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Cost-estimate and proposal for a development impact bond for canine rabies elimination by mass vaccination in Chad

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A B S T R A C T

Close to 69,000 humans die of rabies each year, most of them in Africa and Asia. Clinical rabies can be prevented by post-exposure prophylaxis (PEP). However, PEP is commonly not available or not affordable in developing countries. Another strategy besides treating exposed humans is the vaccination of vector species. In developing countries, the main vector is the domestic dog, that, once infected, is a serious threat to humans. After a successful mass vaccination of 70% of the dogs in N'Djaména, we report here a cost-estimate for a national rabies elimination campaign for Chad. In a cross-sectional survey in four rural zones, we established the canine : human ratio at the household level. Based on human census data and the prevailing socio-cultural composition of rural zones of Chad, the total canine population was estimated at 1,205,361 dogs (95% Confidence interval 1,128,008–1,736,774 dogs). Cost data were collected from government sources and the recent canine mass vaccination campaign in N'Djaména. A Monte Carlo simulation was used for the simulation of the average cost and its variability, using probability distributions for dog numbers and cost items. Assuming the vaccination of 100 dogs on average per vaccination post and a duration of one year, the total cost for the vaccination of the national Chadian canine population is estimated at 2,716,359 Euros (95% CI 2,417,353–3,035,081) for one vaccination round. A development impact bond (DIB) organizational structure and cash flow scenario were then developed for the elimination of canine rabies in Chad. Cumulative discounted cost of 28.3 million Euros over ten years would be shared between the government of Chad, private investors and institutional donors as outcome funders. In this way, the risk of the investment could be shared and the necessary investment could be made available upfront – a key element for the elimination of canine rabies in Chad.

1. Introduction

The most recent analysis estimates that annually worldwide, canine rabies causes 59,000 human deaths, over 3.7 million disability-adjusted life years (DALYs) and 8.6 billion USD economic loss (Hampson et al., 2015). Clinical rabies can be prevented by post-exposure prophylaxis (PEP). However, often PEP is either not available or not affordable in developing countries. Even if PEP were subsidized, out-of-pocket expenses remain a huge cost burden to affected families, exceeding 2–3 months wages (Zinsstag et al., 2009; Frey et al., 2013). Clearly any human exposed to a suspected rabid animal bite must receive PEP. However, the use of PEP alone will never interrupt rabies transmission. In developing countries, the most important vector is the domestic dog, which once infected, is a serious threat to humans (Wandeler et al., 1993). Only mass vaccination of dogs can eventually interrupt transmission and lead to the elimination of the disease.

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Boegel et al. (Bogel and Meslin, 1990) showed that after 15 years a canine rabies control programme consisting of a combination of PEP and canine vaccination becomes more cost-effective than PEP alone (Bogel and Meslin, 1990). This is because the use of PEP alone never interrupts human exposure. A recent simulation of canine rabies mass vaccination in an African city showed that the break-even of the cost of canine rabies vaccination and PEP can occur already after six years (Zinsstag et al., 2009). Because of the low reproductive number of canine rabies transmission, the World Health Organization (WHO) estimates that the immunization of 70% of the canine population could interrupt transmission and prevent the virus from spreading and, thus, rabies could be eliminated (WHO, 1987). The cost of canine mass vaccination should eventually break even with the cumulated cost of human PEP.

However, dog owners in West and Central Africa are often not able to pay for the vaccination of their dogs. In Chad fewer than 19% of the dogs are vaccinated by their owners. In a willingness to pay study that followed a mass vaccination campaign paid by the owner we could show that the reported willingness to pay corresponded well with the actually achieved vaccination coverage (Dürr et al., 2008; Durr et al., 2009). In order to reach a sufficiently high coverage in West and Central Africa, canine mass vaccination campaigns should therefore be free to the owner and freedom from canine rabies should be recognized as a public good.

The Global Alliance for Rabies Control works towards worldwide canine rabies elimination by 2030. After the eradication of Poliomyelitis, and compared to onther ongoing elimination efforts like Guinea worm, malaria and tuberculosis, canine transmitted human rabies is one of the most promising next candidate for global elimination because of its low reproductive number of less than 2. To achieve the elimination of canine transmitted rabies, interventions must be directed towards the domestic dog. This requires a close cooperation between public health and animal health, called "One Health" (Zinsstag et al., 2015). Latin American countries have made enormous progress in this regard and strong efforts are underway in South-East Asia (Hampson et al., 2007). In July 2015, the Pan African Rabies Control Network (PARACON) was founded with the clear aim of worldwide canine rabies elimination.

The elimination of an infectious disease such as rabies requires a highly-coordinated and concerted effort to reach all affected areas of a country in a short time frame. Considerable upfront funding is required to start the mass vaccination and reach a high enough coverage to interrupt transmission. A city-wide canine rabies elimination campaign in N'Djaména at a scale of 35,000 dogs and a human population of 1.1 million was able to do this with the engagement of the Chadian state and private donors (Lechenne et al., 2016). For the mobilization of the necessary funding for a country-wide mass vaccination campaign, alternative financing models are necessary, as neither national states, nor institutional donors are able to provide large amounts upfront. There is a growing interest among development donors and impact investors in the use of so-called "Development Impact Bonds" (DIB): Private investment provides upfront capital for development programmes, only calling on donor funding to repay capital and a potential return based on achieved results (Hughes, 2014), (Welburn and Coleman, Chapter 18 in (Zinsstag et al., 2015)).

