Economic Impact Assessment of *Taenia Solium* in Sub-Saharan Africa Using the EPICYST Model

Advanced One Health

Spring 2021

Kathleen Moriarty

Arunima Bhattacharjee

Kayla Lanker

Introduction

Over thousands of years, the close relationship between animals and humans has resulted in many zoonotic diseases, including several parasites in the family Taeniidae: *Taenia solium* (the pork tapeworm), *Taenia saginata* (the beef tapeworm) and *Taenia asiatica* (Asian tapeworm). Many places around the world are experiencing new levels of economic development resulting in increased pig farming and pig consumption. Infection with *T. solium* occurs either when raw or undercooked infected pork is consumed by humans, leading to taeniasis, or when *T. solium* eggs from humans are passed through feces to humans or pigs, leading to cysticercosis. Humans are the definitive host of *T.solium* (when infected with taeniasis) and pigs are the intermediate host of *T. solium*. Key risk factors for *T. solium* spread and endemicity in a given region are pig rearing (free roaming) and consumption practices (eating infected meat), poor sanitation and hygiene infrastructure, frequent open defecation practices, feeding of human faeces to pigs,and inadequate meat inspection. In each region and country, different practices have a unique effect on the transmission and lifecycle. Elimination in either humans or pigs has not been shown to be effective to eliminate *T. solium* and thus a sustainable One Health approach must be developed.

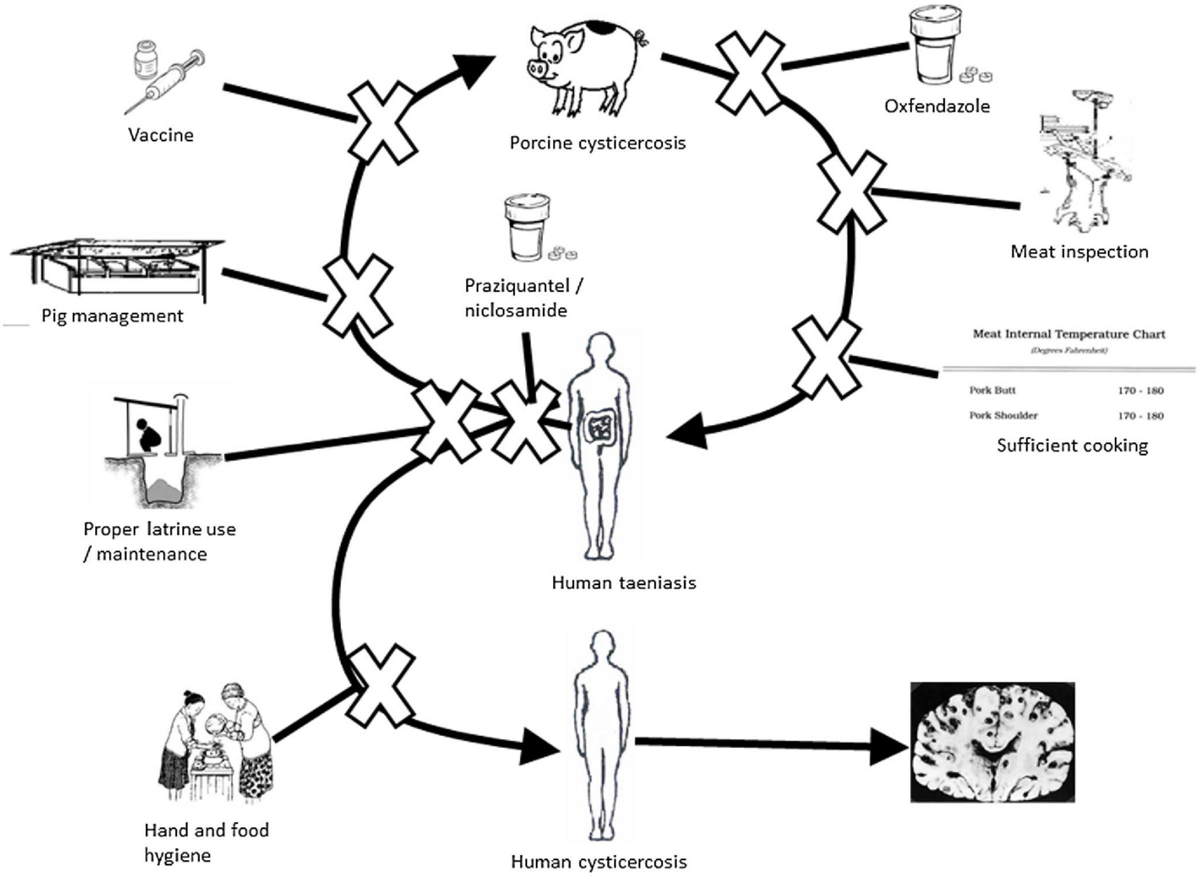

Figure 1. Life Cycle of *Taenia solium* in humans and pigs, including targeted interventions at each stage (Hélène Carabin & Traoré, 2014)

Individuals with taeniasis often have little to no symptoms, with only the occasional abdominal pain, loss of appetite and minor weight loss. Tapeworm segments are observed in the feces of those with taeniasis (CDC, 2020). Tapeworm carriers pose risks of transmission of eggs to themselves and to their close contacts, including parent to child, an important public health issue (White et al., 2018). In humans infected with cysticercosis, the resulting cystic formations and symptoms can cause large morbidity and mortality. With an early and proper diagnosis, treatment can be very effective; however, in endemic regions the absence of proper diagnosis is often the case. Around 60-90% of humans infected with cysticercosis will develop cysts in the parenchymal brain, leading to neurocysticercosis (NCC)(Garcia et al., 2014; Hawk et al., 2005). The development of NCC usually requires invasive and expensive treatment.

While taeniasis in humans and porcine cysticercosis occurs mostly in low and middle income countries (LMIC) where sanitation and agricultural infrastructure is lacking, cysticercosis in humans can occur anywhere, due to the ability for individuals infected with taeniasis to migrate and pass eggs to others without knowing they are infected. However, the burden of human disease from *T. solium* still remains largely in LMIC where the parasite is endemic. Endemic regions include South and Central America, India, Southeast Asia, China, and sub-Saharan Africa. It is estimated that 30% of all epilepsy cases in countries where *T. solium* is endemic are caused by NCC cysts (Owolabi et al., 2020). For taeniasis, it is estimated to cause 2.8 DALYs per 1000 person-years in 2015 (WHO, 2020b), while for cysticercosis, DALYs are estimated to be between 6-9 DALYs per 1000 person-years (Praet et al., 2009; Trevisan et al., 2018). There are also huge monetary costs in human health and the agricultural sector that impacts both private and public sectors in animal and human health (see Section 2). To reduce and remove the global burden of cysticercosis, WHO has set a new road map and encourages all stakeholders to improve their approaches to improve their action regarding this disease (Figure 2) (WHO, 2020a).

Disease	Indicator	2020	2023	2025	2030
TARGETED FOR CONTROL					
Buruli ulcer	Proportion of cases in category III (late stage) at diagnosis	**30%**	**<22%**	**<18%**	**<10%**
Dengue	Case fatality rate due to dengue	**0.80%**	**0.50%**	**0.50%**	**0%**
Echinococcosis	Number of countries with intensified control for cystic echinococcosis in hyperendemic areas	**1**	**4**	**9**	**17**
Foodborne trematodiases	Number of countries with intensified control in hyperendemic areas	**N/A**	**3** (3%)	**6** (7%)	**11** (12%)
Leishmaniasis (cutaneous)	Number of countries in which: 85% of all cases are detected and reported, and 95% of reported cases are treated	**N/A**	**44** (51%)	**66** (76%)	**87** (100%)
Mycetoma, chromoblastomycosis and other deep mycoses	Number of countries in which mycetoma, chromoblastomycosis, sporotrichosis and/or paracoccidioidomycosis are included in national control programmes and surveillance systems	**1** (3%)	**4** (13%)	**8** (27%)	**15** (50%)
Scabies and other ectoparasitoses	Number of countries having incorporated scabies management in the universal health coverage package of care	**0**	**25** (13%)	**50** (26%)	**194** (100%)
Snakebite envenoming	Number of countries having achieved reduction of mortality by 50%	**N/A**	**39** (30%)	**61** (46%)	**132** (100%)
Taeniasis/cysticercosis	Number of countries with intensified control in hyperendemic areas	**2** (3%)	**4** (6%)	**9** (14%)	**17** (27%)

Figure 2. WHO NTD road plan 2021 - 2030 (WHO, 2020a)

Interventions developed and proposed for the control and elimination of *T. Solium* in humans and/or pigs have included mass drug administration (MDA) in humans and pigs, vaccination of pigs, human test and treat, improving sanitation and hygiene, educational interventions, and improving pig husbandry and meat inspection practices. To see more on these intervention strategies, see Section 3. While most have been proven to be effective in clinical trials for short periods of time, many have not been proven to be sustainable. This is due to the fact that many of these interventions only address one link in the transmission chain, which does not take into account the complex ways in which the *T. solium* parasites are transmitted and reenter the environment. Therefore a One Health approach, taking into account long-term sustainability and using a cost-benefit analysis, is necessary to make a long-term impact on communities and countries burdened by the continued endemicity of the disease.

In order to assess the sustainability and cost-effectiveness of several different intervention strategies in humans and pigs, we decided to focus on Burkina Faso, a country with high endemicity of T. solium in humans and pigs. We first collected both disease transmission data and economic data for Burkina Faso. Extensive, timely, and reliable data for porcine cysticercosis, human neurocysticercosis, and the prevention and control strategies for these diseases in Burkina Faso (and many other countries) were found to be lacking. However, if we did not find data from Burkina Faso, we collected it from literature of surrounding countries and other endemic regions. Following the literature search and data collection, we used the deterministic, compartmental model EPICYST (Winskill et al., 2017) to estimate human cysticercosis prevalence with and without various prevention and control strategies. We combined these estimates with our economic data to run a cost-effective analysis for several interventions. These methods are laid out in detail in Sections 2-5.

