEARS	1	2	3	4	5	6	7	8	Total
Actions:									
no. of animals to be vaccinated	884 500	0	918 658	0	0	0	0	0	1 803 158
no. of farms to be visited	11 000	0	11 000	0	0	0	0	0	22 000
Inflows:									
from reduced human health costs	0	5 614	2 564	114 130	159 260	174 460	275 232	226 319	957 578
from reduced losses in animals	0	85 374	79 147	117 264	116 092	160 837	145 848	144 411	848 973
Total benefits	0	90 988	81 711	231 394	275 352	335 297	421 080	370 730	**1 806 552**
Present value of benefits	0	84 877	71 103	187 832	208 502	236 840	277 457	227 874	**1 294 484**
Outflows:									
cost of Rev1 vaccine	132 675	0	137 799	0	0	0	0	0	270 474
cost of aplication	60 582	0	60 959	0	0	0	0	0	121 541
cost of visit per farm	3 767	0	3 767	0	0	0	0	0	7 534
other costs (consumables, etc)	45 437	0	47 191	0	0	0	0	0	92 628
post-vaccination serosurvey	36 349	0	37 753	0	0	0	0	0	74 102
Total cost	278 810	0	287 469	0	0	0	0	0	**-566 279**
Present value of costs	278 810	0	250 151	0	0	0	0	0	**-528 961**
Cash flows:									
Net cash flow	-278 810	90 988	-205 759	231 394	275 352	335 297	421 080	370 730	
Net Present Value by year	-278 810	84 877	-179 048	187 832	208 502	236 840	277 457	227 874	
Cumulative cash flow	-278 810	-187 822	-393 581	-162 187	113 166	448 463	869 543	1 240 272	
Cumulative NPV	-278 810	-193 934	-372 981	-185 150	23 352	260 192	537 650	765 523	
Cost-Benefit indicators:									
Net Present Value								**765 523**	
Benefit Cost Ratio								**2.4**	
Internal Rate of Return for cash flow						25%	35%	**39%**	

Source: Author's own elaboration.

Table A4.4 Cash flow for scenario D: mass vaccination followed by replacement stock vaccinations in small ruminants (USD)

YEARS	1	2	3	4	5	6	7	8	Total
Actions:									
no. of animals to be vaccinated	884 500	180 228	183 732	187 335	190 976	194 666	198 484	202 383	2 222 303
no. of farms to be visited	11 000	11 000	11 000	11 000	11 000	11 000	11 000	11 000	88 000
Inflows:									
from reduced human health costs	0	5 614	3 720	154 382	177 470	183 790	274 439	226 865	1 026 280
from reduced losses in animals	0	85 087	98 855	118 310	119 837	162 941	149 197	148 985	883 212
Total benefits	0	90 701	102 575	272 692	297 307	346 731	423 636	375 850	**1 909 492**
Present value of benefits	0	84 609	89 259	221 354	225 126	244 917	279 141	231 021	**1 375 428**
Outflows:									
cost of Rev1 vaccine	132 675	27 034	27 560	28 100	28 646	29 200	29 773	30 357	333 345
cost of aplication	60 582	12 344	12 584	12 831	13 081	13 333	13 595	13 862	152 213
cost of visit per farm	3 767	3 767	3 767	3 767	3 767	3 767	3 767	3 767	30 137
other costs (consumables, etc)	45 437	9 258	9 438	9 623	9 810	10 000	10 196	10 396	114 159
post-vaccination serosurvey	36 349	7 407	7 551	7 699	7 848	8 000	8 157	8 317	91 328
Total costs	278 810	59 811	60 900	62 020	63 153	64 300	65 488	66 700	**-721 182**
Present value of costs	278 810	55 793	52 994	50 344	47 820	45 419	43 151	40 998	**-615 331**
Cash flows:									
Net cash flow	-278 810	30 890	41 675	210 671	234 154	282 431	358 148	309 150	
Net Present Value by year	-278 810	28 816	36 265	171 010	177 306	199 498	235 990	190 023	
Cumulative cash flow	-278 810	-247 920	-206 244	4 427	238 581	521 012	879 160	1 188 310	
Cumulative NPV	-278 810	-249 995	-213 729	-42 720	134 586	334 084	570 074	760 097	
Cost-Benefit indicators:									
Net Present Value								**760 097**	
Benefit Cost Ratio								**2.2**	
Internal Rate of Return for cash flow						33%	40%	**44%**	

Source: Author's own elaboration.

