


ORIGINAL ARTICLE

A methodology to assess indirect economic impacts of animal disease outbreaks: A case of hypothetical African swine fever outbreak in Switzerland

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Abstract

Indirect costs of animal disease outbreaks often significantly exceed the direct costs. Despite their importance, indirect costs remain poorly characterized due to their complexity. In this study, we developed a framework to assess the indirect costs of a hypothetical African swine fever outbreak in Switzerland. We collected data through international and national stakeholder interviews, analysis of national disease control regulations and industry data. We developed a framework to capture the resulting qualitative and quantitative data, categorize the impacts of these regulations, and rank the impacts in order of importance. We then developed a spreadsheet model to calculate the indirect costs of one category of control measure for an individual group of stakeholders. We developed a decision tree model to guide the most economically favourable implementation plan for a given control measure category, under different outbreak scenarios. Our results suggest that the most important measure/impact categories were 'Transport logistics', 'Consumer demand', 'Prevention of wild boar and domestic pig contact' and 'Slaughter logistics'. In our hypothetical scenario, the greatest costs associated with 'Prevention of wild boar and domestic pig contact' were due to assumed partial or total depopulation of fattening pig farms in order to reduce herd size to comply with the simulated control regulations. The model also provides suggestions on the most economically favourable strategy to reduce contact between wild boar and domestic pigs in control areas. Our approach provides a new framework to integrate qualitative and quantitative data to guide disease control strategy. This method could be useful in other countries and for other diseases, including in data- and resource-poor settings, or areas with limited experience of animal disease outbreaks.

KEYWORDS

African swine fever, disease outbreak, economic models, indirect cost

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1 | INTRODUCTION

Disease control and elimination measures have a significant effect on the economic impacts of animal disease outbreaks. These economic impacts can be loosely categorized into direct and indirect costs. Rushton defines direct costs as those associated with the effects of the disease on animals and herds (e.g., mortality and reduced productivity), and indirect costs (also known as consequential costs) as the costs of control measures (e.g., vaccination, culling, movement controls) and impeded access to markets, both local and international, through trade restrictions (Rushton, 2009). However, there is inconsistency in the literature on the definition of direct and indirect costs (Barratt et al., 2019). These differences usually depend on when, in relation to the elimination of disease, the costs are incurred, as well as which economic sector is affected. This inconsistency makes it difficult to quantify and compare indirect costs between studies and between livestock diseases. Here, we focus on indirect costs as those resulting from disease control regulations and policies, and also include other market phenomena which would result from an outbreak, such as changes in consumer demand.

While direct costs of transboundary animal disease (TAD) outbreaks are well understood, little information is available on the indirect costs of control measures, regardless of their precise definition (Barratt et al., 2019; Bennett, 2003; Knight-Jones & Rushton, 2013). The indirect costs associated with controlling animal diseases are often higher than the direct costs and affect a wide range of sectors beyond the agricultural sector, even after disease-freedom has been achieved (Barratt et al., 2019). For example, the direct and indirect costs of the 2001 Foot and Mouth disease (FMD) outbreak in the United Kingdom were estimated at £3 billion and £5 billion, respectively (Oxford Analytica, 2012); here, the direct costs were defined as costs to the public sector, including compensation and other payments to farmers and costs of disease elimination measures, whilst the indirect costs were costs to the private sector, including agriculture and supporting services and tourism and supporting industries (National Audit Office, 2002). Results from a study modelling a hypothetical African swine fever (ASF) outbreak in Denmark—a country with significant pork export—showed that the indirect costs associated with export losses alone were at least 29 times higher than the direct costs in all simulated scenarios (Halasa et al., 2016). It is however crucial to note that, unlike Switzerland, Denmark exports approximately 90% of pork meat produced, making it one of the world's largest pork meat exporters, with pork meat making up nearly half of all agricultural exports and over 5% of Denmark's total exports (Danish Agriculture & Food Council, 2021). In contrast, Switzerland exports less than 2% of pork meat produced, and therefore, in comparison, pork export is far less economically important (Agridea, 2019). Despite their importance, indirect costs of disease are often poorly characterized due to their complexity and paucity of accurate data (Weaver & Habib, 2020). When considering disease control policies, there is a risk that only the immediately apparent, direct consequences of a disease at individual or farm-level are considered, without addressing the more wide-

ranging indirect impacts at population level (Knight-Jones & Rushton, 2013).

A good estimation of the indirect costs of disease allows us to comprehensively understand the economic impact of different disease control measures, permitting a careful and evidence-based weighing of options, and therefore economically sound policy decision-making. Various methodologies to quantify indirect costs of disease have been developed in previous studies. Halasa and colleagues developed a simulation model to assess the epidemiological and economic consequences of a hypothetical ASF outbreak in Denmark (Halasa et al., 2016). Their model simulates disease spread within and between herds and models disease detection and the resulting control strategies. The simulated control strategies are based on legislated EU and national disease control measures as well as the EU ASF contingency plan. Their economic analysis focussed on direct (domestic) costs and export losses due to an outbreak. They predicted that outbreaks of ASF in Denmark tended to be small and short in duration, and that the direct costs associated would be significantly smaller than the export losses. However, they did not perform an in-depth analysis of indirect costs on sectors other than the export of pork. In a 2019 study, Barratt and colleagues developed a time series model to estimate the indirect costs associated with a hypothetical FMD outbreak in Scotland (Barratt et al., 2019). They used time series analysis to estimate price and commodity supply changes over time, using market data. Specifically, and important to note, they focussed on the changes occurring after the end of an outbreak (*ex post*), as they defined indirect costs as those incurred after disease freedom is declared. They modelled the outbreak under two main control policies, culling only or culling combined with vaccination to live. Based on this definition, their model estimated indirect costs as considerably smaller than direct costs, with median direct costs ranging between 10 and 24 times greater than the indirect costs. However, they did not consider export losses, a potentially significant cost, due to lacking export trade data and importantly, they also did not consider indirect costs to other sectors during the outbreak.

In an earlier study, Barratt and colleagues also innovated an economic approach to assess the overall changes in societal economic welfare for milk producers and consumers in Scotland associated with the introduction of Johne's disease in dairy cattle (Barratt et al., 2018). Although their analysis does not capture wide-ranging indirect costs of disease across a variety of sectors beyond agriculture, it provides an insight into the societal economic impacts of the disease by focussing on gains and losses for infected and uninfected dairy producers and gains and losses for consumers due to price changes as a result of changes in supply and demand.

Previous studies have not captured the full range of indirect economic impacts on other sectors of society excluding producers. For policies and legislation to be made appropriately, the indirect economic impacts and far-reaching implications of these new policies must be considered at the start of the policy-making process, rather than waiting for them to be exposed at the end. To address this need, the Swiss government employs the method of Regulatory Impact Analysis (RIA), a process to analyse the economic impacts of new

federal legislative proposals. The RIA provides a good framework to assess new legislation but has to date not been employed to analyse animal disease regulations.

In our study, we tried to add to existing research and techniques by providing a systematic analysis of existing regulations in a hypothetical scenario of animal disease, and produce a method to provide guidance on how these can be implemented in the face of an outbreak. We developed a framework to estimate the indirect costs of an animal disease outbreak in Switzerland, using ASF in domestic pigs and wild boar as an example. ASF is a viral notifiable infectious disease affecting both wild boar and domestic pigs (Galindo & Alonso, 2017; Guinat et al., 2016). The case-fatality rate approaches 100% in the acute form of the disease and there is currently no treatment or vaccine against ASF (OIE, 2019). Excluding Sardinia in Italy, the European Union (EU) has been free of ASF since the mid-1990s until the disease was introduced into eastern European regions in 2007 (Dixon et al., 2020). Since then, ASF has spread throughout a number of EU member states, affecting Lithuania, Poland, Latvia, Estonia, the Czech Republic, Romania, Hungary, Slovakia, Bulgaria, Belgium and Germany, as well as Ukraine, Belarus, Moldova and Serbia (European Commission, 2021; FACE, 2021). As a result of this situation and the increasing geographical proximity of the infection, the Swiss Federal Food Safety and Veterinary Office (FSVO) defines the risk of ASF introduction into Switzerland as high (FSVO, 2021).