The present study intends to contribute to the efforts of PARACON by estimating the cost of canine rabies elimination on a national scale for an African country by providing a comprehensive cost estimate and a proposal for a DIB for the elimination of canine rabies in Chad. A cost estimate for Chad will allow the extrapolation of the costs of campaigns in other countries of the Sahel (Dürr et al., 2008; Durr et al., 2009; Zinsstag et al., 2009).

2. Materials and methods

2.1. Canine population and cost estimate

2.1.1. Study area

Chad is a landlocked country located in Central Africa and is spreading over 1.284 million km^2. Geographically, Chad is divided into three distinct regions: the Sahara Desert in the north bordering Libya, the Sahelian belt and the Sudanese savannah in the south bordering the Central African Republic. Administratively, Chad is divided into 23 regions and each region is headed by a governor. Regions are divided into 61 departments each lead by a prefect. The departments are again divided into sub-prefectures (200 in total) comprising each a number of different cantons (over 400 in total) led by a chief of canton. Within the cantons, the smallest administrative entity in a rural setting is the village with its village chief.

58% of Chadians are Muslim (the vast majority Sunni) predominantly inhabiting northern Chad. Christians (19% Catholics, 16% Protestants), Animists (4%) and others (3%) primarily live in the southern regions (INSEED, 2009).

2.1.2. Sampling procedure and data collection

For a household study of the canine: human population ratio, the Sahara area of Borkou-Ennedi-Tibesti (BET) was omitted, having a negligible canine population. The remainder of Chad was divided into north (predominantly Sahelian) and south (predominantly Savannah) regions and was subjected to stratified multilevel sampling (Mbilo et al., 2017). Two northern regions and two southern regions (4 regions in total) were randomly selected, with selection probability proportional to the size of the population. In each region, one department was selected proportional to size (4 departments in total) and in each department 10 villages were randomly selected (40 villages in total). As data on the population at village level was not available, simple random sampling was used. The departments sampled were Kouh Ouest in the region of Logone Oriental, Grand Sido in Moyen Chari, Dar Tam in the region Wadi Fira and Guera in the region Guera. Details of the characteristics of the studied regions are provided in the companion paper on rabies awareness and canine ownership (Mbilo et al., 2017). The household study was approved by the ethical review board of the cantons of Basel, Switzerland (Ethik Kommission beider Basel, EKBB ref. 168/13, 29 July 2013) and authorized by the Chadian public health authorities.

2.1.3. Canine: human ratio

The estimation of the canine: human ratio is based on results of the data collection as well as recommendations by Chadian experts at the *Institut de Recherches en Elevage pour le Development (IRED)*. It was assessed for every administrative region of Chad. The canine: human ratio is largely determined by the socio-cultural and religious composition of a region. Essentially, there are more dogs per humans in Christian/Animist communities than in Muslim communities (Mbilo et al., 2017). Hence empirically observed canine: human ratios were assigned to the relative numbers of Christians/Animists and to Muslims (Table 1). For every region the overall canine population was summed up. The overall total canine population of Chad was then obtained from the sum of canines in all regions. For the variability of the canine population we took the overall variation of the canine: human ratio of 1:6.3 to 1:9.7 from Mbilo's study (Mbilo et al., 2017).

2.1.4. Organization of the vaccination campaign

Decentralized operations are important for the administration of a nationwide vaccination campaign. The 61 departments of Chad

Table 1
Canine: human ratios and estimated canine population in the respective study zones.