1. Case Study - Burkina Faso

Region profile

West Africa, covering 20% of the African continent (approximately 6 million km^2 in area) includes 16 countries. Rapid urbanization and rural-urban migration resulted in an increasing number of informal housing settlements with high population densities, poor sanitation and low-standard housing. Inadequate water supply and sewage systems together with population movement have increased the transmission of parasitic infections. Figure 3 reports the cases of human taeniasis, human cysticercosis and porcine cysticercosis in Benin, Burkina Faso, Côte d'Ivoire, The Gambia, Ghana, Guinea Bissau, Nigeria, and Senegal (Melki et al., 2018).

The increasing demand for meat along with urbanization has resulted in informal livestock systems, without registered slaughter slabs nor sanitary precautions (Edia-Asuke et al., 2014). This is described as backyard pig production. Often pigs roam free during the day, ingesting human feces, allowing for the *T. solium* parasite to find a host in the pig (Weka et al., 2019).

Another regional factor to be considered is the social and economic impact of disease. Many studies in West Africa have found that those who suffer from epilepsy are stigmatized, often unemployed and shunned from society (Weka et al., 2019). The overall burden of T. solium in West Africa is estimated to be around 28 million USD (Zoli et al., 2003).

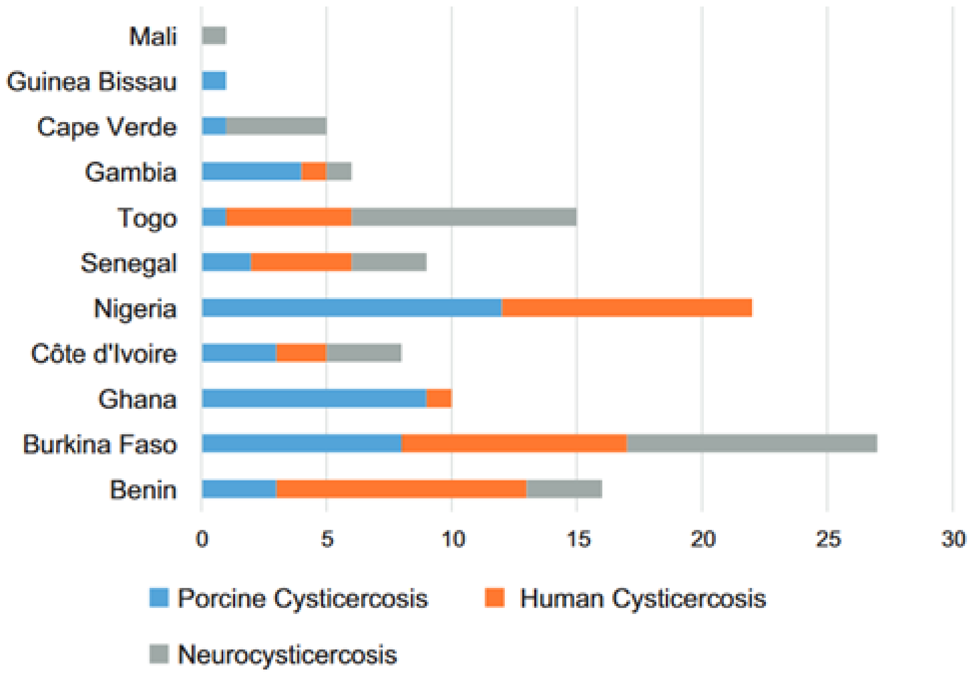

Figure 3. Reported cases of Neurocysticercosis in West Africa (Melki et al., 2018)

Pig farming in Burkina Faso

Pig breeding in Burkina Faso has been increasing steadily over the last few decades and constitutes the second pillar of the economy. The number of pigs in Burkina Faso increased from 1.89 million in 2003 to 2.59 million in 2019 (Kiendrebeogo et al., 2012; Konema, 2019). Despite the increase in breeding of pigs and popularity of pig husbandry, surveillance in pigs is still weak in West Africa (Tialla et al., 2020). A meat inspection survey in 2000 reported a 0.6 prevalence rate in pigs slaughtered at an abattoir (Zoli et al., 2003). However, many pigs are usually sold informally or kept for personal consumption (Hélène Carabin et al., 2006). Another community based study conducted in Burkina Faso to check the seroprevalence of porcine cysticercosis found that 32.5% and 39.6% of pigs were infected with *T. solium* in two villages (Ganaba et al., 2011). Most recently, another study in Burkina Faso estimated the prevalence of porcine cysticercosis to be around 18.8% (Skrip et al., 2021).

2. Costs and burdens of *T. solium* infection in humans and pigs

T. solium infection in humans and pigs has many direct and indirect social burdens and economic costs, which can be measured in various ways.

2a. Human burden

Taeniasis, the milder infection in humans, does not usually produce a physical or economic burden for affected individuals. However, the more insidious infection, cysticercosis and neurocysticercosis (NCC), often has a large impact on an individual's health and results in social and economic burdens for the individual, their community, and the public health care system. NCC causes the largest burden and cost associated with *T. solium* infection in humans and is the main focus of burden estimates in the literature (Hawk et al., 2005).

Direct costs and burdens

The largest direct burden associated with *T. solium* induced neurocysticercosis in humans is chronic illness due to relapsing seizures (acquired epilepsy), hydrocephalus, intracranial hypertension, and chronic headaches (Bhattarai et al., 2012). In India and Mexico, NCC was found to be present in more than 50% of patients admitted for epilepsy, and it is believed to be the leading cause of juvenile and adult-onset acquired epilepsy around the world (Hawk et al., 2005; WHO, 2010). These conditions, particularly epilepsy, require expensive and invasive diagnostics (MRI and CT scans), medical treatment (chemotherapy, steroids, antiparasitics) and/or neurosurgery. Additionally, brain damage from epileptic attacks and injuries due to seizures can cause life-long disabilities, captured by DALY and QALY estimates (Bhattarai et al., 2012). Lastly, treatment of NCC remains difficult; removal of cysts from the brain can be life-threatening and emerging drug resistance to anti-parasitic agents complicates the management of the disease (Ahmad et al., 2017).

Indirect costs and burdens

Indirect costs and burdens associated with NCC in humans has been estimated to account for up to 84% of the total cost of cysticercosis in humans and pigs in a country (Praet et al., 2009). Indirect costs accounted for in economic analyses usually include missed working days and/or unemployment due to NCC-associated illness. In sub-Saharan African countries, it is estimated that individuals with severe NCC miss on average 10 [+/- 19 days] working days per year, while up to 21.3% are unemployed due to their illness (Praet et al., 2009). There are also unmeasured community-level burdens. The prevalence of taeniasis and cysticercosis is higher in areas of economic and social disadvantage, where communities also tend to have the least access and resources to prevent disease and receive proper treatment (WHO, 2010). Therefore, the burden of disease falls on already underprivileged individuals and communities, and the cycle of ill health and poverty is continued. The cumulative life-long, intergenerational, and community-level effect of disease from *T. solium* infection is not accounted for in burden analyses, which would be a recommended area for further study. In Table 1, the direct and indirect costs of *T. solium* infection are outlined.

Table 1. Direct and Indirect annual costs of *T. solium* infection in Humans

	Country					
Name	**Mozambique**	**Tanzania**	**South Africa**	**Mexico**	**West Cameroon**	**Burkina Faso**
Human population of study	330,328	44,928,923	7,088,000	125,235,587	5,065,382	20,321,378
Human NCC prevalence	0.0070	0.0011	0.0053	0.0025	0.0099	0.0185
Human NCC cases	2151	17853	34662	307583	50326	375539
Direct human losses (US$)	$9,626	$745,711	$15,100,000	$54,929,000	$1,552,644	$9,886,270
% of total	0.10	0.09	0.75	0.30	0.10	0.10
Indirect human losses (US$)	$61,462	$3,903,082	-	$111,720,000	$12,611,425	$80,301,689
% of total	0.66	0.49	-	0.60	0.85	0.85
Pig related losses (US$)	$22,282	$3,284,301	$5,000,000	$19,551,000	$698,543	$4,447,885
% of total	0.24	0.41	0.25	0.11	0.05	0.05
Total losses (US$)	$93,370	$7,933,094	$20,100,000	$186,200,000	$14,862,612	$94,635,844
Price per NCC case (US$)	$33	$106	$436	$542	$252	$214
Approx DALYs/1000 person-years	6	1	-	-	9	9
Source	(Trevisan et al., 2018)	(Trevisan et al., 2017)	(Hélène Carabin et al., 2006)	(Bhattarai et al., 2019)	(Praet et al., 2009)	(Millogo et al., 2012)
Type of study	District level primary data	Systematic review	Review and primary data	Review and primary data	Review	Calculations, Assumptions

2b. Pig costs and burdens

While porcine cysticercosis does not usually cause painful illness in pigs, there are still economic burdens in the public and private sectors that are associated with porcine cysticercosis. The estimated losses in several countries due to porcine cysticercosis are outlined in Table 2 below.

Direct costs and burdens

Direct infection in pigs does not usually cause harm to the animal, as the average lifespan before sale and slaughter is 1.5-1.8 years (Hobbs et al., 2018; Skrip et al., 2021). This is usually not enough time for cysts, forming in various organs, to cause pain.

Indirect costs and burdens

The majority of indirect costs associated with porcine cysticercosis falls onto the farmer owning the pigs due to the lost income from the infected meat. Many pigs with noticeable cysts are still able to be sold, however usually at a loss of 30-50% of the original value (Praet et al., 2009; Trevisan et al., 2017). The cost of an adult pig ranges from 30-100 USD, depending on the country. If a farmer chooses to build a pig pen or administer anti-parasitic drugs to their pigs, the burden of this cost is usually carried by the farmers. The cost of meat inspection and disposal of infected meat is usually carried by the government if a structured process is in place. However, most pigs are sold in informal markets where the tongue is examined for cysts; this has not shown to be very effective at detecting infected meat (Pondja et al., 2010).