The models described here were part of a larger study commissioned by the FSVO. The goals of the study were to estimate the indirect costs associated with a potential ASF outbreak in Switzerland, with a focus on understanding the economic impacts of various control strategies. The goal of this publication is to share and propose our methodology for these models to be considered and used by a wider, international audience involved in disease control decision-making.

2 | MATERIALS AND METHODS

The study investigated the indirect impacts of a hypothetical ASF outbreak in Switzerland and was carried out throughout 2020. We collected a combination of quantitative and qualitative data describing the outcomes of an outbreak and the range of affected stakeholders. We specifically looked at the outcomes and costs associated with the national disease control regulations. We dissected these regulations to reveal and assess their implications in terms of economic impacts (both qualitative and quantitative) and created a framework to capture these impacts and the likely affected stakeholders. Within this framework, we created a system to rank disease control measures and their impacts by importance (from an economic and policy point of view). We then developed two analytical models, a cost calculator and a decision tree model, to calculate the indirect costs for specific stakeholders given various outbreak scenarios, and to provide guidance on the most economically favourable control policy, respectively. The general structure of the study is outlined in Figure 1, and the stages are described in detail later.

2.1 | Literature review

Relevant literature regarding ASF, including the current epidemiological situation, the Swiss swine industry, and the control measures taken in countries recently affected by epidemic ASF was surveyed. This provided a baseline knowledge to guide the data-collection stage.

2.2 | Data collection

The data used in our models were collected from three sources: Stakeholder interviews, industry data, and Swiss disease control regulations.

2.2.1 | Stakeholder interviews

We first conducted preliminary interviews with stakeholders in selected ASF-affected countries in the EU, including representatives from key animal health, industry, trade, and government bodies. The main objective of these interviews was to obtain a general understanding of the type of impacts expected in an ASF outbreak and help us identify categories of key stakeholders who would be affected by an outbreak in the Swiss context. Suitable interviewees for Switzerland were then identified through the SAFOSO network, contacts from the FSVO and stakeholder or industry representative websites. Contacts of interest were approached by email with a request to support a socio-economic study on ASF by participating in a semi-structured interview. Interviews were scheduled by MS Teams (Microsoft Office® 365), Skype (for Windows 10, version 8.68.0.96) or telephone call. Topics of discussion were shared in advance with the interviewees. Interviewees were informed of the study's background and that responses would be reported in condensed form without revealing individuals' identities. Interviews were approximately 40–60 min long and were conducted in German or French.

2.2.2 | Industry data

Raw quantitative data required for cost calculations were acquired predominantly from governmental databases, including from the Federal Statistical Office, the Federal Office for Agriculture and AGRIDEA (the Swiss Association for the Development of Agriculture and Rural Areas). Some quantitative data were also acquired through stakeholder interviews.

2.2.3 | National disease control regulations

The relevant Swiss disease control regulations were examined ('Ordinance on epizootic diseases' [OFE], 1995; 'Technical guidelines on minimum control measures for African swine fever in wild boar', 2019) and the individual disease control measures enforceable or recommended

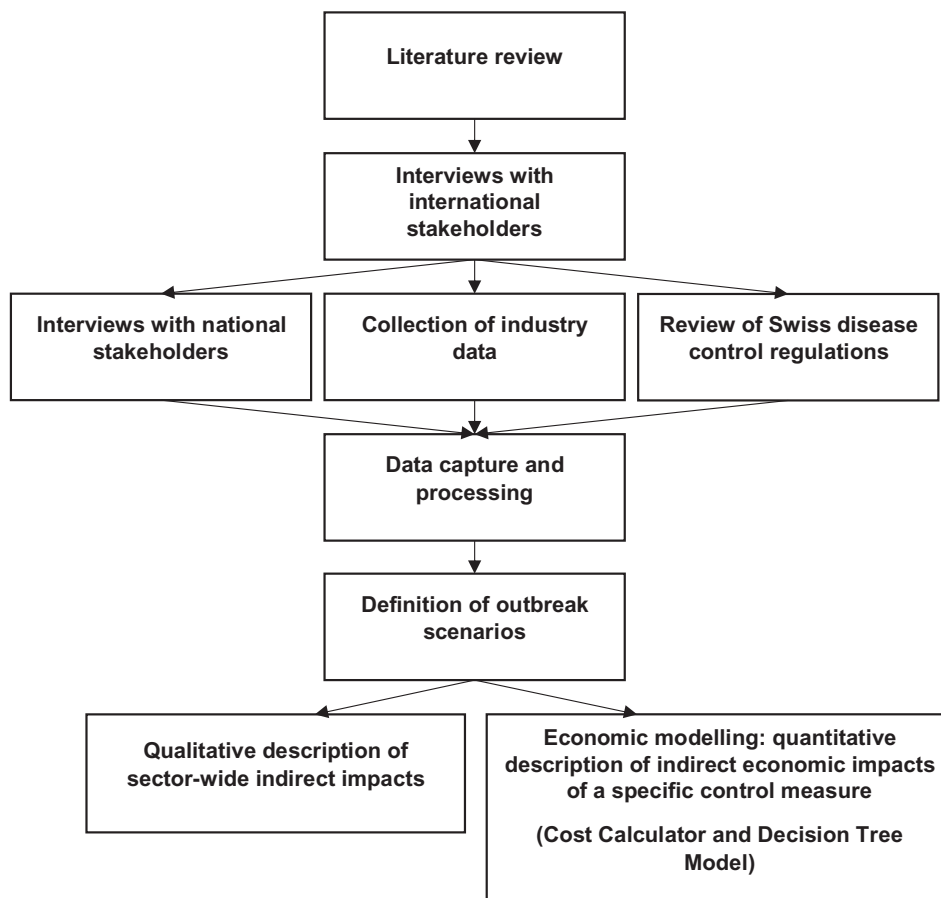


FIGURE 1 Summary of study methodology

in case of an ASF outbreak were extracted and entered into the data-capture framework.

2.3 | Data capture and processing

The information collected from stakeholder interviews, industry data and national disease control regulations were entered into a spreadsheet database as 'measures and impacts' which would occur in an outbreak (using Microsoft® Excel® for Office 365). The following information was also entered for each measure/impact:

- whether they occur in an outbreak involving domestic pigs, wild boar, or both;
- which legislated disease control zone they affect (e.g., Protection Zone, Surveillance Zone);
- the minimum time period during which the measure or impact will be in place, if stated;
- the data source.

About 104 individual control measures and impacts were identified and grouped into 14 measure/impact categories: (1) transport logistics, (2) consumer demand, (3) pig movement, (4) hunting, (5) pork product trade, (6) forest access, (7) slaughter price, (8) prevention of domes-

tic pig-wild boar contact, (9) reproduction, (10) crops, (11) pig price, (12) slaughter logistics, (13) wildlife, and (14) image loss (categories are defined in Table 2). An individual measure could fall into more than one impact/measure category. These categories formed the basis for further analysis of the measures and impacts through economic modelling. Each of the individual 104 control measures or impacts were mapped according to which stakeholder was affected; this was numerized by entering '1' if a stakeholder was affected by the measure/impact, and '0' if they were not. Seven stakeholders were mapped in this way (pig feed producers, pig transporters, pig semen producers, forestry, pig farmers, slaughterhouses, hunters); these stakeholders were identified and selected based on the literature review, stakeholder interviews and disease control regulations. Then, the 14 measure/impact categories were ranked according to how frequently they affected stakeholders, by summing the effect numeral ('1' or '0') for all the individual measures or impacts that are part of each measure/impact category (see [Supporting Information](#)). This numerical ranking was combined with a qualitative assessment of the stakeholder interviews to produce a list of measure/impact categories in order of importance. For example, some measure/impact categories did not affect stakeholders particularly frequently, but they were deemed very significant because their method of implementation remained uncertain and would require major investment and planning.