Region	Christians (catholics and protes-tants) and animists in %	Muslims %	Total number of Christians / Animists	Canine : human ratio among Christians / Animists	Estimated dog number among Christians / Animists	Total number of Muslims	Canine : human ratio among Muslims	Estimated dog number among Muslims	Total dog estimate	Source of data	Total human population (Census 2009)
Batha	1.2	98.8	5,861	1:5.1	1,149	482,597	1:14.0	34,471	35,620	2	488,458
Borkou	0.7	99.3	655	1:5.1	128	92,929	1:14.0	6,638	6,766	2	93,584
Chari Baguirmi	15.9	84.1	91,970	1:5.1	18,033	486,455	1:14.0	34,747	52,780	2	578,425
Guéra	4.4	95.6	23,688	01:10	2,369	514,671	1.34.5	14,918	17,287	1	538,359
Hadjer Lamis	1.8	98.2	10,203	1:5.1	2,001	556,655	1:14.0	39,761	41,762	2	566,858
Kanem	0.6	99.4	2,000	1:5.1	392	331,387	1:14.0	23,670	24,063	2	333,387
Lac	1.2	98.8	5,205	1:5.1	1,021	428,585	1:14.0	30,613	31,634	2	433,790
Logone Occidental rural	92.3	7.7	497,431	1:5.1	97,536	41,498	1:14.0	2,964	100,500	2	538,929
Logone Occidental urbain (Moundou)	92.3	7.7	138,556	01:14	9,897	11,559	1:220	53	9,949	3	150,115
Logone Oriental rural	91.4	8.6	615,064	1:4.3	143,038	57,872	1:14.0	4,134	147,172	1	672,936
Logone Oriental urbain (Doba)	91.4	8.6	97,252	01:14	6,947	9,151	1:220	42	6,988	3	106,403
Mandoul	91.3	8.7	573,423	1:5.1	112,436	54,642	1:14.0	3,903	116,339	2	628,065
Mayo Kebbi Est	82.1	17.9	636,096	1:5.1	124,725	138,686	1:14.0	9,906	134,631	2	774,782
Mayo Kebbi Ouest	88.9	11.1	501,814	1:5.1	98,395	62,656	1:14.0	4,475	102,870	2	564,470
Moyen Chari rural	74.6	25.4	340,877	1:6.7	50,877	116,063	1:34.5	3,364	54,241	1	456,940
Moyen Chari urbain (Sarh)	74.6	25.4	97,777	01:14	6,984	33,291	1:220	151	7,135	2	131,068
Ouaddaï rural	1.2	98.8	6,990	1:5.1	1,371	575,492	1:14.0	41,107	42,477	2	582,482
Ouaddaï urbain (Abéché)	1.2	98.8	1,664	01:14	119	137,020	1:220	623	742	3	138,684
Salamat	1.4	98.6	4,232	1:5.1	830	298,069	1:14.0	21,291	22,120	2	302,301
Tandjilé	91.6	8.4	606,306	1:5.1	118,884	55,600	1:14.0	3,971	122,855	2	661,906
Wadi Fira	0.7	99.3	3,559	01:10	356	504,824	01:10	50,482	50,838	1	508,383
N'Djaména	29.3	70.7	278,765	01:14	19,912	672,653	1:220	3,058	22,969	3	951,418
Barh El Gazal	0.7	99.3	1,801	1:5.1	353	255,466	1:14.0	18,248	18,601	2	257,267
Ennedi	0.6	99.4	1,008	1:5.1	198	166,911	1:14.0	11,922	12,120	2	167,919
Sila	1	99	2,935	1:5.1	575	290,516	1:14.0	20,751	21,326	2	293,450
Tibesti	2	98	426	1:5.1	84	20,877	1:14.0	1,491	1,575	2	21,303
Total	41.54	58.46	4,545,559	1:5.3	818,607	6,396,123	1:14.6	386,754	1,205,361		10,941,682

Source of data: 1 = national household survey data; 2 = extrapolated from national household survey results; 3 = vaccination campaign data 2013.

Table 2
Scenarios used for the cost calculations.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Duration of 1 round (in years)	3	3	1	1
Dogs vaccinated/day/VP	100	50	100	50

were chosen as the administrative unit suitable for the organization of the campaign. Each of the 61 departments has several veterinary posts and at least one health centre, which can provide infrastructure, equipment, and professionally- trained manpower. Local staff need to be recruited in every department. Training of vaccinators must take place in each department. Chadian veterinary staff regularly vaccinate large cattle populations against Anthrax and other livestock diseases. With support from the Pan-African Rinderpest Campaign (PARC), Chad successfully eliminated Rinderpest (FAO, 2012). In 2012 and 2013 a canine rabies mass vaccination campaign reached 70% of the canine population, hence we can be confident, that with sufficient training, canine rabies mass vaccination campaigns can also be operated in rural Chadian areas (Lechenne et al., 2016).

2.1.5. Public engagement

Information can be spread nation-wide via posters displayed in public places, radio broadcasts, and megaphone announcements of the on-going campaign. Informing the population efficiently reduces unnecessary waiting time at the vaccination points (VP), thus reducing the cost of the campaign. Prior to the vaccination campaign, an information day for the governors of the 22 regions should be held in N'Djaména, the capital and largest city of Chad, to inform them about the campaign. The information will then be passed to smaller government units and from them to the leaders of smaller settlements, who are connected to the local population. In this way information on the mass vaccination will be conveyed in a contextually- adapted way to all concerned.

2.1.6. Vaccination campaign

The nationwide vaccination campaign must be coordinated carefully with respect to seasonal meteorological dynamics. During the rainy season (June to September) vaccination can only be performed in central and northern regions. The vaccination campaign in N'Djaména showed that one VP with three vaccinators can vaccinate 50 to 200 canines a day. In a nationwide campaign, we assume that, on average, 100 canines can be vaccinated by one VP per day.

For the feasibility and budget planning of the campaign, we examined four different scenarios to be able to assess how different cost items influence the overall costs of a campaign (Table 2). Scenario 1, for example presumes that the whole canine population is vaccinated within three years (936 working days), at a rate of 100 canines per VP per day. In the case of scenario 1, 6 VP and thus 18 vaccinators are needed at a time. At least 2 cars, each with 1 driver and 1 supervisor, are needed to coordinate the teams and supply the VP with material. One additional manned car will be needed to visit the settlements scheduled next. Several villages, small towns, or districts of bigger towns will be vaccinated simultaneously.