Table 2. Indirect annual costs of *T. solium* infection in Pigs

Name	Country					
Country	**Mozambique**	**Tanzania**	**South Africa**	**Mexico**	**West Cameroon**	**Burkina Faso**
Pig population of study	20,411	1,573,080	290,350	17,315,000	285,018	2,587,862
Estimated PCC prevalence	0.13	0.117	0.0925	0.19	0.056	0.1887
Estimated PCC cases	2595	184050	26857	3289850	15,961	488330
Pig related losses (US$)	$22,282	$3,284,301	$5,000,000	$19,551,000	$698,543	$4,447,885
% of total	0.24	0.41	0.25	0.11	0.05	0.05
Value of healthy adult pig (US$)	55	90	-	96	145	100
Value reduction of infected pig	50%	50%	50 US$	25%	30%	30%
Source	Trevisan et al 2018	Trevisan et al 2015	Carabin et al 2006	Bhattarai et al, 2019	Praet et al, 2009	Skirp et al, 2021
Type of study	District level primary data	Systematic review	Review and primary data	Review and primary data	Review	Calculations, Assumptions

Table 3 shows estimated baseline, status quo, costs of *T. solium* infection in humans and pigs in Burkina Faso. Some values were estimated based on other African and endemic countries, but with similar prevalence rates. The calculation of the burden for human Neurocysticercosis was $population\ of\ BK\ *\ prevalence\ of\ NCC\ *\ cost\ per\ case\ of\ NCC$. The calculation to estimate the annual burden for porcine cysticercosis in Burkina Faso was $population\ of\ pigs\ in\ BK\ *\ prevalence\ of\ PCC\ *\ cost\ per\ case\ of\ PCC\ *\ \%\ slaughtered/year$. These values were used in Section 5 for our cost-benefit analyses.

Table 3. Status quo monetary cost in Burkina Faso

Name	**Value (US$)**	**Source**	**Country**
Cost per case of human NCC	214	Praet et al, 2009	Cameroon
Cost per PCC	30	Praet et al, 2009; Bhattarai et al, 2019; Trevisan et al 2015	Cameroon, Mexico, Tanzania
% of pigs slaughtered / year	0.6	(FAO UN, 2005)	Burkina Faso
Economic burden of human NCC	80365360	Calculated	
Economic burden of PCC	8789932	Calculated	
Total annual monetary burden	89155292	Calculated	

3. Prevention and control strategies for elimination of *T. solium*

Over the last decades, there have been proposed and tested interventions to eliminate *T. solium* in humans and pigs. These include human interventions such as test and treatment (HT&T), pig interventions such as mass drug administration (MDA) and vaccination campaigns, and community interventions such as improvement of sanitation and hygiene. Improving pig husbandry, community based educational programs, and meat inspection are additional strategies that we did not investigate.

3a. Human Test and Treatment

Treatment of taeniasis is done either on an individual basis or as Mass Drug Administration. Single doses of praziquantel (10 mg/kg) or niclosamide (2g for adults and children over 6 years, 1 g for children aged 2–6 years) and albendazole (400 g) for 3 consecutive days are normally used for taeniasis. In neurocysticercosis the specialised treatment may include high doses of praziquantel and/or albendazole for a longer duration. In addition to other drugs, some supporting therapy with corticosteroids and antiepileptic drugs are used (WHO, 2020b).

Surgery would be expected to be the most efficient medical intervention of neurocysticercosis to decrease provoked inflammation, but because of the risk of surgery and bleeding due to adherent cysts, this treatment is not always recommended (White et al., 2018). The estimated total cost of an annual HT&T intervention in Burkina Faso is shown in Table 4.

Table 4. Human test and treat (HT&T) annual monetary cost

Name	Value (US$)	Source	Country
Cost of Praziquantel (10mg/kg) single dose	0.15	(WHO, 2020b)	
Cost of Albendazole (400 mg) 1 pill	0.04	(Hall et al., 2009; WHO, 2020b)	
Cost of diagnostic (ELISA)	2	(Proaño-Narvaez et al., 2002)	Mexico
Cost of visit to health clinic	1.2	(Salari et al., 2020)	
Cost per taeniasis case	0.15	Calculation	
Cost per mild cysti case (HCC)	2.3	(Garcia et al., 2016)	Peru
Cost per severe cysti case (NCC)	31	Praet et al, 2009	Cameroon
Number of taeniasis cases	568,999	Calculation	
Number of mild cysti cases (HCC)	585,662	Calculation	
Number of severe cysti cases (NCC)	375,539	Calculation	
Cost to test all individuals	65,028,410	Calculation	
Total cost of T&T of taeniasis cases	85,350	Calculation	
Total cost of T&T of mild cases (HCC)	1,347,023	Calculation	
Total cost of T%T of severe cases (NCC)	11,641,711	Calculation	
Overall cost per cysti case (HCC and NCC)	13.51	Calculation	
Overall cost per Taeniasis and Cysti case	12.95	Calculation	

3b. Pig Interventions

There are several chemotherapies that have been tested in the field to treat *T. solium* in pigs. Oxfendazole is one of the few that is registered for use in pigs and it has been shown to be the most effective (Mkupasi et al., 2013). These treatments are generally mass administered because antigen and antibody tests are expensive and have low sensitivity and specificity. Oxfendazole protects pigs for up to 3 months after treatment, but it takes between 8 and 26 weeks for cysticerci to clear (Sikasunge et al., 2008). One major drawback to this form of intervention is that between the time of treatment and the time of slaughter, the pig can become reinfected. In a study of Oxfendazole conducted in Mozambique, when pigs were given the chemotherapy at 4 months, 21.4% were positive for cysticercosis at slaughter (12 months) and when given it at 9 months, 9.1% were positive at slaughter (Pondja et al., 2012). In Northern Africa, Oxfendazole can be purchased for $0.50 USD per 30kg pig (Geerts, 2016). The estimated total cost of an annual MDA campaign of all pigs in Burkina Faso is shown in Table 5.

Table 5. MDA of pigs annual monetary cost

Name	Value per dose (US$)	Source	Country
Cost of medication (Oxfendazole)	0.5	Geerts, 2016	
Indirect costs of MDA (transport, education)	0.05	(Tago et al., 2017)	Senegal & Nigeria
% of pigs slaughtered / year	0.6	FAO 2005	Burkina Faso
% of pigs cyst free	90	Pondja et al, 2012	Mozambique
Total cost each year	853,994	Calculation	

Another intervention of *T. solium* through pigs is vaccination. There are three vaccinations available: one synthetic peptide vaccine, and two recombinant oncosphere vaccines (Geerts, 2016). The two recombinant oncosphere vaccines, TSOL16 and TSOL18, have been found effective in several field trials. One such trial conducted in Peru (Jayashi et al., 2012) showed that a combination of two vaccine doses of TSOL16 and TSOL18 reduced the number of viable cysts in pigs by almost 100%. The Global Alliance for Livestock Veterinary Medicines has partnered with the Indian Immunologicals Limited to produce TSOL18 at a large scale and low cost for farmers. It is currently available at an estimated $0.10 USD per dose (Geerts, 2016). We used the vaccine cost calculation tool, VacciCost to estimate the indirect costs of the vaccine, including the salary of the paraveternian, animal tagging, transportation and overhead (Tago et al., 2017). We estimated the cost of one dose of vaccination per pig to be $0.44 USD. Since each pig requires two doses, it is $0.88 per pig. The estimated cost of an annual pig vaccination campaign is shown in Table 6.

Table 6. Vaccination of pigs annual monetary cost

Name	Value per dose (US$)	Source	Country
Cost of TSOL18 vaccine	0.1	Geerts, 2016	
Indirect costs of vaccination campaign	0.34	Tago et al, 2017	Senegal and Nigeria
Number of times required to vaccinate	2	Geerts, 2016	
Initial number of pigs to vaccinate	2,345,188	Calculation	
New pigs/year	1,407,113	Calculation	
Total cost in first year	2,063,765	Calculation	
Total cost after first year	1,238,259	Calculation	

However, one problem with pig vaccination is timing. These vaccinations do not kill any already established parasite so a vaccination would be futile for infected pigs. The recommended intervention, therefore, is for a combination of pig vaccine with MDA, which we also consider in our analysis in Sections 4 and 5. Additionally, there are current alternatives under development for oral vaccination (Monreal-Escalante et al., 2016). This would reduce the costs and logistic difficulties in vaccine administration. Since it is not yet an available option, we did not explore it further.

3c. Sanitation and Hygiene Initiatives

Poor sanitation and hygiene are closely related to several negative health outcomes in small children (under 5) as well as entire communities, and improved sanitation and hygiene is now one of the United Nations sustainable development goals for 2030 (SDG 6). Included in the negative health outcomes associated with poor sanitation and hygiene is the transmission of *T. solium* eggs from humans infected with taeniasis to other humans or pigs, leading to cysticercosis. In 2017, 65% of the Burkina Faso population still practiced open defecation, while in some rural regions open defecation practices reached as high as 90% (WSP, 2011). Additionally, in Burkina Faso, only 8% of rural households have access to soap and water (IRC, 2019; WSP, 2011). The building of latrines and handwashing stations in rural areas of Burkina Faso would likely greatly reduce the transmission of *T. solium* eggs to pigs, humans, and the environment. It is estimated that this would cost around 20 million USD per year to build, with an additional 7 million USD per year for operational and maintenance costs, in rural areas of Burkina Faso (WSP, 2011). The estimated cost of an annual sanitation and hygiene infrastructure initiative in rural parts of Burkina Faso, where 70% of the population resides, is shown in Table 7. Capital expenses, totalling 20 million USD per year, will make up the majority of the cost, however, we assume that the building of the latrines takes no longer than 2 years to complete. Therefore after the first two years, we expect just the operational and maintenance costs to contribute to the annual cost of such a program.