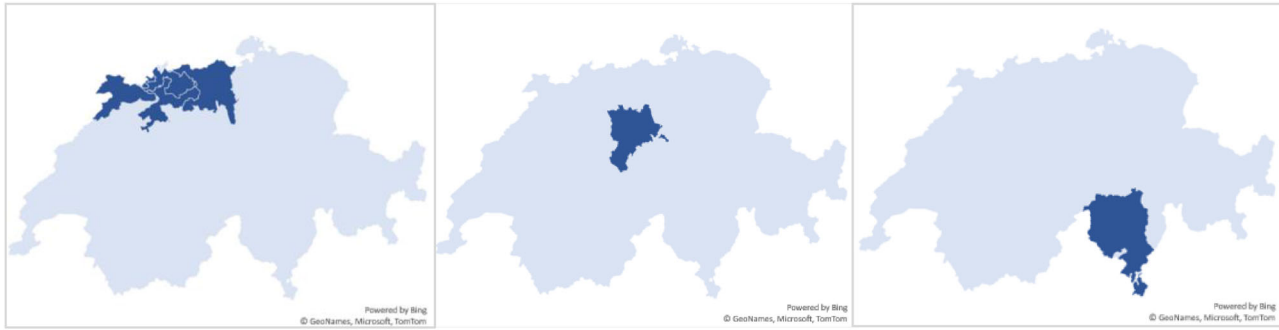


FIGURE 2 Different Swiss regions covered in the outbreak scenarios. From left to right, North West Switzerland (cantons of Aargau, Basel-Landschaft, Solothurn and Jura; the adjacent canton of Basel-Stadt was excluded as no data was available for the pig industry in this canton.), Canton Luzern and Canton Ticino. Figure created using Microsoft® Excel® for Office 365, with ©Geonames, Microsoft, TomTom

2.4 | Definition of outbreak scenarios

We considered outbreaks of three different sizes in three distinct regions of Switzerland, namely Canton Luzern, North West Switzerland and Canton Ticino (Figure 2). These regions were selected because of their significant variation in wild boar density and size and structure of their pig industry. Canton Luzern, located in the centre of the country, is characterized by high-density pig farming including many breeding farms and a low wild boar population. North West Switzerland, bordering Germany and France, has a moderate pig density and a large wild boar population. Canton Ticino, located in the south and bordering Italy, has a small pig industry but a large wild boar population. An important feature of Swiss pig production is the high percentage of farms with outdoor access, with over 50% of pig farms receiving subsidies for complying with minimal outdoor access criteria as part of the RAUS ('regular outdoor access') welfare programme (Agridea, 2019). 'Outdoor access' requirement is not synonymous with pasture, but ranges from outdoor pens with concrete enclosures and a roof (with no possibility of contact with wildlife), to more exposed outdoor pens. Outbreak scenarios were defined according to three criteria: The region in which the outbreak occurred, the size of the outbreak, and whether the outbreak affected wild boar or domestic pigs. The outbreak sizes refer to the land areas directly covered by the control measures rather than the number of outbreaks. The number of farms and pigs affected by a control measure were then estimated based on the farm and pig density in the area under consideration. For small and medium outbreaks, these land areas refer directly to statutory control areas. The three outbreak size scenarios, small, medium and large, are defined in Table 1.

2.5 | Economic models

2.5.1 | Cost calculator

The cost calculator developed here is a framework through which the costs of individual disease control methods can be calculated using a partial budgeting approach, depending on the different outbreak scenarios. The model was created using Microsoft® Excel® for Office 365.

For the purpose of this study, we selected the measure category 'Prevention of domestic pig-wild boar contact' for further analysis. We calculated only costs that apply to fattening pig farms, and not to other stakeholders. However, the framework can be expanded to calculate costs for other stakeholders. The model can also be adjusted to calculate costs associated with other measure/impact categories.

To create the cost calculator, we isolated the measure/impact category 'Prevention of domestic pig-wild boar contact'. Using a mind map (hereafter referred to as 'impacts map') (Figure 3), we identified how the measures belonging to this category would be implemented in the event of an ASF outbreak affecting either wild boar or domestic pigs; we identified the following implementation options for prevention of domestic pig-wild boar contact in both domestic pig and wild boar outbreaks:

1. Banning all outdoor access for pigs on farms in the affected area (Impacts map: 'ONLY INDOOR').
2. Instigating wild boar-secure fencing on all farms with outdoor access in the affected area (Impacts map: 'ONLY FENCING').
3. Allowing farmers to select either to bring all their pigs indoors, or to install wild boar-secure fencing (Impacts map: 'INDOOR AND/OR FENCING').

The implications of these three implementation options are summarized in the Impacts Map. Assumptions were made regarding the percentage of farms that would opt for each solution (Appendix I). This included assumptions of the percentage of farmers who would change their operation to comply with the policy versus the percentage of farmers who depopulate their farms completely in order to wait out the end of outbreak. A degree of partial depopulation was also assumed for farms that comply with a given policy; for example, farms that move all their stock exclusively indoors to comply with a control policy are assumed to depopulate their herds by 50%, as they would have insufficient indoor space to accommodate their full herd if outdoor access areas are removed. Furthermore, we took into account that a certain percentage of farms will already have the necessary infrastructure to comply with the policy; for example, a certain percentage of farms are already exclusively indoors, and therefore would not need to make

TABLE 1 Size of affected land area for each outbreak scenario

Legislated control areas	Protection zone (PZ) (3 km radius)	Surveillance zone (SZ) (10 km radius)	Initial region (10–15 km radius)	Control region		Observation region
				Central region (~3 km radius)	Tampon region (~7 km radius)	
Legislated sizes/ranges (km ²) ^a	~28 km ²	~314 km ²	~350–700 km ²	~30 km ²	~150 km ²	May mimic the Initial Region or be redefined depending on the situation.
Scenario 1: Small outbreak						
Domestic pigs	~28 km ²	~314 km ²	–	–	–	–
Wild boar	–	–	~350 km ²	~30 km ²	~150 km ²	~350 km ²
Scenario 2: Medium outbreak						
Domestic pigs	~84 km ² (3x 'Small')	~942 km ² (3x 'Small')	–	–	–	–
Wild boar	–	–	~700 km ²	~60 km ²	~300 km ²	~700 km ²
Scenario 3: Large outbreak						
Domestic pigs	Whole canton ^b	Whole canton ^b	–	–	–	–
Wild boar	–	–	Whole canton ^b	~120 km ²	~600 km ²	Whole canton ^b

^aFor a domestic pig outbreak, sizes of control areas are legislated in the Ordinance on epizootic diseases, 1995 (OFE). For a wild boar outbreak, recommended sizes of control areas are published in Technical guidelines on minimum control measures for African swine fever in wild boar (2019).

^bFor North West Switzerland, 'whole canton' was taken to include all the cantons included in this defined region.

changes in order to comply with policies to prevent contact with wild boar. In addition, certain farms already have wild-boar proof fencing, which would allow them to continue business as usual in case of a policy enforcing fencing. These assumptions are based on industry data (for example, the percentage of farms in a region with verifiable outdoor access, which would need to be addressed in case of an outbreak) as well as qualitative information from the national stakeholder interviews (for example, the prediction that most organic farms would opt to build a fence rather than move indoors or depopulate, if given a choice). Each of these final solutions, or implications, were labelled (wbA-wbL for a wild boar outbreak and dpA-dpL for a domestic pig outbreak). Each individual implication was examined and subdivided into their relevant costs. The cost calculator was then constructed as a table to allow calculation of each individual cost (equations in Appendix II). The necessary figures were identified and used for the calculations. Each individual cost is calculated for each of the nine possible outbreak scenarios for wild boar and domestic pig outbreaks, that is, for three different regions and three outbreak sizes. This workflow is summarized in Figure 4. The duration of the outbreak can also be altered within the model, allowing factors such as the number of pig production cycles per year to be reflected.