Table A4.5 Cash flow for scenario E: continuous mass vaccinations in large ruminants (USD)

YEARS	1	2	3	4	5	6	7	8	9	10	Total
Actions:											
no. of animals to be vaccinated	892 900	910 758	928 973	947 553	966 504	985 834	1 005 550	1 025 661	1 046 175	1 067 098	9 777 006
no. of farms to be visited	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000	1 700 000
Inflows:											
from reduced human health costs	0	30 767	30 660	41 632	35 017	52 609	44 703	45 472	58 100	79 483	418 443
from reduced losses in animals	0	3 816	204 536	403 618	581 238	709 631	806 839	887 707	940 489	979 670	5 517 545
Total benefits	0	34 584	235 196	445 251	616 255	762 240	851 542	933 179	998 590	1 059 152	**5 935 988**
Present value benefits	0	32 261	204 664	361 427	466 639	538 416	561 096	573 590	572 570	566 507	**3 877 169**
Outflows:											
cost of RB51 vaccine	669 675	683 069	696 730	710 664	0	0	0	0	0	0	2 760 138
cost of aplication	152 894	155 952	159 071	162 252	0	0	0	0	0	0	630 168
cost of visit per farm	58 219	58 219	58 219	58 219	0	0	0	0	0	0	232 877
other costs (consumables, etc)	107 026	109 166	111 350	113 577	0	0	0	0	0	0	441 118
Total cost	987 814	1 006 406	1 025 369	1 044 712	0	0	0	0	0	0	**-4 064 301**
Present value costs	987 814	938 811	892 259	848 032	0	0	0	0	0	0	**-3 666 916**
Cash flows:											
Net cash flow	-987 814	-971 822	-790 173	-599 462	616 255	762 240	851 542	933 179	998 590	1 059 152	
Net Present Value by year	-987 814	-906 550	-687 595	-486 605	466 639	538 416	561 096	573 590	572 570	566 507	
Cumulative cash flow	-987 814	-1 959 636	-2 749 809	-3 349 270	-2 733 015	-1 970 775	-1 119 234	-186 055	812 534	1 871 687	
Cumulative NPV	-987 814	-1 894 364	-2 581 959	-3 068 564	-2 601 925	-2 063 509	-1 502 413	-928 824	-356 254	210 254	
Cost-Benefit indicators:											
Net Present Value										**210 254**	
Benefit Cost Ratio										**-1.1**	
Internal Rate of Return for cash flow								-1%	5%	**9%**	

Source: Author's own elaboration.

Table A4.6 Cash flow for scenario F: replacement stock vaccinations in large ruminants (USD)