Table 7. Rural sanitation and hygiene initiative annual monetary cost

Name	Value (US$)	Source	Country
Capital expenses (first few years only)	20,000,000	WSP, 2011	Burkina Faso
Operational expenses	2,000,000	WSP, 2011	Burkina Faso
Maintenance and Repair	5,000,000	WSP, 2011	Burkina Faso

However, the building of latrines and handwashing stations will not reduce the transmission dynamics of *T. solium* (among other pathogens) if knowledge, attitudes, and practices are not also addressed, along with a gender equity lens (Thys et al., 2015). When latrines are poorly built or when human waste is intentionally fed into pigsties, the rate of porcine cysticercosis has been seen to increase (Diaz et al., 1992; Shey-Njila et al., 2003). Additionally, implementing sanitation and hygiene initiatives along with educational initiatives that emphasize the need for renewal and maintenance of latrines to interrupt the *T. solium* life cycle is imperative for sustainability.

3d. Other strategies

Other strategies proposed or tested that interfere in the life cycle of *T. solium* to prevent infection include improving pig husbandry practices, introducing community based educational programs, and improving meat inspection infrastructure (Hélène Carabin & Traoré, 2014). Improving pig husbandry practices would include promoting the building of pig pens to avoid open roaming of pigs (thus likely reducing the transmission rate of *T. solium* eggs to pigs), providing a feed that is not contaminated with human faeces and nutritious to the animals, and promoting the caretaker to inspect the pig and provide veterinary care to the pig, if necessary (Assana et al., 2010; Winskill et al., 2017). Community based educational initiatives (through films, leaflets, focus-group discussions, etc) aim to improve local knowledge of the *T. solium* life cycle, health risks, and benefits when eliminated, as well as empower community led sanitation initiatives (Bulaya et al., 2015; Hélène Carabin et al., 2006, 2018). Finally, improving the meat inspection infrastructure has been suggested, although this would be difficult to implement in hard-to-access rural areas and areas where a large degree of sales occur in informal markets (Assana et al., 2010; Diaz et al., 1992). We have chosen to limit our analysis to the previously mentioned interventions.

3e. Sustainability

Sustainability is an important factor when assessing investment in any public health intervention. Determining the cost-effectiveness and the cost-benefit of the intervention is a key component of sustainability. The overall investment required to ensure the success of the intervention needs to be feasible for the country and its funders. Feasibility over the long run is another integral part of the intervention assessment given that reintroduction of *T.*

solium after elimination is possible and likely in certain vulnerable contexts. This would be impacted by social and political instability in a region where certain interventions might then prove to be more sustainable provided insecure funding and an unstable environment. Acceptance of local people and communities of the intervention must also be addressed when assessing sustainability. If the intervention is not fully accepted, the success of the intervention in the long run could be compromised. For example, if rural communities in Burkina Faso do not accept the use of latrines as the only place for defecation, then the sanitation intervention will most likely not be sustainable (Thys et al., 2015). Or if pig MDA is deemed to negatively impact the value of the meat, then this intervention will not be readily accepted. Lastly, reintroduction of *T. solium* into the community after the intervention has ended is possible and has been shown, such as after a 3 year human MDA intervention in Madagascar (Ramiandrasoa et al., 2020). Therefore, the main aim of our cost-benefit analysis of interventions in the following section is to consider the long-term sustainability of several of the above-listed interventions for eliminating *T. solium* in humans and pigs in Burkina Faso.

4. Modelling disease and intervention dynamics

In order to predict the future prevalence of cysticercosis in Burkina Faso, with and without interventions, we explored many mathematical models that were fully developed, validated, and published. Several of the models that we explored are listed here.

a. **EPICYST** model is a deterministic, compartmental transmission model, which was developed to capture the dynamics of *T. solium* (taeniasis/cysticercosis disease) in the human and pig hosts (Winskill et al., 2017). It allows for many different intervention scenarios to be applied.

b. **cystiSim** is an agent-based, stochastic model which is able to simulate age-structured, field-realistic interventions in varying settings. cystiSim used different scenarios combining interventions in both hosts, mass drug administration to humans, and vaccination and treatment of pigs.

c. **Modified Reed-Frost stochastic model** considers both deterministic and stochastic versions. The proposed model includes a dynamic population of the intermediate host by including birth and slaughter of pigs.

d. **CystAgent model:** CystiAgent is a spatially-explicit agent-based model. It includes a spatial framework and behavioral parameters of pigs and human hosts (e.g., pig roaming, human travel, and open defecation).

In the end, we chose EPICYST because it was open access, it was based on data from sub-Saharan Africa, and because of its extensive possibilities of incorporating intervention strategies into the model. Table 8 shows the parameters for Burkina Faso that we used to run the baseline of *T. solium* using the EPICYST model.

Table 8. Baseline parameter values of *T. Solium* for Burkina Faso

Name	Parameter	Value	Source	Country
Pig population	PPS	2,587,862	Knoema, 2021	Burkina Faso
Human population	HPS	20,321,378	(World Bank, 2019)	Burkina Faso
Human taeniasis prevalence	HTPrev	0.028	Skrip et al, 2021	Burkina Faso
Human cysticercosis prevalence	HCPrev	0.0473	Skrip et al, 2021	Burkina Faso
Estimated human NCC epilepsy prevalence	HNCPrev	0.01848	Millogo et al, 2012	Burkina Faso
Porcine cysticercosis prevalence	PCPrev	0.1887	Skrip et al, 2021	Burkina Faso
Human average life expectancy [years]	LEH	61	(World Bank, 2019)	Burkina Faso
Pig average life expectancy [years]	LEP	1.88	Skrip et al, 2021	Burkina Faso

5. Model Results

After running the model at baseline as status quo, we then ran the model with four individual interventions: pig mass drug administration (pig MDA), pig vaccination, human test and treat (HT&T), and sanitation. We additionally ran the model incorporating a few combinations of the interventions: pig mass drug administration with pig vaccination; pig mass drug administration, pig vaccination, and human test and treat; pig mass drug administration and sanitation. Figure 4 shows the results of these model runs and the effect of human cysticercosis cases in Burkina Faso over 30 years.

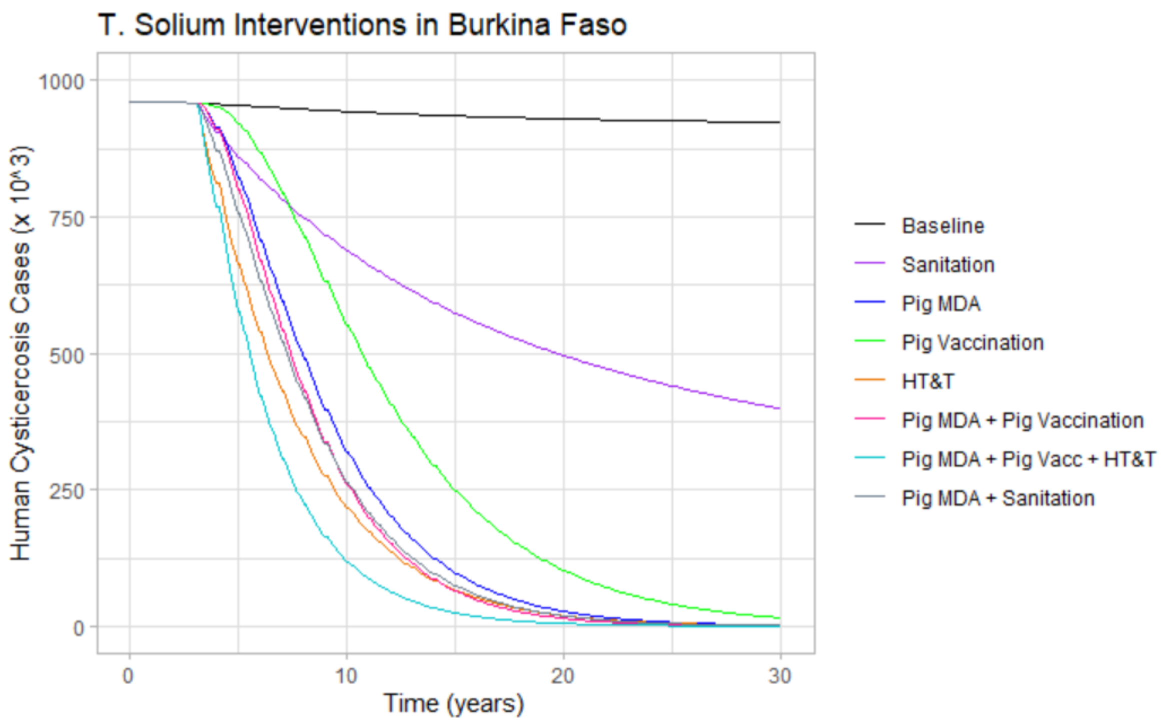

Figure 4. EPICYST model output of human cysticercosis cases in Burkina Faso after various interventions have been implemented.

6. Cost Benefit Analysis

We took the results from the transmission model and combined them with the results from our economic literature review (Tables 3 through 7) and evaluated the cost-effectiveness of the interventions.