2.6 | Decision tree model

A decision tree model is an economic model considering probability-adjusted costs and benefits of decision options that is used to support decision-making. Based on a flowchart-style diagram, it maps the disease control options and their associated costs and the probabilities of

chance events. The model selects which decision is most economically favourable by considering the costs associated with each decision, as well as the probability of each outcome (Huirne & Dijkhuizen, 1997). The example of a decision tree we produced aids decision-making in implementing the measure/impact category 'Prevention of domestic pig-wild boar contact'. It provides guidance when policy makers are faced with two choices: (1) whether to instigate control measures or not in the face of an outbreak and, (2) when faced with an outbreak in either wild boar or domestic pigs, which of three implementation plans to select. The decision tree is summarized in Figure 5. The model was created in Microsoft® Excel® for Office 365, using the Tree Plan Student 181 add-in.

We produced three decision trees, one for each geographic region, to model potential outbreaks that were parametrized by the costs calculated in the cost calculator spreadsheet model. The decision tree is directly linked to the outputs of the cost calculator, so that any changes in the latter, including duration of the outbreak, are directly reflected in the decision tree. The decision tree is programmed to allow selection of the outbreak size, from a choice of small, medium or large. The decisions the model investigates are (1) whether to instigate control measures in the face of an outbreak, or to do nothing, (2) which control implementation plan, out of a choice of three, to instigate when faced with an outbreak. In this case, 'doing nothing' is defined as not instigating the control measures pertaining to the category 'Prevention of domestic pig-wild boar contact'. In our modelling framework, this would mean that in case of an ASF outbreak in either domestic pigs or wild boar, the veterinary authorities would not prohibit outdoor access nor enforce construction of wild boar-proof fencing on affected pig farms. In this deterministic decision tree model, the probability of

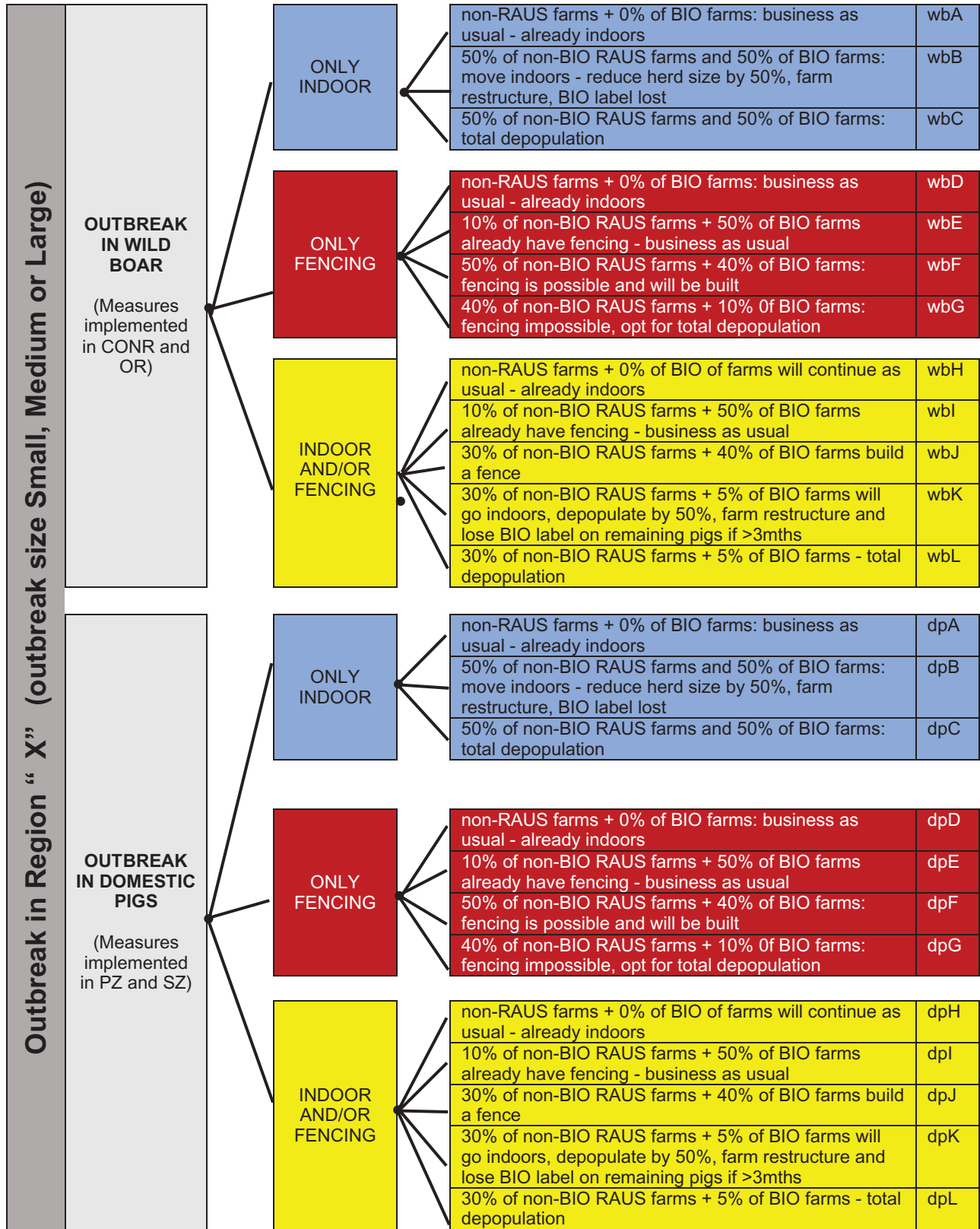


FIGURE 3 Impacts Map; CONR: Control region, OR: Observation region, PZ: Protection zone, SZ: Surveillance zone, BIO: Organic farms, RAUS: farms that are part of the RAUS subsidy scheme, which requires a minimum amount of outdoor-access for animals, WB: wild boar, DP: domestic pigs

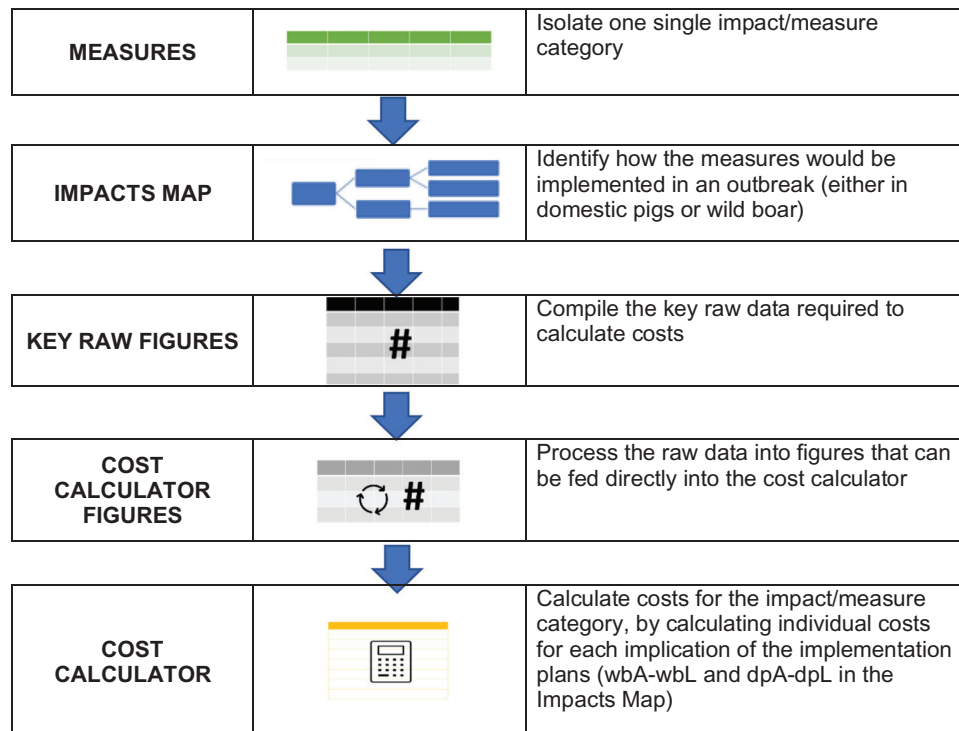


FIGURE 4 Cost calculator workflow

an outbreak occurring in wild boar was assumed to be 75%, compared to 25% for a domestic pig outbreak. These assumptions were deduced from an internal risk assessment of ASF introduction into Switzerland (Friker & Schüpbach, 2021).