2.2. Cost description

The costs of a pilot vaccination campaign in N'Djaména in 2005 were split into public and private costs (Kayali et al., 2006).

$$\text{Public costs} = \text{Marginal vaccination cost} + \text{Equipment of VP}$$
$$+ \text{Staffallowance} + \text{Information} + \text{Transportation}$$

$$\text{Private costs} = \text{Lost work time} + \text{Transportation}$$

$$\text{Societal costs} = \text{Public costs} + \text{private costs(Kayaliet al., 2006)}.$$

Public cost: Marginal vaccination costs per canine include 1 syringe and needle, 1 dose of vaccine, and 1 vaccination certificate. The prices of the vaccine are quoted by the local importer; syringes and needles are bought in Chad. Equipment for VP and vehicles will be bought locally. Vaccination cards will be printed locally. Megaphones and first-aid kits will be bought in Switzerland. Staff working with canines must be protected from rabies exposure by pre-exposure prophylaxis. The local importer will determine the prices of the human vaccine. All people involved in the vaccination campaign will be paid a daily allowance. The prices of the equipment, consumables and personnel cost are derived from the vaccination campaign in N'Djaména in 2012 and 2013 (Lechenne et al., 2016). A detailed cost analysis of this campaign will be published shortly.

Information and transportation costs: Posters will be printed locally. Radio spots on Radiodiffusion Nationale Tchadienne (RNT) will be broadcast twice a week; spots on local channels twice a day. We assessed the distances covered during the whole campaign by one car at 75,000 km and the fuel consumption per car at 7,500 L.

Private costs consist of the loss of salary due to lost work time and transportation costs arising from taking an animal to the VP. We expect transportation costs to be insignificant because vaccination posts will be positioned close to settlements and moved frequently.

The average per capita income in Chad is 52,325 FCFA (80 Euros) per month, i.e. 327 FCFA (0.50 Euros) per hour (IBRD, 2015) (International Bank for Reconstruction and Development; data.worldbank.org/country/chad?view = chart, accessed 8 October 2016, 1 USD = 0.91 Euro). Assuming the process of vaccinating one dog vaccinated lasts 90 min on average, each dog owner incurs the costs of the lost work time equal to 490 FCFA (0.75 Euros) per dog (opportunity cost of labour).

Societal cost: The societal cost of rabies mass vaccination is the sum of the public cost and the private cost incurred to the dog owner. In the present calculation we assume that the private dog owners will bear the opportunity cost of bringing their dog to the vaccination cost and do not include it in the further assessment which considers only the social costs.

2.2.1. Consideration of uncertainty

Our assumptions and estimations are variable and we took into consideration the uncertainty of the involved parameters via Monte Carlo simulation. The cost analysis was implemented in Microsoft Excel using a Monte Carlo simulation add-on (Ersatz, Epigear.com) using 50,000 iterations. Canine: human ratios and cost items were expressed as probability distributions (Table 3).

2.2.2. Surveillance

In addition to the costs of a vaccination campaign, surveillance has been taken into account in the budget planning. Given the geographical size and limited transport infrastructure of Chad, at least one laboratory with an optical microscope should be established in each regional capital of the 22 regions assuming that the direct immunohistochemical test (DRIT) could be used, combined with confirmation by the fluorescence antibody test (FAT), which is the current gold standard (Durr et al., 2008). Chad has currently only one fluorescence microscope in Ndjamena, the capital city. In addition, rapid laboratory diagnosis at the 108 veterinary posts (peripheral laboratories) should be established. This is, however, pending the successful validation of the rapid laboratory diagnosis. Only rabies diagnostics have been considered in these budget cal-

Table 3
Model parameters and their distributions.

Item	Most likely dog numbers/ Most likely prices applied in scenarios	Min.	Max.	Probability distribution	Unit
Dog population	1,205,361	1,128,008	1,736,774	Pert	dogs
Canine : human ratio	1 : 9.07	1 : 9.7	1 : 6.3		
Doses of vaccine	0.20	n/a	n/a	n/a	Euro
Syringes and Needles	0.04	n/a	n/a	n/a	Euro
Vaccination Certificates	0.08	n/a	n/a	n/a	Euro
Human vaccine	76.34	n/a	n/a	n/a	Euro
Tables	0	0	0	n/a	Euro
Chairs	0	0	0	n/a	Euro
Registers	15.27	12.21	18.32	Pert	Euro
Red Pens	0.23	0.15	0.31	Pert	Euro
Blue Pens	0.23	0.15	0.31	Pert	Euro
Markers	0.76	0.61	0.92	Pert	Euro
Stamps	15.27	13.74	16.79	Pert	Euro
Muzzles	22.90	15.27	30.53	Pert	Euro
Cooling Boxes	45.80	38.17	53.44	Pert	Euro
Cooling Elements	1.53	0.76	2.29	Pert	Euro
First Aid Kits	49.62	22.90	76.34	Pert	Euro
Megaphones	68.70	22.90	114.50	Pert	Euro
					Euro
Posters	0.76	0.76	2.29	Pert	Euro
Radio Broadcasts (national)	45.80	38.17	53.44	Pert	Euro
Radio Broadcasts (local)	38.17	30.53	45.80	Pert	Euro
Cars	21374.05	18320.61	24427.48	Pert	Euro
Fuel	0.92	0.76	0.99	Pert	Euro
Supervisors (training)	30.53	22.90	45.80	Pert	Euro
Supervisors (vaccination)	45.80	22.90	45.80	Pert	Euro
Supervisors (information)	45.80	22.90	45.80	Pert	Euro
Drivers	30.53	7.63	30.53	Pert	Euro
Vaccinators (training)	15.27	7.63	30.53	Pert	Euro
Vaccinators (vaccination)	22.90	7.63	30.53	Pert	Euro
Veterinarians	30.53	22.90	45.80	Pert	Euro
Health workers	30.53	22.90	45.80	Pert	Euro
Delegate of the ministry of animal husbandry	61.07	30.53	61.07	Pert	Euro
Governors of regions	45.80	15.27	45.80	Pert	Euro