We first calculated the Benefit-Cost Ratio (BCR) which states how much benefit is gained per unit of cost. To determine the BCR, we first determined the total cost of each case of human cysticercosis, multiplied by the number of cases prevented from the intervention. We did the same for the pig cases of cysticercosis. These were summed and divided by the total cost of the intervention. This can be represented by the following formula:

$$BCR = \frac{cost\ per\ pig\ case * pig\ cases\ averted + cost\ per\ human\ case * human\ cases\ averted}{cost\ of\ intervention}$$

The results can be seen in Figure 5. Pig MDA has the highest cost savings per cost spent on the intervention. Human Test and Treat (HT&T) has the lowest savings per cost spent. At year 30, Pig MDA's BCR was 248 USD while Human Test and Treat was a little over 3 USD. At the 5 year mark, all interventions achieved a BCR higher than 1 USD, indicating that any intervention is better economically than staying with the status quo.

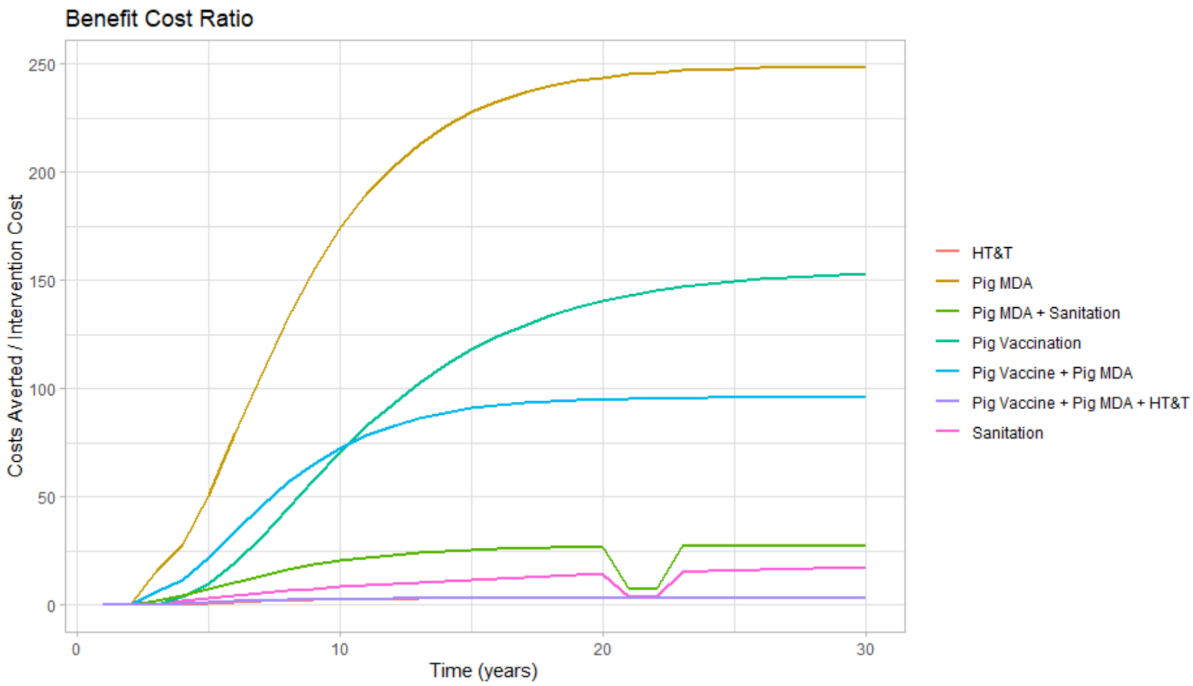

Figure 5. Benefit cost ratio of various interventions implemented in Burkina Faso

We not only looked at the economic benefits, but also at the reduction of disability-adjusted life years (DALYs). According to the Institute for Health Metrics and Evaluation (IHME) (IHME, 2021), the DALYs from cysticercosis in Burkina Faso in 2019 reached 2,064. Burkina Faso has an average of 4.5% of the population with active cysticercosis (Skrip et al., 2021). With a population of 20.3 million in 2019 (World Bank, 2019), we calculate that there are approximately 913,500 cases of active human cysticercosis. Therefore, we assume that each case, on average, represents 0.0023 DALYs. From our transmission model, we were able to calculate how many DALYs were averted each year from the status quo. Figure 6 shows the results of cumulative DALYs averted over 30 years for each intervention. The combined interventions of Human Test and Treat with Pig MDA and Pig Vaccine averted the most DALYS over 30 years, but those three interventions individually were not far behind.

With the previous cost data we collected, we were able to determine the cost per DALY averted after 30 years. The results of these calculations are shown in Figure 7a and 7b. If the interventions are only implemented for 5 years, the cost per DALY is very high. After 10 years, all costs per DALY averted are below 100,000 USD and after 30 years, all are below 45,000 USD. Human Test and Treat is the most expensive per DALY while Pig MDA is the least expensive per DALY with 572 USD. The limitation with this analysis is that it does not incorporate the costs of the burden of disease at the baseline (at status quo). When comparing these costs with the status quo, the cost per DALY averted would be negative.

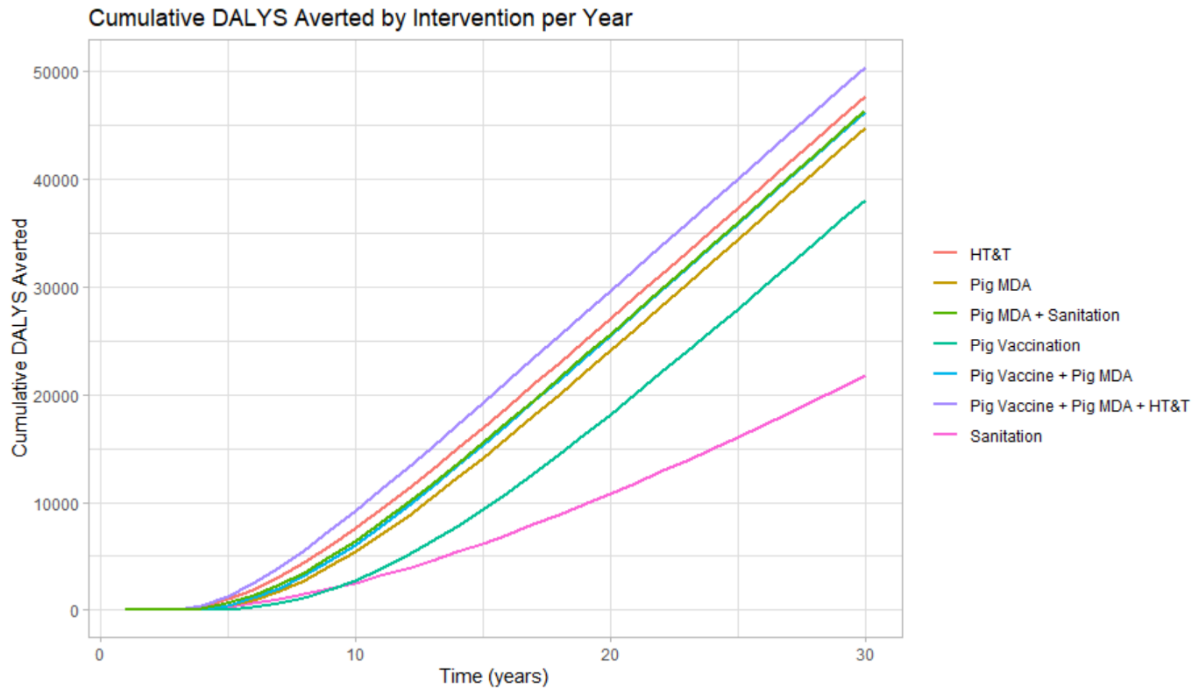

Figure 6. Cumulative costs per DALY for various interventions over 30 years.

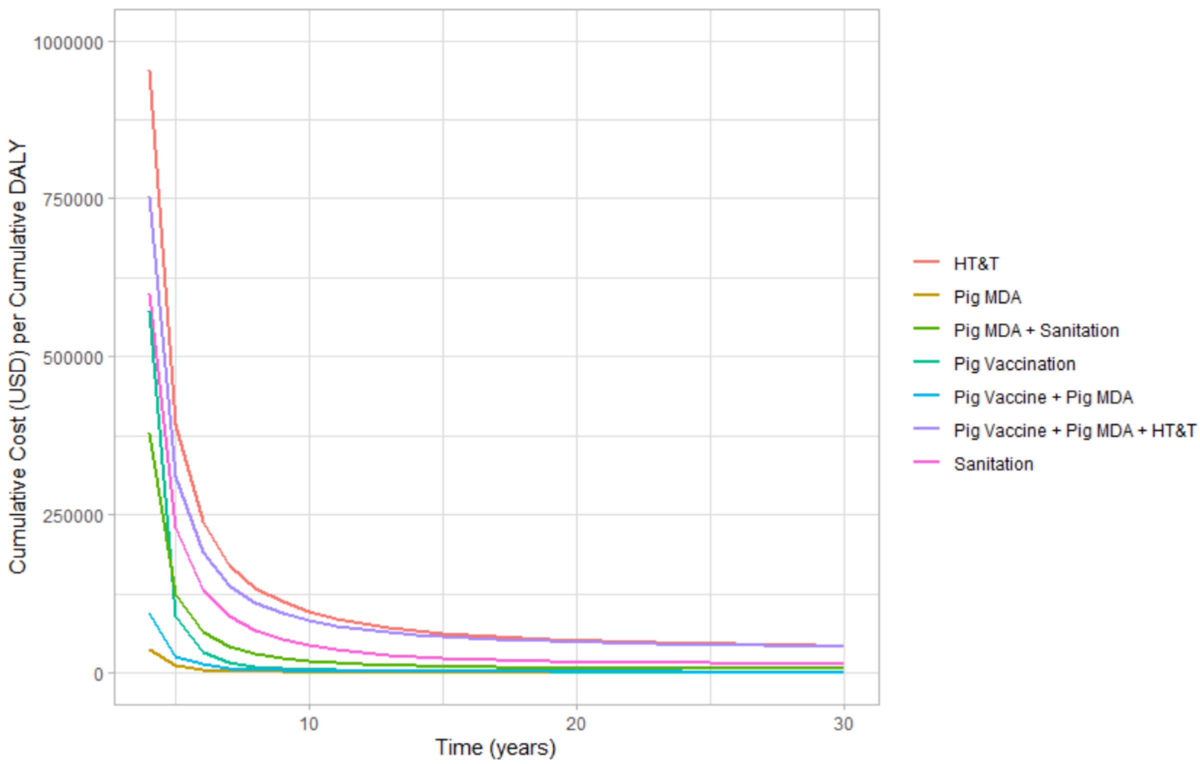

Figure 7a. Cumulative costs per DALY for various interventions over 30 years.