3 | RESULTS

3.1 | Measure/impact category ranking

The results of the measure/impact category ranking are summarized in Table 2. This ranking allowed us to recognize which measures critically required analysis. Some measure/impact categories did not affect stakeholders particularly frequently, but they were deemed very significant because there remained uncertainty in how they would be implemented, and major investment and planning would be required to implement them. This was the case for 'Prevention of domestic pig-wild boar contact' and 'Slaughter logistics'. This framework also allowed us to estimate which stakeholders were most frequently and heavily affected by the measures and impacts, which allowed us to prioritize the focus of our models on certain stakeholders.

Preventing contact between domestic pigs and wild boar could be achieved by different possible implementation plans, including enforcing indoor housing for pigs, fence building, or allowing farmers to choose between both these options. The national disease control regulations allow for both options, but the official veterinary bodies had not yet made a final decision on which would be enforced, leading to industry uncertainty on which option to prepare for. Slaughter logistics in the

face of an outbreak also remained uncertain. There was ambiguity as to whether pigs from the affected areas would be accepted by slaughterhouses, because in previous cases of disease outbreaks or animal welfare cases, there have been challenges in finding slaughterhouses willing to slaughter fit-for-slaughter animals from affected farms. This was due to concerns from slaughterhouses over consumer perception and marketability of the meat (F. Loup, personal communication, 23 July 2021). Furthermore, there was ambiguity surrounding the implementation of logistics for separate slaughter of pigs from affected areas. The disease control regulations allow pigs from the affected areas to be slaughtered, but consumer acceptance will likely drive whether slaughterhouses decide to accept these pigs or not. There is no definitive agreement between the Swiss authorities and slaughterhouses on this at present, although the issue is currently being discussed. If slaughterhouses were to refuse pigs from affected areas, there is currently no contingency plan for how these pigs would be slaughtered (or culled) to prevent welfare issues. The other categories deemed important, as they affected stakeholders at a high frequency, were 'Transport logistics' and 'Consumer demand'.

3.2 | Economic models

3.2.1 | Costs of prevention of domestic pig-wild boar contact for finishing pig farms

The cost calculator yielded an individual cost for each implication of a given control policy. Our model focussed specifically on the

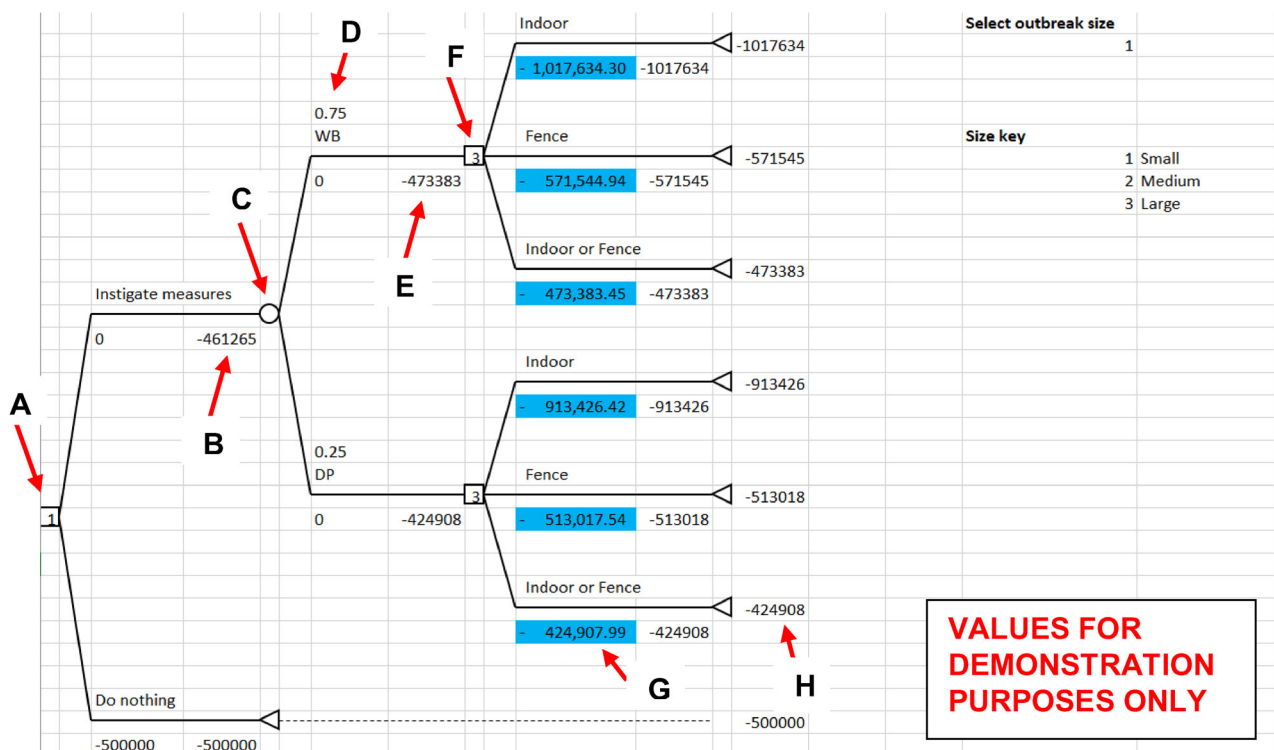


FIGURE 5 Example decision tree model. (NB the values present here are for demonstration purposes only). A: Decision node—the number 1 signifies that the model recommends the first branch, ‘Instigate measures’, as the most economically favourable decision; B: average cost (or ‘Expected Value’) if ‘Instigate measures’ is selected, taking into account probabilities of outbreak scenarios; C: event node—represents a chance event, e.g., the outbreak can occur either in wild boar (WB) or domestic pigs (DP); D: probability of an outbreak occurring in wild boar; E: cost associated with most economically favourable implementation plan in case of a wild boar outbreak; F: decision node—the number 3 signifies that the model recommends the third branch as the most economically favourable decision (‘Indoor or fence’: allowing farmers to select either to bring all their pigs indoors, or to install wild boar-secure fencing); G: cost associated with instigating the control measure ‘Indoor or fence’ in a domestic pig outbreak; H: cost associated with instigating the control measure ‘Indoor or fence’, plus other costs associated with instigating other controls and a domestic pig outbreak (which would occur regardless of the choice of implementation plan)—in this case, these ‘extra costs’ were not calculated or integrated into the model

indirect costs for fattening pig farms, as it became apparent it would not be feasible to calculate the costs for more stakeholders in the available timeframe. Although we did not carry out a sensitivity analysis for this model, it was apparent that the greatest costs were associated with depopulation, either partial or complete, under the conditions explained earlier. The main cost of depopulation lies in lost revenues with continued fixed costs. This explains why the costs were highest in the studied region with the highest density of fattening pig farms, namely Canton Luzern. These results are summarized in Figure 6. Our model assumes that measures to prevent contact between wild boar and domestic pigs would be instigated in the same way, in defined disease control zones around index cases, regardless of whether the outbreak occurred in domestic pigs or wild boar. However, under current contingency plans, it is more likely that an outbreak in domestic pigs would be rapidly identified and stamped out, before any supplementary biosecurity fencing could even be envisaged. Therefore, the implementation plans considered here are more relevant in the context of a wild boar outbreak, and not domestic pig outbreaks (Dominique Suter, personal communication, 17 February 2022).