culations. However, these same facilities can be used in the future for the di-agnosis of other animal diseases (Table 4)

3. The investment case scenario

A development impact bond (DIB) proposal is composed of an organizational and a financial plan. The essential components of the organizational plan (Fig. 1) are investors who are willing to make available the required funds upfront to a rabies elimination authority. The rabies elimination authority is a special purpose vehicle in charge of the implementation of the suppression and maintenance phase but also for the “One Health” campaign effectiveness (Muthiani et al., 2015) and for surveillance of elimination. Its aim is to reach a recognized freedom of rabies status for Chad. Based on the effective reduction of rabies transmission, to be verified independently by the rabies elimination authority, the outcome funder, (an institutional donor, such as the European Union or other development agencies) refunds the investor with a previously-determined profit based on the result. In this way the risk of the investment is shared between the investors, the outcome funders and the national government. National governments cover the cost of the surveillance system and inform the outcome funder of the surveillance results independently of the outcome verification. In this way the outcome is verified by two independent sources. The supervisory board is composed of all involved stakeholders and directly supervises the rabies elimination authority.

The rabies elimination campaign is composed of four stages:

1) During the pre-implementation phase, the detailed design of the campaign is prepared, surveillance and effectiveness tools are established in the central and peripheral laboratories; the state to cover the surveillance cost (Fig. 1).
2) During the suppression phase, the first round of mass vaccination takes place within one year to not more than 18 months. The second round of mass vaccination requires preparation and would take place in the third year and fourth year.
3) During the consolidation phase, the basis for a third round would be prepared in order to protect borders and areas where rabies re-emerges in years five to eight.
4) Finally, during the post-elimination maintenance phase, active surveillance is sustained and fully financed by the government of Chad.

4. Result-based return on investment

The return to investors was divided into two components (1) a return of the capital outlaid to fund operational activities in the four different phases, and (2) premium payments, over and above the return of capital, based on the successful reduction in rabies transmission from the start of the consolidation phase onwards. The division of the payments reflects the risks being transferred to the investors; risk of operational delivery failure and epidemiological risk that following the successful operational delivery the expected reduction in disease transmission is not achieved.

For the capital repayments, we assume cash is returned to the investors in year 3, at the end of the mass vaccinations in the suppression phase, year 6, midway through the consolidation phase, year 8, the end of the consolidation phase, and year 10. For the premium payments, reflecting a reward for a successful reduction in

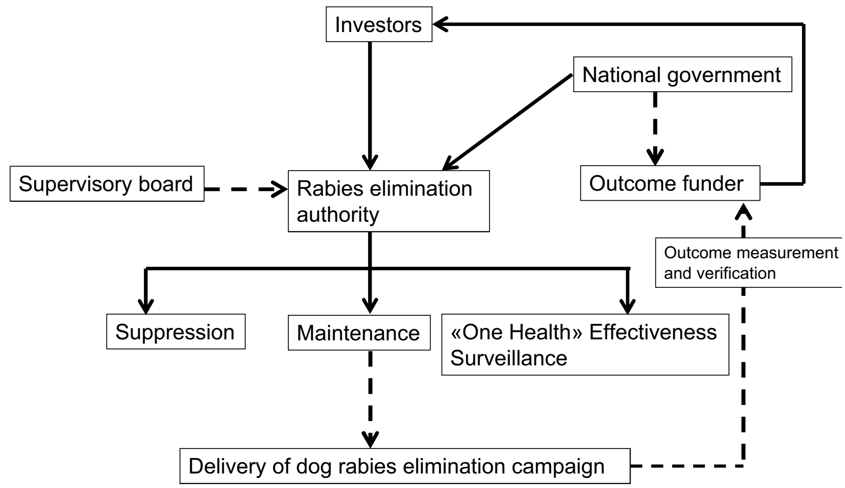

Fig. 1. Proposed development impact bond organizational structure.

Table 4
Budget calculations for surveillance laboratories.