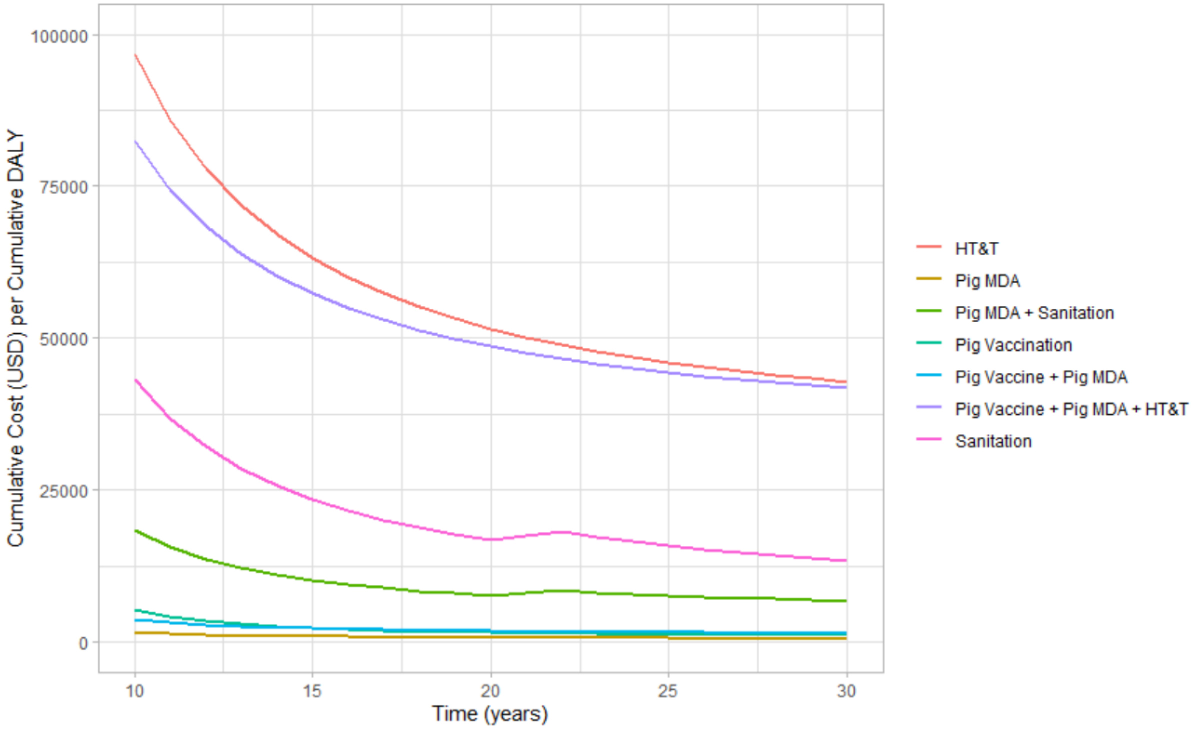

Figure 7b. A closer look at Figure 7a.

7. Sensitivity Analysis

Because there was uncertainty in our cost estimates, we modified some of the dynamics of our cost calculations. We ran a basic sensitivity analysis for the four individual interventions. The parameters that we modified include

- Pig Vaccines, Pig MDA: changed indirect costs (personnel, transportation)
- Sanitation: changed the capital expenditures to vary from 15 million to 20 million
- HT&T: changed testing coverage from 90% to 75% of the population

We did not run a sensitivity analysis on the disease parameters as the EPICYST model creators had already done this and thoroughly reported on their analysis (Winskill et al., 2017). We ran 1000 simulations for each intervention with equal probability given to the values in the range of our minimum and maximum costs. We then calculated the Incremental Cost Effectiveness Ratios (ICER) after 10 years with the Status Quo as the comparator (Table 9). The ICER indicates that if the incremental cost per incremental DALY is below a certain willingness to pay threshold, then the intervention is the better option than the comparator, i.e. the intervention dominates. All of the incremental costs are negative. If we chose any value for a willingness to pay, the intervention would dominate. This is even after accounting for uncertainty in our cost data. Table 9 shows the results of the ICERs.

Table 9. ICERs for four individual interventions with Status Quo as the comparator. Incremental costs are represented in millions.

Incremental Cost-effectiveness Ratio (ICER) Compared to Status Quo after 10 Years

Outcome	HT&T	Pig MDA	Pig Vaccine	Sanitation
Incremental DALY Averted	7586.00 (7586.00, 7586.00)	5424.00 (5424.00, 5424.00)	2750.00 (2750.00, 2750.00)	2541.00 (2541.00, 2541.00)
Incremental costs	-149 (-210, -86)	-806 (-808, -804)	-801 (-806, -797)	-712 (-717, -707)
Incremental NMB	758,713 (758,650, 758,774)	543,209 (543,207, 543,211)	275,794 (275,790, 275,798)	254,833 (254,828, 254,838)
ICER	Dominates	Dominates	Dominates	Dominates

Note:

Costs in Millions USD

Decision Analysis

Often the price for an intervention is predetermined by the funding source. We ran a decision analysis on the simulation data mentioned above for only the four individual interventions. Based on the willingness to pay per DALY averted, we determined which intervention gave the most probability of being effective (Figure 8). If there were less than 250,000 USD available, then Pig MDA would be the most cost effective. If there were more than 350,000 USD then Human Test and Treat would be the best option.

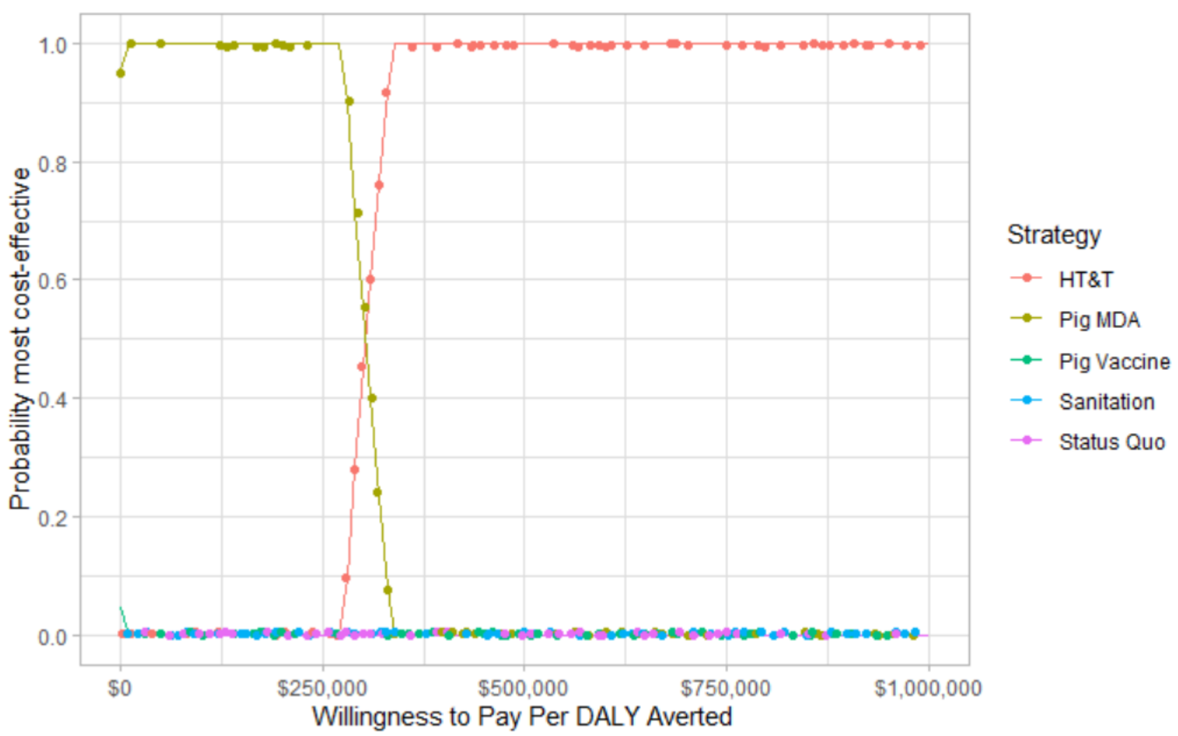

Figure 8. Decision analysis of probability of effectiveness for willingness to pay.

However, we criticize this approach when choosing an intervention because this analysis does not consider other criteria of the intervention such as the cost of the burden of disease, the feasibility, and the sustainability.

8. Limitations

There are several limitations to this preliminary cost-benefit analysis of interventions to eliminate *T. solium* in humans and pigs in Burkina Faso. First, some of our parameter estimates for Burkina Faso were found based on data of other sub-Saharan in peer-reviewed journal articles based on data and studies conducted in other countries of sub-Saharan Africa (mostly conducted in West Africa, with some from South or East Africa). Even with these other data sources, we still made many assumptions in our cost estimates (such as for sanitation or vaccination of pigs) and we struggled to find realistic data for all of the parameters. Secondly, due to time-constraints, we did not run an in depth sensitivity analysis for all of our parameters. We believe this is necessary to validate our findings, and will be further explored in future projects. Lastly, we assumed a lot about a context for which all three authors are not familiar. For example, to simplify analysis, we made the assumption that no one in Burkina Faso is currently receiving treatment for cysticercosis (when calculating the annual cost of Status Quo and Human Test and Treat). We also assumed that the population of Burkina Faso is homogeneous, and that both the pig and human populations do not grow over the period of 30 years, as this is not currently built into the EPICYST model. Additionally we did not incorporate inflation into our calculations. Many of these limitations we would plan to address in future analyses.