3.2.2 | Selecting the most economical measure for prevention of domestic pig–wild boar contact in an outbreak

We designed a decision tree model to allow us to provide recommendations on the implementation of controls to prevent contact between domestic pigs and wild boar (Figure 5). For the first decision (i.e., whether to ‘do nothing’ or instigate control measures), a quantitative calculation of the cost of ‘do nothing’ was not included in this study; however, the model allows us to estimate threshold costs associated with ‘do nothing’ above which it becomes more financially favourable to instigate control measures, rather than ‘do nothing’.

The stakeholder interviews, in particular interviews with the official veterinary authorities further qualify these figures. It was noted that the consequences of not instigating any measures at all to prevent contact between domestic pigs and wild boar will likely be associated with significant costs, both direct and indirect. In a wild boar outbreak, this would increase the risk of introduction of ASF into domestic pigs, drastically increasing the costs associated with the outbreak. In a domestic

TABLE 2 Measure categories ranked in order of how frequently stakeholders are affected by them. Four categories are highlighted (transport logistics, consumer demand, prevention of domestic pig-wild boar contact, and slaughter logistics) as they were considered to be most important from a policy point of view when the stakeholder effect ranking and qualitative information from stakeholder interviews are considered together

Measure category	Description	Frequency of stakeholder effect
Transport logistics	Includes all the measures which directly affect the circulation of vehicles to and between farms located within and outside disease control areas during an outbreak. Also includes increased vehicle cleaning and disinfection requirements between farms.	53
Consumer demand	Includes all impacts of an outbreak (including those resulting from public perception of the outbreak, or control measures) on consumer demand for pork.	30
Pig Movement	Includes measures that limit movements of live pigs.	27
Hunting	Includes controls and bans on hunting in case of a wild boar outbreak.	21
Pork product trade	Includes measures and impacts of an outbreak on the trade of pork products, both nationally and internationally.	21
Crops	Includes control measures and their impacts on the harvest and use of arable crops, specifically animal feed crops.	16
Forest access	Includes controls and bans on forest access in areas affected by a wild boar outbreak.	16
Slaughter price	Includes all impacts of an outbreak and control measures on pig slaughter price.	16
Prevention of domestic pig - wild boar contact	Includes all measures aimed at preventing contact between wild boar and domestic pigs in an outbreak.	13
Reproduction	Includes all controls and impacts on pig reproduction, including artificial insemination.	13
Slaughter logistics	Includes control measures and industry behaviours that will directly affect how pigs will be slaughtered.	13
Pig Price	Includes the effect of an outbreak and control measures on prices of live pigs.	10
Wildlife	Includes impacts of an outbreak and control measures that will directly affect wildlife.	6
Image loss	Includes impacts and control measures that will have a negative effect on the public and professional image of a stakeholder.	2

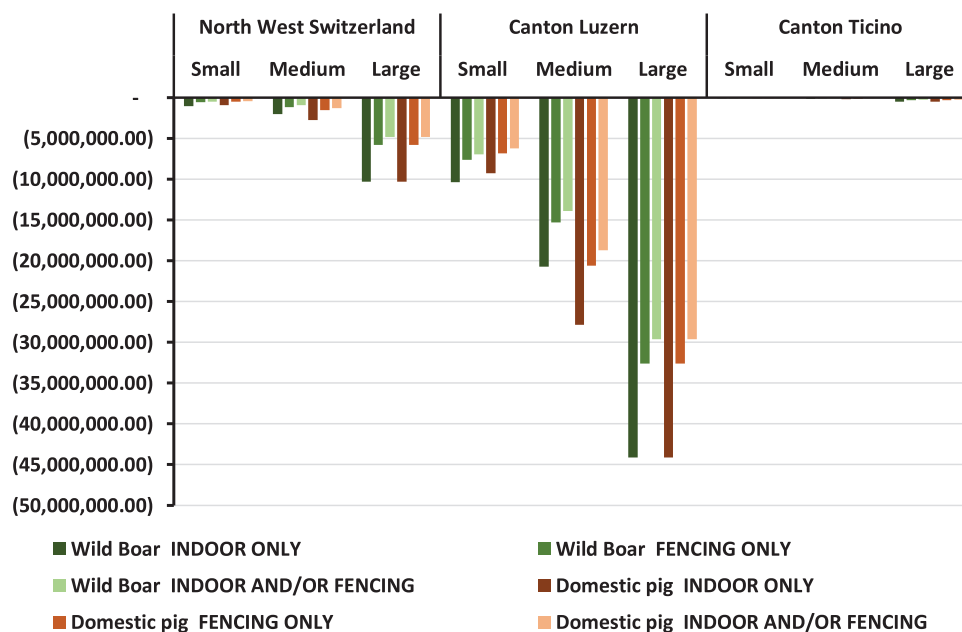


FIGURE 6 Estimated costs for fattening pig farms from the cost calculator model, associated with implementation of 'Prevention of domestic pig-wild boar contact' in an ASF outbreak lasting 12 months, in three studied regions. Costs in CHF. Detailed figures are not provided, as the scope of the publication is to present a novel methodology, rather than economic estimates. Since these results are based on assumptions (Appendix I), and no sensitivity analysis was carried out on the cost calculator model, these figures should not be taken as accurate costs of implementation, but rather as a useful demonstration of the differences between different regions and implementation plans

	Duration of the control measures (months)											
	1	2	3	4	5	6	7	8	9	10	11	12
North West Switzerland	Blue	Blue	Blue	Blue	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Canton Luzern	Blue	Blue	Blue	Red	Red	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow
Canton Ticino	Blue	Blue	Blue	Blue	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Key: The most economically favourable implementation plan selected by the decision tree is coloured according to this scheme												
'OUTDOOR ACCESS BANNED'												Blue
'APPROPRIATE FENCING TO PREVENT CONTACT WITH WILD BOAR'												Red
'EITHER INDOOR ONLY OR FENCING ALLOWED'												Yellow

FIGURE 7 Most economically favourable implementation plan according to the decision tree model, depending on duration of the control measures

pig outbreak, not instigating these measures would increase the risk of introduction of ASF into wild boar populations, which will increase the probability of disease spread, make disease elimination more complicated and costly and would likely increase the duration (and therefore the costs) of an outbreak. Furthermore, significant public and media scrutiny and pressure should be expected if no measures are instigated.

With regards to the second decision in the tree, the decision tree model reports the option INDOOR AND/OR FENCING' to be the most economically favourable, when the control measures last 12 months (i.e., allowing farmers to choose between building a wild boar-secure fence or to bring all their stock indoors). This is because the largest costs are due to losing revenues over the longer term (i.e., in subsequent pork cycles following the cycle first affected by the outbreak) from reduced herd sizes or total depopulation. These costs increase with increasing outbreak duration, or the longer these farms operate with reduced herd size or totally depopulated.