	Price per Unit (Euro)	Units	Euro
Budget calculations for veterinary posts			
Equipment			
Fridge	305	1	305
Cool-boxes	17	2	34
Generator	214	1	214
Fuel for generator	46	36	1,649
Water & electricity	46	36	1,649
Cellular phone	26	1	26
Credit for cell phone	31	36	1,099
Total Equipment			4,976
Reagents			
Rabies antigene test	5	150	750
Total Reagents			750
Transportation			
Scooter	1,527	1	1,527
Fuel	8	180	1,374
Total Transportation			2,901
Subtotal			8,626
Management fees		0.13	1,121
Total			9,748
108 veterinary posts			1,052,758
Budget calculations for central laboratories			
Reagents			
Rabies antigene test	5	450	2,250
Diagnostic consumables			6,412
Sampling material			4,580
Total reagents			13,242
Transportation			
Vehicles with drivers	107	180	19,237
Fuel	15	180	2,748
Total transportation			21,985
Training			
Taining of veterinarians	76	10	763
Intersectorial workshop			3,053
Total training			3,817
Subtotal			39,044
Management fees		0.13	5,076
Total			44,120
22 central laboratories			970,631

rabies transmission, we assume annual payments from year 4, the start of the consolidation phase, onwards.

Different thresholds of operational delivery could be set to determine what fraction of outstanding capital is returned at different phases. Similarly, the premium payments can be explicitly linked with a measure of reduction in rabies transmission or incidence of cases. Depending on the investor/donor negotiations, refunding schemes could be adapted to regional outcome targets. The selection of these thresholds can be used to incentivise investors to ensure the long-term reduction in transmission e.g. back-loading return of capital and premium payments. However, there are cost implications to the donors, as the longer the investor capital is not repaid the higher the premium will be sort by investors and so the more expensive, in absolute terms, the DIB.

Here, we examine the trade-offs in structuring payments to investors under three main payment scenarios:

1 back-loaded – in which payments (capital return and premium) are weighted towards later years
2 front-loaded – with payments weighted towards earlier years
3 even – with payment spread more evenly across the different years.

The total premium paid by the donors was varied from zero to 50% of the total capital investment made by the investors, and the internal rate of return (IRR) received by the investors calculated under the three different scenarios.

4.1. Results

4.1.1. Canine population

Based on Mbilo's household study (Mbilo et al., 2017) and the regional breakdown of the human population by prevailing social-cultural and religious composition, the canine population of Chad is estimated at 1,205,361 canines (95% confidence limits: 1,128,008–1,736,774 canines),

4.1.2. Campaign costs and campaign scenarios

The average cost of the different scenarios is between 1.9 and 4.7 million Euros depending on the number of canines vaccinated per day per vaccination post and the overall duration of one round of country-wide vaccination between 1 and 3 years. Using an estimated canine population of 1.2 million dogs the social cost per vaccinated dog varies between 1,047-2,575 FCFA (1.5-3.9 Euros, 1 Euros = 655 FCFA) (Table 4). The high turnover of the canine populations in Chad, with an average live-span of not more than three years (Mindekem et al., 2005), indicates that scenarios favouring the vaccination of the total Chadian canine population should be prioritized. Thus the following sensitivity analyses and DIB investment calculation is focused on scenarios 3 and 4 (see Table 5).

Table 5
Output of Monte Carlo simulations of the cost estimate of different scenarios of nation-wide canine mass vaccination in Chad.

Scenario	Median Euro	Mean Euro	StDev Euro	Low Euro	High Euro	LCI 95% Euro	HCI 95% Euro
(1) 100 dogs/3 years	1,919,999	1,928,120	126,111	1,528,017	2,471,773	1,705,622	2,191,253
(2) 50 dogs/3 years	3,036,124	3,051,286	245,936	2,341,363	4,044,089	2,619,973	3,564,933
(3) 100 dogs/1year	2,712,426	2,716,359	159,042	2,217,077	3,342,698	2,417,353	3,035,081
(4) 50 dogs/1 year	4,733,178	4,739,432	316,036	3,657,035	5,891,900	4,140,898	5,370,532

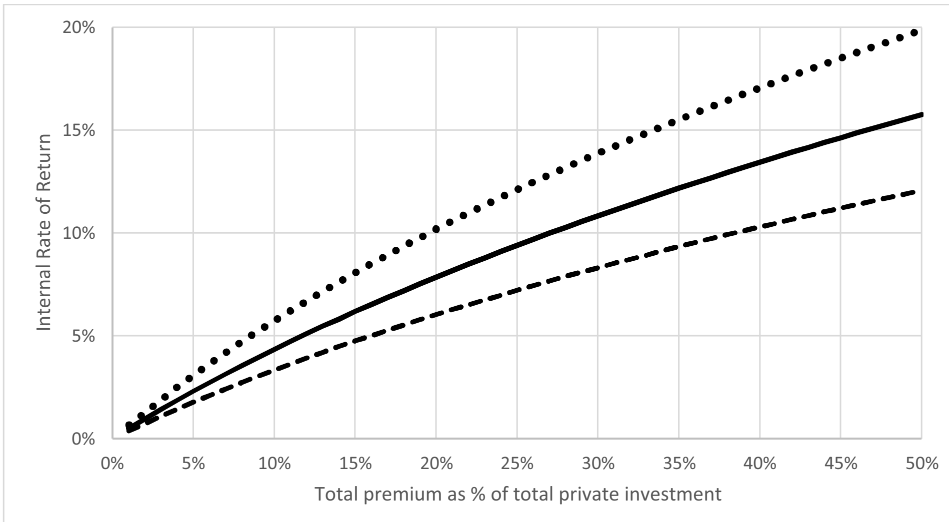

Fig. 2. Internal Rate of Return (IRR) under the three different payment scenarios for different total premiums: straight line = even; dotted line = front loaded; dashed line = back loaded.