YEARS	1	2	3	4	5	5	7	8	9	10	Total
Actions:											
no. of animals to be vaccinated	89 290	91 076	92 897	94 755	96 650	98 583	100 555	102 566	104 617	106 710	977 701
no. of farms to be visited	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000	170 000	1 700 000
Inflows:											
from reduced human health costs	0	34 069	31 014	33 934	29 411	49 890	40 828	41 301	54 977	76 913	392 337
from reduced losses in animals	0	0	69 737	140 836	229 937	320 396	450 525	574 905	669 993	758 218	3 214 546
Total benefits	0	34 069	100 751	174 770	259 347	370 286	491 353	616 205	724 970	835 131	**3 606 883**
Present value benefits	0	31 781	87 672	141 868	196 383	261 555	323 761	378 758	415 683	446 685	**2 284 145**
Outflows:											
cost of RB51 vaccine	66 968	68 307	69 673	71 066	72 488	73 938	75 416	76 925	78 463	80 032	733 275
cost of aplication	15 289	15 595	15 907	16 225	16 550	16 881	17 218	17 563	17 914	18 272	167 414
cost of visit per farm	58 219	58 219	58 219	58 219	58 219	58 219	58 219	58 219	58 219	58 219	582 192
other costs (consumables, etc)	10 703	10 917	11 135	11 358	11 585	11 817	12 053	12 294	12 540	12 791	117 190
Total cost	151 179	153 038	154 934	156 868	158 841	160 854	162 907	165 000	167 136	169 314	**-1 600 072**
Present value costs	151 179	142 759	134 821	127 336	120 278	113 621	107 342	101 419	95 832	90 561	**-1 185 148**
Cash flows:											
Net cash flow	-151 179	-118 969	-54 183	17 902	100 506	209 432	328 446	451 205	557 834	665 816	
Net Present Value by year	-151 179	-110 978	-47 149	14 532	76 105	147 934	216 419	277 339	319 850	356 124	
Cumulative cash flow	-151 179	-270 147	-324 331	-306 429	-205 923	3 509	331 956	783 161	1 340 995	2 006 811	
Cumulative NPV	-151 179	-262 157	-309 306	-294 775	-218 670	-70 735	145 684	423 023	742 873	1 098 997	
Cost-Benefit indicators:											
Net Present Value										**1 098 997**	
Benefit Cost Ratio										**1.9**	
Internal Rate of Return								27%	33%	**37%**	

Source: Author's own elaboration.

Table A4.7 Cash flow for scenario G: interval mass vaccinations in large ruminants (USD)

YEARS	1	2	3	4	5	6	7	8	9	10	Total
Actions:											
no. of animals to be vaccinated	892 900	0	0	0	966 504	0	0	0	0	0	1 859 404
no. of farms to be visited	170 000	0	0	0	170 000	0	0	0	0	0	340 000
Inflows:											
from reduced human health costs	0	31 010	34 869	35 162	35 283	53 954	43 701	44 619	58 958	79 742	417 298
from reduced losses in animals	0	3 816	156 959	349 954	481 555	592 225	727 246	826 208	892 168	950 691	4 980 821
Total benefits	0	34 826	191 828	385 116	516 837	646 179	770 947	870 826	951 126	1 030 433	**5 398 120**
Present value benefits	0	32 487	166 926	312 613	391 359	456 435	507 991	535 264	545 356	551 146	**3 499 576**
Outflows:											
cost of RB51 vaccine	669 675	0	0	0	724 878	0	0	0	0	0	1 394 553
cost of aplication	152 894	0	0	0	165 497	0	0	0	0	0	318 391
cost of visit per farm	58 219	0	0	0	58 219	0	0	0	0	0	116 438
other costs (consumables, etc)	107 026	0	0	0	115 848	0	0	0	0	0	222 874
Total cost	987 814	0	0	0	1 064 442	0	0	0	0	0	**-2 052 256**
Present value costs	987 814	0	0	0	806 015	0	0	0	0	0	**-1 793 828**
Cash flows:											
Net cash flow	-987 814	34 826	191 828	385 116	-547 605	646 179	770 947	870 826	951 126	1 030 433	
Net Present Value by year	-987 814	32 487	166 926	312 613	-414 656	456 435	507 991	535 264	545 356	551 146	
Cumulative cash flow	-987 814	-952 987	-761 159	-376 043	-923 648	-277 469	493 479	1 364 305	2 315 431	3 345 864	
Cumulative NPV	-987 814	-955 326	-788 401	-475 787	-890 444	-434 009	73 982	609 246	1 154 602	1 705 748	
Cost-Benefit indicators:											
Net Present Value										**1 705 748**	
Benefit Cost Ratio										**2.0**	
Internal Rate of Return								17%	22%	**26%**	

Source: Author's own elaboration.

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