This 'best decision' recommendation by the decision tree model therefore changes depending on the duration of the control measures. The model suggests that for all regions, for outbreaks lasting from 7.5 months to a year, the most economically favourable strategy to reduce contact between wild boar and domestic pigs in control areas is to allow farmers to choose between indoor-only farming and biosecure fencing. In outbreaks lasting less than 7.5 months, the most favourable decision depends on the region and duration of the outbreak; for North West Switzerland and Ticino, from 3.5 months to a year, the most economically favourable strategy remains allowing farmers to choose between indoor-only farming and biosecure fencing. For Luzern, it is more favourable to enforce fence-building for outbreaks between 3.5 and 7.5 months duration (Figure 7). The difference between regions is likely the result of higher median farm size and higher farm density and fewer farms with outdoor access in Canton Luzern compared to the other regions. For outbreaks lasting up to 3.5 months in all regions, it is most economically favourable to ban outdoor access on affected pig farms. In all cases, the most economically favourable decision is the same regardless of the size of the outbreak, and whether the outbreak is in wild boar or domestic pigs. Of course, this aspect is not useful when selecting a control measure at the start of an outbreak, as it may be

difficult to predict the duration of the outbreak with certainty. Indeed, the duration of the outbreak would depend on the effectiveness of the control measures. Therefore, the evaluation of the decision tree with regard to duration of the outbreak is more useful for identifying differences between regions and the effects of individual factors, for example, farm depopulation, on the cost of a given control measure.

4 | DISCUSSION

Animal disease outbreaks in countries of varied socioeconomic settings have proven to have effects spanning beyond the agricultural sector, for example on tourism, transportation and other sectors (Allan et al., 2003; Rich & Wanyoike, 2010). The indirect costs of disease often exceed the direct costs (Barratt et al., 2019; Fofana et al., 2016), but despite their importance, few studies evaluate the full economic impact of outbreaks on a variety of sectors, in a broader socio-economic context (Knight-Jones & Rushton, 2013; Rich & Niemi, 2017). The literature has identified a need for frameworks which accentuate and harmonize the impacts of animal disease into general categories, whilst remaining applicable to a variety of socio-economic settings (Rich & Niemi, 2017).

The framework we developed attempts to respond to this need. A major challenge for estimating the indirect impacts of disease is the translation of qualitative information, for example from interviews with stakeholders and experts, into quantifiable terms. We developed our methodology in a stepwise process tackling the difficulties and questions of the subject as they arose. The first set of questions we were faced with were: Which stakeholders would be impacted by an ASF outbreak, what are the indirect costs incurred, especially those resulting from disease control activities, and how significant are these costs? We answered these questions through the stakeholder interviews and data collection, capture and processing steps. The second set of questions were: How can a category of control measures be implemented and how do we quantify the cost of different implementation plans? We developed the cost calculator model to respond to this. Finally, the last question was: When faced with different

possible outbreak scenarios, how can we identify the most economically favourable implementation plan? We developed the decision tree model in response to this. In summary, the results obtained were: (1) a ranking of control/impact categories in order of importance to policy-making, (2) a quantitative calculation of the indirect costs of one specific category of controls, for one specific stakeholder, with a breakdown of the individual contributing costs and (3) a decision tree model indicating the threshold costs of not instigating a policy and the best implementation plan to select.

Our method shares significant overlap with previous well-documented disciplines, including value chain analysis (VCA), regulatory impact assessment, economic and epidemiological modelling and disease impact assessment, whilst remaining distinct from these.

A value chain represents the full range of activities required to bring a product from conception, through different phases of production to delivery to the final customer and final disposal after use (Kaplinsky, 2000). A VCA therefore focuses on the links and relationships between the actors of the chain (Rich & Wanyoike, 2010), and can include both qualitative and quantitative tools (Hellin & Meijer, 2006). The use of VCA to estimate animal disease impacts is exemplified in a 2010 study on Rift Valley Fever (RVF) in Kenya, by Rich and Wanyoike. Similar to our study, they used interviews of key value chain stakeholders to gather qualitative data on the effects of the ongoing RVF outbreak on stakeholders of the cattle, sheep and goat value chain. They supplemented this primary data with secondary data on the industry and economy. They also gleaned some industry figures, like we did, from stakeholder interviews. In contrast to our study, they looked at an ongoing outbreak and therefore had an existing outbreak scenario, whilst we needed to consider a variety of hypothetical outbreak scenarios. Furthermore, instead of ranking the impacts and control measures in order of importance like we did, this VCA looked qualitatively at the impacts on each interviewed stakeholder, whilst also reporting quantitative losses estimated from the interviews. Finally, a VCA generally looks only at the value chain, and not at indirect impacts on sectors outside of this, although Rich and Wanyoike also touched on impacts on the hotel and tourism sectors.

Our study also shared many similarities with regulatory impact assessments (RIAs), whilst maintaining some differences. Most Organisation for Economic Co-operation and Development (OECD) countries have invested in RIA policy (Davidson et al., 2021). The RIA process is highly flexible, and there tends to be no set methodology (Davidson et al., 2021). The Swiss RIA process requires a Quick Check at the start of the process, carried out by the responsible authority (for animal health regulations, the FSVO) (*Federal Council Directives on regulatory impact analysis for legislative proposals applicable to legislative projects of the confederation, 2019*[RIA Directives]). The Quick Check requires policy makers to consider 5 points which form the basis of the RIA framework, namely (1) the need and possibility for state intervention, (2) possible options (for a new policy), (3) consequences for different groups in society, (4) consequences for the economy as a whole, and (5) practical aspects of implementation. Following scrutiny of the Quick Check by the Swiss Secretariat for Economic Affairs (SECO), the responsible authority may be advised to commission a full RIA (this may be out-

sourced to another organization). Our study reflects some similarities with RIA, especially points 2, 3 and 5 of the Quick Check, as it provides a qualitative overview of the wide-ranging impacts of disease control regulations. However, the RIA by definition focusses solely on (new) regulations, whilst we also looked at other impacts of disease such as changes in consumer demand, at least qualitatively. In contrast to RIA, we did not propose to assess a new regulation, but rather evaluate the impacts of an outbreak under the existing regulations whilst providing different possibilities for its implementation. However, our methods could feasibly be adapted to be used as part of a RIA.

Epidemiological and economic modelling have also been employed to assess the impacts of animal disease. Halasa et al. (2016) used a stochastic and dynamic spatial spread model to simulate the spread of ASF in the Danish swine population. Following simulation of disease spread within and between herds, disease detection, and control strategies, they estimated the direct costs and export costs associated with various simulated ASF outbreaks. In contrast, our method did not involve any epidemiological modelling, and was based on hypothetical outbreak scenarios. However, coupling our methods with epidemiological model of ASF spread in the Swiss context would add to its forecasting power and render it more focussed.

Disease impact-assessment studies often aim to quantify the economy-wide impacts of an outbreak (or endemic disease). Various methods may be used for this. Knight-Jones and Rushton (2013) used literature review to assess the impacts of FMD. Rich and Wanyoike (2010) used a social accounting matrix (SAM) to model economy-wide interactions between sectors and assess the macro-level impacts of RVF in Kenya. Conversely, our study provides a qualitative assessment of the indirect impacts of an outbreak on a broad range of sectors, whilst providing the opportunity for in-depth, quantitative modelling of the impacts on an individual stakeholder level.

Our method represents a novel approach to estimating indirect impacts of animal disease. It provides a solution for dissecting disease control regulations and combining qualitative and quantitative data to describe their impacts on specific sectors, in specific geographical locations. Ranking the measure/impact categories allowed us to weight them in order of importance, based on how frequently they affected stakeholders. However, this ranking alone does not provide an accurate estimate of which categories are associated with the highest costs, as it is possible for one category to be associated with very high indirect costs overall, but only affect one or a few stakeholders, whilst other categories may affect many stakeholders, but only result in a comparably small cost. Whilst differentiating between these kinds of categories was beyond the scope of this study, our method allows us to quickly add to the weighted ranking, by considering qualitative information from the national stakeholder interviews. Namely, the interviews revealed that the precise implementation of certain measure/impact categories remained uncertain, and these categories were likely to be very important in terms of cost and impact, therefore requiring attention from policy makers (for example, slaughter logistics). This 'qualitatively augmented' ranking can be used as an independent tool, without proceeding to calculating costs, to identify areas requiring urgent awareness and preparation by policy makers.