4.1.3. Sensitivity analysis

A sensitivity analysis of the Monte Carlo simulation using the Spearman correlation coefficient (SCC) related the cost estimate with the variability of all input variables (Table 3). In scenario 3 and 4, the most sensitive variables are the human vaccination cost, the vaccinator numbers and vaccinator allowances with SCC values above 0.2. Canine population numbers were less sensitive with SCC values below 0.1.

4.1.4. Development impact bond financing

Based on the laboratory cost for surveillance and effectiveness (Table 4) and the cost of the mass vaccination scenarios 3 and 4 (Table 5), a cash flow profile for a development impact bond (DIB) for the nation-wide elimination of canine rabies in Chad was developed. Table 6a presents the undiscounted contributions of the Chadian Government for the surveillance and those of the investor for the effectiveness monitoring and the mass vaccination. The outcome funder starts paying back the investor from year four onwards. Over a period of ten years, the Chadian government would contribute 14.5 million Euros and the investor 21.2 million Euros, which are refunded successively upon the achievement of operational delivery in the different phases and elimination result, expressed as the effective reproductive number R_e tending towards zero. The percentage of capital and premium payments back to the investors (assuming all output and outcome targets are met) for the three different scenarios are also shown. Table 6b gives an example for the "Even" repayment scenario and a total premium paid by the donors of 5 million Euros for successful operational and disease reduction delivery. The annual net cash to the investors gives an IRR of 9%.

Fig. 2 explores how the IRR varies as a function of the total premium donors are prepared to pay for success under the different scenarios of weighting payments by time. To give a target IRR that is acceptable to investors will cost more the more back-loaded the repayments are. Back-loading payments is important to ensure payments equate to long-term successfully delivered outcomes. However, this comes at a cost in terms of total premiums paid. In reality, the details of the payment triggers and levels of returns will require extensive negotiations between investors and payers. The more complex the DIB financing structure is conceived, the higher are the transactions costs, which are an additional hidden cost not included here.

5. Discussion

We used data from a representative national household study on the canine: human ratio and the last population census of Chad for the estimation of the total canine population of Chad (Mbilo et al., 2017). Further, the vaccination costs of a mass vaccination campaign in N'Djaména, Chad of 18,000 canines in 2012 and 22,000 canines in 2013 were used for a nation-wide extrapolation (Lechenne et al., 2016). The estimated total costs are based on the effective cost of materials, means of informing the population, salaries, methods of vaccinating, and time factor of the process of vaccinating canines. The costs of coordinating and performing the campaign, and the distances to be travelled during the campaign were also estimated.

There are few studies estimating the costs per canine vaccinated in a parenteral mass vaccination campaign in Africa. A representative study was performed by Bögel et al. in 1990, which assumes vaccination costs of 1.18 Euros per canine. A smaller study was performed in N'Djaména in 2005, when 3000 canines were vaccinated in a parenteral vaccination campaign. The societal costs per canine vaccinated added up to FCFA 1,610 (2.46 Euros) per canine and marginal costs for every additional canine were FCFA 1,036 (1.58 Euros) (Kayali et al., 2006). A recent study in South-Eastern Tanzania reports cost per vaccinated dog between 2.5 USD and 22.49

Table 6a
DIB financing overview and repayment scenarios.

Cash flow profile		a) Undiscounted cost					Outcome Founder		Front-loaded Scenario		Even Scenario	
	Effective	Government	Investor	Investor	Investor	Total	Outcome Funder		Outcome Funder		Outcome Funder	
Year	Reproductive	Surveillance	Effectiveness	Mass vaccination	Total annual cost	Annual cost	% Outstanding Capital	% Total Premium	% Outstanding Capital	% Total Premium	% Outstanding Capital	% Total Premium
	Number	Euro	Euro	Euro	Euro	Euro						
−1	1.5	1,000,000	1,100,000		1,100,000	2,100,000						
0	1.5	1,000,000	1,100,000	3,000,000	4,100,000	5,100,000						
1	0.7	1,000,000	1,100,000		1,100,000	2,100,000						
2	0.5	1,000,000	1,100,000	3,000,000	4,100,000	5,100,000						
3	0.3	1,000,000	1,100,000		1,100,000	2,100,000	0.5		1		0.8	
4	0.15	1,000,000	1,100,000	1,000,000	2,100,000	3,100,000		0.05		0.25		0.142857
5	0.075	1,000,000	1,100,000	1,000,000	2,100,000	3,100,000		0.05		0.2		0.142857
6	0.0375	1,500,000	600,000	1,000,000	1,600,000	3,100,000	0.75	0.1	1	0.2	0.8	0.142857
7	0.017	1,500,000	600,000	500,000	1,100,000	2,600,000		0.1		0.1		0.142857
8	0.0085	1,500,000	600,000	500,000	1,100,000	2,600,000	0.9	0.15	1	0.1	0.8	0.142857
9	0.004	1,500,000	600,000	500,000	1,100,000	2,600,000		0.15		0.1		0.142857
10	0.002	1,500,000	600,000		600,000	2,100,000	1	0.4	1	0.05	1	0.142857
		14,500,000	10,700,000	10,500,000	21,200,000	35,700,000						