9. Conclusion

This is the first cost benefit analysis of *T. solium* interventions. *T. solium* is endemic throughout sub-Saharan Africa, as well as Latin America, and parts of Asia. It is thought to be a growing cause of acquired epilepsy. *T. solium* infection can cause a considerable loss to livelihood from neurocysticercosis infection in humans, lost value of infected pigs, and lifelong disability.

Our findings suggest that all interventions would be cost effective and they would reduce the number of DALYs. Nevertheless, one intervention addresses the root of the problem, sanitation. Even though sanitation costs are high and other interventions provide more benefit for less cost to treat cysticercosis, the overall benefit of improved sanitation supersedes the benefits of the others. The pig and human testing, treating and vaccinating interventions only remedy the cysticercosis intervention. Improved sanitation, on the other hand, has a wider impact of potentially ameliorating many health outcomes of the population, including diarrheal diseases, other helminth infections, cholera, and dysentery.

We would recommend a combination intervention of sanitation with pig MDA. Pig MDA is inexpensive, the cheapest price per DALY averted. Pig MDA would provide fast results in reducing cysticercosis while sanitation and hygiene would provide the long-term, sustainable solution. Since *T. solium* disease dynamics are multi-faceted with animal, human and environment interactions, there are many diverse stakeholders involved in the *T. solium* elimination solution. A One Health approach would be necessary for intervention acceptability and sustainability.

References

Ahmad, R., Khan, T., Ahmad, B., Misra, A., & Balapure, A. K. (2017). Neurocysticercosis: A review on status in India, management, and current therapeutic interventions. *Parasitology Research*, *116*(1), 21–33. https://doi.org/10.1007/s00436-016-5278-9

Assana, E., Amadou, F., Thys, E., Lightowlers, M. W., Zoli, A. P., Dorny, P., & Geerts, S. (2010). Pig-farming systems and porcine cysticercosis in the north of Cameroon. *Journal of Helminthology*, *84*(4), 441–446. https://doi.org/10.1017/S0022149X10000167

Bhattarai, R., Budke, C. M., Carabin, H., Proaño, J. V., Flores-Rivera, J., Corona, T., Ivanek, R., Snowden, K. F., & Flisser, A. (2012). Estimating the non-monetary burden of neurocysticercosis in Mexico. *PLoS Neglected Tropical Diseases*, *6*(2), e1521. https://doi.org/10.1371/journal.pntd.0001521

Bhattarai, R., Carabin, H., Proaño, J. V., Flores-Rivera, J., Corona, T., Flisser, A., León-Maldonado, L., & Budke, C. M. (2019). The monetary burden of cysticercosis in Mexico. *PLOS Neglected Tropical Diseases*, *13*(7), e0007501. https://doi.org/10.1371/journal.pntd.0007501

Bulaya, C., Mwape, K. E., Michelo, C., Sikasunge, C. S., Makungu, C., Gabriel, S., Dorny, P., & Phiri, I. K. (2015). Preliminary evaluation of Community-Led Total Sanitation for the control of Taenia solium cysticercosis in Katete District of Zambia. *Veterinary Parasitology*, *207*(3), 241–248. https://doi.org/10.1016/j.vetpar.2014.12.030

Carabin, Hélène, Krecek, R. C., Cowan, L. D., Michael, L., Foyaca-Sibat, H., Nash, T., & Willingham, A. L. (2006). Estimation of the cost of Taenia solium cysticercosis in eastern Cape Province, South Africa. *Tropical Medicine and International Health*. https://doi.org/10.1111/j.1365-3156.2006.01627.x

Carabin, Hélène, Millogo, A., Ngowi, H. A., Bauer, C., Dermauw, V., Koné, A. C., Sahlu, I., Salvator, A. L., Preux, P.-M., Somé, T., Tarnagda, Z., Gabriël, S., Cissé, R., Ouédraogo, J.-B., Cowan, L. D., Boncoeur-Martel, M.-P., Dorny, P., & Ganaba, R. (2018). Effectiveness of a community-based educational programme in reducing the cumulative incidence and prevalence of human Taenia solium cysticercosis in Burkina Faso in 2011–14 (EFECAB): A cluster-randomised controlled trial. *The Lancet Global Health*, *6*(4), e411–e425. https://doi.org/10.1016/S2214-109X(18)30027-5

Carabin, Hélène, & Traoré, A. A. (2014). Taenia solium taeniasis and cysticercosis control and elimination through community-based interventions. *Current Tropical Medicine Reports*, *1*(4), 181–193. https://doi.org/10.1007/s40475-014-0029-4

CDC. (2020). *CDC - Taeniasis*. https://www.cdc.gov/parasites/taeniasis/index.html

Diaz, F., Garcia, H. H., Gilman, R. H., Gonzales, A. E., Castro, M., Tsang, V. C. W., Pilcher, J. B., Vasquez, L. E., Lescano, M., Carcamo, C., Madico, G., & Miranda, E. (1992). Epidemiology of Taeniasis and Cysticercosis in a Peruvian Village. *American Journal of Epidemiology*, *135*(8), 875–882. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3103216/

Edia-Asuke, A. U., Inabo, H. I., Umoh, V. J., Whong, C. M., Asuke, S., & Edeh, R. E. (2014). Assessment of sanitary conditions of unregistered pig slaughter slabs and post mortem examination of pigs for Taenia solium metacestodes in Kaduna metropolis, Nigeria. *Infectious Diseases of Poverty*, *3*(1), 45. https://doi.org/10.1186/2049-9957-3-45

FAO UN. (2005). Livestock Sector Brief: Burkina Faso. *BURKINA FASO*, 20. http://www.fao.org/ag/againfo/resources/en/publications/sector_briefs/lsb_BFA.pdf

Ganaba, R., Praet, N., Carabin, H., Millogo, A., Tarnagda, Z., Dorny, P., Hounton, S., Sow, A., Nitiéma, P., & Cowan, L. D. (2011). Factors associated with the prevalence of circulating antigens to porcine cysticercosis in three villages of burkina faso. *PLoS Neglected Tropical Diseases*, *5*(1), e927. https://doi.org/10.1371/journal.pntd.0000927

Garcia, H. H., Lescano, A. G., Gonzales, I., Bustos, J. A., Pretell, E. J., Horton, J., Saavedra, H., Gonzalez, A. E., Gilman, R. H., & Cysticercosis Working Group in Peru. (2016). Cysticidal Efficacy of Combined Treatment With Praziquantel and Albendazole for Parenchymal Brain Cysticercosis. *Clinical Infectious Diseases: An Official Publication of the Infectious Diseases Society of America*, *62*(11), 1375–1379. https://doi.org/10.1093/cid/ciw134

Garcia, H. H., Nash, T. E., & Del Brutto, O. H. (2014). Clinical symptoms, diagnosis, and treatment of neurocysticercosis. *The Lancet. Neurology*, *13*(12), 1202–1215. https://doi.org/10.1016/S1474-4422(14)70094-8

Geerts, S. (2016). *Elimination of Taenia solium cysticercosis through vaccination of pigs: A realistic option?*

Hall, A., Horton, S., & de Silva, N. (2009). The Costs and Cost-Effectiveness of Mass Treatment for Intestinal Nematode Worm Infections Using Different Treatment Thresholds. *PLoS Neglected Tropical Diseases*, *3*(3). https://doi.org/10.1371/journal.pntd.0000402

Hawk, M. W., Shahlaie, K., Kim, K. D., & Theis, J. H. (2005). Neurocysticercosis: A review. *Surgical Neurology*, *63*(2), 123–132. https://doi.org/10.1016/j.surneu.2004.02.033

Hobbs, E. C., Mwape, K. E., Devleesschauwer, B., Gabriel, S., Chembensofu, M., Mambwe, M., Phiri, I. K., Masuku, M., Zulu, G., Colston, A., Willingham, A. L., Berkvens, D., Dorny, P., Bottieau, E., & Speybroeck, N. (2018). *Taenia solium from a community perspective: Preliminary costing data in the Katete and Sinda districts in Eastern Zambia*. https://doi.org/10.1016/j.vetpar.2018.01.001

IHME. (2021). *Institute for Health Metrics and Evaluation. GBD Compare*. http://vizhub.healthdata.org/gbd-compare

IRC. (2019). *Burkina Faso: A water sanitation and hygiene information sheet*. https://www.ircwash.org/sites/default/files/country_profile_burkina_final.pdf

Jayashi, C. M., Kyngdon, C. T., Gauci, C. G., Gonzalez, A. E., & Lightowlers, M. W. (2012). Successful immunization of naturally reared pigs against porcine cysticercosis with a recombinant oncosphere antigen vaccine. *Veterinary Parasitology*, *188*(3–4), 261–267. https://doi.org/10.1016/j.vetpar.2012.03.055

Kiendrebeogo, T., Logtene, Y. M., Kondombo, S. R., & Kabore-Zoungrana, C. Y. (2012). Characterization and importance of pig breeds in the pork industry of the zone of Bobo-Dioulasso (Burkina Faso, West Africa). *International Journal of Biological and Chemical Sciences*, *6*(4), 1535–1547. https://doi.org/10.4314/ijbcs.v6i4.13

Konema. (2019). *Burkina Faso—Number of pigs 2019*. https://knoema.com//atlas/Burkina-Faso/topics/Agriculture/Live-Stock-Production-Stocks/Number-of-pigs

Melki, J., Koffi, E., Boka, M., Touré, A., Soumahoro, M.-K., & Jambou, R. (2018). Taenia solium cysticercosis in West Africa: Status update. *Parasite*, *25*. https://doi.org/10.1051/parasite/2018048

Millogo, A., Nitiéma, P., Carabin, H., Boncoeur-Martel, M. P., Rajshekhar, V., Tarnagda, Z., Praet, N., Dorny, P., Cowan, L., Ganaba, R., Hounton, S., Preux, P.-M., & Cissé, R. (2012). Prevalence of neurocysticercosis among people with epilepsy in rural areas of Burkina Faso. *Epilepsia*, *53*(12), 2194–2202. https://doi.org/10.1111/j.1528-1167.2012.03687.x

Mkupasi, E. M., Sikasunge, C. S., Ngowi, H. A., & Johansen, M. V. (2013). Efficacy and safety of anthelmintics tested against Taenia solium cysticercosis in pigs. *PLoS Neglected Tropical Diseases*, *7*(7), e2200. https://doi.org/10.1371/journal.pntd.0002200

Monreal-Escalante, E., Govea-Alonso, D. O., Hernández, M., Cervantes, J., Salazar-González, J. A., Romero-Maldonado, A., Rosas, G., Garate, T., Fragoso, G., Sciutto, E., & Rosales-Mendoza, S. (2016). Towards the development of an oral vaccine against porcine cysticercosis: Expression of the protective HP6/TSOL18 antigen in transgenic carrots cells. *Planta*, *243*(3), 675–685. https://doi.org/10.1007/s00425-015-2431-0

Owolabi, L. F., Adamu, B., Jibo, A. M., Owolabi, S. D., Imam, A. I., & Alhaji, I. D. (2020).

Neurocysticercosis in people with epilepsy in Sub-Saharan Africa: A systematic review and meta-analysis of the prevalence and strength of association. *Seizure*, *76*, 1–11. https://doi.org/10.1016/j.seizure.2020.01.005
Pondja, A., Neves, L., Mlangwa, J., Afonso, S., Fafetine, J., Iii, A. L. W., Thamsborg, S. M., & Johansen, M. V. (2012). Use of Oxfendazole to Control Porcine Cysticercosis in a High-Endemic Area of Mozambique. *PLOS Neglected Tropical Diseases*, *6*(5), e1651. https://doi.org/10.1371/journal.pntd.0001651
Pondja, A., Neves, L., Mlangwa, J., Afonso, S., Fafetine, J., Willingham, A. L., Thamsborg, S. M., & Johansen, M. V. (2010). Prevalence and Risk Factors of Porcine Cysticercosis in Angónia District, Mozambique. *PLoS Neglected Tropical Diseases*, *4*(2). https://doi.org/10.1371/journal.pntd.0000594
Praet, N., Speybroeck, N., Manzanedo, R., Berkvens, D., Nsame Nforninwe, D., Zoli, A., Quet, F., Preux, P.-M., Carabin, H., & Geerts, S. (2009). The Disease Burden of Taenia solium Cysticercosis in Cameroon. *PLoS Neglected Tropical Diseases*, *3*(3). https://doi.org/10.1371/journal.pntd.0000406
Proaño-Narvaez, J. V., Meza-Lucas, A., Mata-Ruiz, O., García-Jerónimo, R. C., & Correa, D. (2002). Laboratory Diagnosis of Human Neurocysticercosis: Double-Blind Comparison of Enzyme-Linked Immunosorbent Assay and Electroimmunotransfer Blot Assay. *Journal of Clinical Microbiology*, *40*(6), 2115–2118. https://doi.org/10.1128/JCM.40.6.2115-2118.2002
Ramiandrasoa, N. S., Ravoniarimbinina, P., Solofoniaina, A. R., Andrianjafy Rakotomanga, I. P., Andrianarisoa, S. H., Molia, S., Labouche, A.-M., Fahrion, A. S., Donadeu, M., Abela-Ridder, B., & Rajaonatahina, D. (2020). Impact of a 3-year mass drug administration pilot project for taeniasis control in Madagascar. *PLoS Neglected Tropical Diseases*, *14*(9), e0008653. https://doi.org/10.1371/journal.pntd.0008653
Salari, P., Fürst, T., Knopp, S., Utzinger, J., & Tediosi, F. (2020). Cost of interventions to control schistosomiasis: A systematic review of the literature. *PLOS Neglected Tropical Diseases*, *14*(3), e0008098. https://doi.org/10.1371/journal.pntd.0008098
Shey-Njila, O., Zoli, P. A., Awah-Ndukum, J., Nguekam, null, Assana, E., Byambas, P., Dorny, P., Brandt, J., & Geerts, S. (2003). Porcine cysticercosis in village pigs of North-West Cameroon. *Journal of Helminthology*, *77*(4), 351–354. https://doi.org/10.1079/joh2003179
Sikasunge, C. S., Johansen, M. V., Willingham, A. L., Leifsson, P. S., & Phiri, I. K. (2008). Taenia solium porcine cysticercosis: Viability of cysticerci and persistency of antibodies and cysticercal antigens after treatment with oxfendazole. *Veterinary Parasitology*, *158*(1), 57–66. https://doi.org/10.1016/j.vetpar.2008.08.014
Skrip, L. A., Dermauw, V., Dorny, P., Ganaba, R., Millogo, A., Tarnagda, Z., & Carabin, H. (2021). Data-driven analyses of behavioral strategies to eliminate cysticercosis in sub-Saharan Africa. *PLOS Neglected Tropical Diseases*, *15*(3), e0009234. https://doi.org/10.1371/journal.pntd.0009234
Tago, D., Sall, B., Lancelot, R., & Pradel, J. (2017). VacciCost – A tool to estimate the resource requirements for implementing livestock vaccination campaigns. Application to peste des petits ruminants (PPR) vaccination in Senegal. *Preventive Veterinary Medicine*, *144*, 13–19. https://doi.org/10.1016/j.prevetmed.2017.05.011
Thys, S., Mwape, K. E., Lefèvre, P., Dorny, P., Marcotty, T., Phiri, A. M., Phiri, I. K., & Gabriël, S. (2015). Why latrines are not used: Communities' perceptions and practices regarding latrines in a Taenia solium endemic rural area in Eastern Zambia. *PLoS Neglected Tropical Diseases*, *9*(3), e0003570. https://doi.org/10.1371/journal.pntd.0003570
Tialla, D., Sausy, A., Cissé, A., Sagna, T., Ilboudo, A. K., Ouédraogo, G. A., Hübschen, J. M., Tarnagda, Z., & Snoeck, C. J. (2020). Serological evidence of swine exposure to pandemic H1N1/2009 influenza A virus in Burkina Faso. *Veterinary Microbiology*, *241*, 108572. https://doi.org/10.1016/j.vetmic.2019.108572
Trevisan, C., Devleesschauwer, B., Praet, N., Pondja, A., Assane, Y. A., Dorny, P., Thamsborg, S. M., Magnussen, P., & Johansen, M. V. (2018). Assessment of the

societal cost of Taenia solium in Angónia district, Mozambique. *BMC Infectious Diseases*, *18*(1), 1–11. https://doi.org/10.1186/s12879-018-3030-z
Trevisan, C., Devleesschauwer, B., Schmidt, V., Winkler, A. S., Harrison, W., & Johansen, M. V. (2017). The societal cost of Taenia solium cysticercosis in Tanzania. *Acta Tropica*, *165*, 141–154. https://doi.org/10.1016/j.actatropica.2015.12.021
Weka, R. P., Kamani, J., Cogan, T., Eisler, M., & Morgan, E. R. (2019). Overview of Taenia solium cysticercosis in West Africa. *Acta Tropica*, *190*, 329–338. https://doi.org/10.1016/j.actatropica.2018.12.012
White, A. C., Coyle, C. M., Rajshekhar, V., Singh, G., Hauser, W. A., Mohanty, A., Garcia, H. H., & Nash, T. E. (2018). Diagnosis and Treatment of Neurocysticercosis: 2017 Clinical Practice Guidelines by the Infectious Diseases Society of America (IDSA) and the American Society of Tropical Medicine and Hygiene (ASTMH). *Clinical Infectious Diseases: An Official Publication of the Infectious Diseases Society of America*, *66*(8), e49–e75. https://doi.org/10.1093/cid/cix1084
WHO (Ed.). (2010). *Working to overcome the global impact of neglected tropical diseases: First WHO report on neglected tropical diseases*. Department of Reproductive health and Research, World Health Organization.
WHO. (2020a). *Ending the neglect to attain the Sustainable Development Goals: A road map for neglected tropical diseases 2021–2030*. https://apps.who.int/iris/bitstream/handle/10665/332094/WHO-UCN-NTD-2020.01-eng.pdf?ua=1
WHO. (2020b). *Taeniasis/Cysticercosis*. https://www.who.int/news-room/fact-sheets/detail/taeniasis-cysticercosis
Winskill, P., Harrison, W. E., French, M. D., Dixon, M. A., Abela-Ridder, B., & Basáñez, M.-G. (2017). Assessing the impact of intervention strategies against Taenia solium cysticercosis using the EPICYST transmission model. *Parasites & Vectors*, *10*(1), 73. https://doi.org/10.1186/s13071-017-1988-9
World Bank. (2019). *Population, total—Burkina Faso | Data*. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=BF
WSP. (2011). *Water Supply and Sanitation in Burkina Faso: Turning Finance into Services for 2015 and Beyond*. Water and Sanitation Program. https://www.wsp.org/sites/wsp/files/publications/CSO-burkina-faso.pdf
Zoli, A., Shey-Njila, O., Assana, E., Nguekam, J.-P., Dorny, P., Brandt, J., & Geerts, S. (2003). Regional status, epidemiology and impact of Taenia solium cysticercosis in Western and Central Africa. *Acta Tropica*, *87*(1), 35–42. https://doi.org/10.1016/s0001-706x(03)00053-6