Table 6b
Example for the Even Scenario and a Total Premium of 5 million Euro giving an IRR to the investors of 9%.

		a) Undiscounted cost					Outcome Founder			Investor
	Effective	Government	Investor	Investor	Investor	Total	Outcome Funder		Net Cash Flow	
Year	Reproductive	Surveillance	Effectiveness	Mass vaccination	Total annual cost	Annual cost	Capital	Premium	Total	Annual
	Number	Euro	Euro	Euro	Euro	Euro	Euro	Euro	Euro	Euro
−1	1.5	1,000,000	1,100,000		1,100,000	2,100,000				−1,100,000
0	1.5	1,000,000	1,100,000	3,000,000	4,100,000	5,100,000				−4,100,000
1	0.7	1,000,000	1,100,000		1,100,000	2,100,000				−1,100,000
2	0.5	1,000,000	1,100,000	3,000,000	4,100,000	5,100,000				−4,100,000
3	0.3	1,000,000	1,100,000		1,100,000	2,100,000	9,200,000		9,200,000	8,100,000
4	0.15	1,000,000	1,100,000	1,000,000	2,100,000	3,100,000		714,286	714,286	−1,385,714
5	0.075	1,000,000	1,100,000	1,000,000	2,100,000	3,100,000		714,286	714,286	−1,385,714
6	0.0375	1,500,000	600,000	1,000,000	1,600,000	3,100,000	6,480,000	714,286	7,194,286	5,594,286
7	0.017	1,500,000	600,000	500,000	1,100,000	2,600,000		714,286	714,286	−385,714
8	0.0085	1,500,000	600,000	500,000	1,100,000	2,600,000	3,056,000	714,286	3,770,286	2,670,286
9	0.004	1,500,000	600,000	500,000	1,100,000	2,600,000		714,286	714,286	−385,714
10	0.002	1,500,000	600,000		600,000	2,100,000	2,464,000	714,286	3,178,286	2,578,286
		14,500,000	10,700,000	10,500,000	21,200,000	35,700,000	21,200,000	5,000,000	26,200,000	5,000,000
										23.6%
										9.0%

USD (2.26–20.4 Euros) (Hatch et al., 2016) Our estimates of the scenario 3 and 4 of 1,476 (2.25) and 2,575 FCFA (3.93 Euros) are slightly higher than earlier campaigns in Chad, which is largely due to increasing personnel costs, reflecting the economic development in Chad over the past ten years. As the sensitivity analysis shows, vaccinator salaries paid during a nationwide parenteral vaccination campaign is the cost item with the greatest impact on the budget calculations, followed by the cost of human vaccination, depending on the number required.

This is the first DIB cash flow profile estimate for a nation-wide canine rabies elimination campaign in Africa. As the basic concept of a DIB, the overall risk is shared between investors, outcome funders and national governments. As the refunding of the investor is result- based, the cost of surveillance and campaign effectiveness is substantial. However, this investment in animal disease surveillance will be of considerable benefit to the surveillance of other animal diseases in Chad, such as foot and mouth disease (FMD) or contagious bovine pleuro-pneumonia (CBPP). Overall this analysis shows that a DIB is beneficial to all parties: The nation of Chad becomes free of canine rabies and gains a functional animal disease surveillance system; the investor benefits reasonably from his/her investment, and the outcome funder obtains a tangible result for result-based refunding of the primary investment. A successful result requires a well-functioning organizational structure with effective communication between the supervisory board, the rabies elimination authority, the outcome funder, and the investor (Fig. 1).

6. Conclusion & recommendations

Eliminating canine rabies by vaccinating the primary vector species has been successful in many countries in Eurospe and in North America (Freuling et al., 2013). Canine mass vaccination campaigns can interrupt canine-to-canine transmission of the virus, upon which the incidence of canine rabies significantly depends. Vaccination coverage of at least 70% is expected to stop canine-to-canine transmission completely.

Provided the experience with the previous canine mass-vaccination campaigns in N'Djaména in 2012 and 2013 are applicable to other areas of Chad, our results indicate that a parenteral canine rabies mass-vaccination campaign provided free-of-charge, repeated one or two times, and covering the whole of Chad each time is a feasible and cost-effective way to eliminate rabies nationwide. We recommend testing campaigns in rural areas on a small scale to validate our assumption of the number of dogs that can be vaccinated daily in rural areas of Chad.

This study serves as a preparatory step for a development impact bond-funding (DIB) request to several governments and private investors http://www.cgdev.org/initiative/development-impact-bonds-0. DIBs are an extension of Social Impact Bonds (Hughes, 2014) and are based on the principle of sharing risk between donors and a stringent result-based pay-back regime. Thereby private investors make available the needed funds upfront and are refunded by an institutional donor i.e. a development agency based on the effective results of the operation. In this way all participants take a more active role towards a successful operation. This approach could become an instrument for a global subsidiary principle of zoonoses elimination, which is currently not part of the Global Fund portfolio (Zinsstag et al., 2007).

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