Given the goal of the study was to inform disease control decision-making, we wanted to develop a tool which would aid this process in a clear, accessible format. We opted to use a decision tree model for this purpose, as it allowed us to incorporate not only the calculated costs of different implementation options, but also considers the probability of specific occurrences—in this case, whether the outbreak occurred in domestic pigs or wild boar. By linking the decision tree model to the cost calculator, any changes in the latter, for example changing the duration outbreak, were automatically reflected in the decision tree. Although not carried out here, this model could be coupled with a benefit cost analysis, with the cost of 'do nothing' in the face of an outbreak, being compared to the costs associated with the possible control policies. As it stands, however, the model provides an estimate of the threshold cost of 'do nothing' above which it becomes economically favourable to instigate controls. The end result is a model that can be used in an interactive way to rapidly advise on which course of action to take for a specific set of policy options.

Some limitations of our method include the lack of a systematic interview process, that is, the interviews were not based on a predefined set of questions to be answered by all stakeholders, but were rather more catered towards the individual stakeholder. This may prevent adequate comparison of results between different interviews and affect the assessment of the importance of various impacts. A more systematic and predefined interview process should be considered in further studies. Furthermore, our methods, particularly the cost calculator model is too complex to be feasibly used to provide a single estimate of the society-wide indirect costs. In addition, we have not performed a quantitative comparison to past outbreaks of ASF in similar socio-economic settings; therefore, the accuracy of our results has not been tested. Furthermore, no sensitivity analysis was performed on our models to test the effect of our assumptions on the results of the cost calculator.

Our approach allows us to identify affected sectors that may not be immediately obvious, by using the experience of other countries as well as building on the knowledge and expertise of various sector representatives, and provides a broad, qualitative view of the range of affected sectors, as well as the likely impact of different control strategies on the overall cost. Our method is well suited to provide guidance and forecasting in areas still unaffected by a disease, with limited experience of animal disease outbreaks, such as Switzerland. It also allows policy makers to identify gaps in the detail of current contingency plans, by 'testing' the disease control regulations against hypothetical outbreak scenarios. In addition, the decision tree model has the potential to guide policy makers in filling these gaps by providing guidance on which implementation plan should be selected.

Our approach is also well suited to data-poor settings, as it does not rely on a vast availability of industry and government data to yield useful results. The qualitative data from stakeholder interviews can be quantified in a meaningful way, without the requirement to continue to the more detailed cost-calculation phase. Low-resource settings can also benefit from this method, as it is relatively low in cost, requiring a small number of personnel and equipment. In addition, through field interviews and communication with the industry, this method has the

potential to expose the true situation on the ground and aspects of animal disease outbreaks which could otherwise be overlooked, such as the social and psychological impacts on affected communities. Furthermore, the method could be useful in studies on zoonotic diseases. Although not strictly systematic, the interviews allowed us to gain an important insight into industry and policy viewpoints, a crucial aspect in facilitating appropriate decision-making.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in *Agarbericht* at <https://www.agrarbericht.ch/de>

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SUPPORTING INFORMATION

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APPENDIX I: COST CALCULATOR ASSUMPTIONS

Solution label (see Impacts Map)	wbA dpA	wbB dpB	wbC dpC		
Solution	Business as usual—Farms that are already completely indoors.	Farms that will move indoors.	Farms that will depopulate totally		
Percentage of non-BIO farms	= % of all Swiss pig farms that are 'non-RAUS'	= 50% of all RAUS farms that are not BIO	=50% of all RAUS farms that are not BIO		
Assumption and reasoning	These farms do not have a verifiable outdoor access requirement; assumption that they are indoor farms.	A 50:50 ratio is assumed for farms that opt to move indoors to farms that opt for total depopulation			
Percentage of BIO farms	= 0% of BIO farms	= 50% of BIO farms	=50% of BIO farms		
Assumption and reasoning	BIO farms, by definition, require outdoor access.	A 50:50 ratio is assumed for farms that opt to move indoors to farms that opt for total depopulation			
Solution label (see Impacts Map)	wbD dpD	wbE dpE	wbF dpF	wbG dpG	
Solution	Business as usual—farms that are already completely indoors.	Business as usual—farms that already have appropriate fencing	Farms that will build fence	Farms that will depopulate totally	
Percentage of non-BIO farms	= % of all Swiss pig farms that are 'non-RAUS'	= 10% of all RAUS farms that are not BIO	= 50% of all RAUS farms that are not BIO	=40% of all RAUS farms that are not BIO	
Assumption and reasoning	These farms do not have a verifiable outdoor access requirement; assumption that they are indoor farms.	According to stakeholder interviews, 'only a small number of Swiss pig farms already have double fencing' – assumption that this represents roughly 10% of farms with outdoor access.	Assumption	Assumption	
Percentage of BIO farms	= 0% of BIO farms	= 50% of BIO farms	= 40% of BIO farms	=10% of BIO farms	
Assumption and reasoning	Bio, by definition, requires outdoor access	According to stakeholder interviews 50% of BIO farms have a modern set-up where 'outdoor' area has a roof and a good safety record for preventing contact with wild boar.	According to stakeholder interviews, most BIO farmers will opt for fencing		
Solution label (see Impacts Map)	wbH dpH	wbI dpI	wbJ dpJ	wbK dpK	wbL dpL
Solution	Business as usual—farms that are already completely indoors.	Business as usual—farms that already have appropriate fencing	Farms that will build fence	Farms that will move indoors	Farms that will depopulate totally
Percentage of non-BIO farms	= % of all Swiss pig farms that are 'non-RAUS'	= 10% of all RAUS farms that are not BIO	= 30% of all RAUS farms that are not BIO	= 30% of all RAUS farms that are not BIO	= 30% of all RAUS farms that are not BIO

(Continues)

Solution label (see Impacts Map)	wbH dpH	wbI dpl	wbJ dpJ	wbK dpK	wbL dpL
Assumption and reasoning	Non-RAUS farms do not have (verifiable) outdoor access	According to stakeholder interviews, 'only a small number of Swiss pig farms already have double fencing'—assumption that this represents roughly 10% of farms with outdoor access.	Assumption—roughly equal proportions of farms opt for fencing, going indoors and total depopulation		
Percentage of BIO farms	= 0% of BIO farms	= 50% of BIO farms	= 40% of BIO farms	= 5% of BIO farms	=5% of BIO farms
Assumption and reasoning	Bio, by definition, requires outdoor access	According to stakeholder interviews 50% of BIO farms have a modern set-up where 'outdoor' area has a roof and a good safety record for preventing contact with wild boar.	According to stakeholder interviews, most BIO farmers will opt for fencing rather than going indoors, especially due to welfare impacts of going indoors. Of the farms that don't opt for fencing, a 50:50 ratio is assumed for farms that move indoors to farms that depopulate totally.		

Abbreviations: CONR: Control region, OR: Observation region, PZ: Protection zone, SZ: Surveillance zone, BIO: Organic farms, RAUS: farms that are part of the RAUS subsidy scheme, which requires a minimum amount of outdoor-access for animals, WB: wild boar, DP: domestic pigs.

APPENDIX II: COST CALCULATOR FORMULAS

Impacts Map code	Indoor Only	Formula
	Individual Cost	
wbB dpB	50% of non-BIO RAUS farms move indoors (50% depopulation per farm) (selling pigs light: loss of revenue)	% of farms * % depopulated * no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * % price reduction * farmgate price per pig AQ (90 kg)
wbB dpB	50% of non-BIO RAUS farms move indoors (50% depopulation per farm), Loss of revenue over the remaining production cycles	(pigs cycles per year - 1)*no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * %percentage of farms * % depopulation * farmgate price per pig AQ (90 kg)*duration (years)
wbB dpB	50% of non-BIO RAUS farms move indoors (50% depopulation per farm) (reduced variable cost)	-1 * % of farms * number of farms non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * variable cost per pig * median farm size* % depopulated * duration (years)
wbB dpB	50% of non-BIO RAUS farms move indoors, (farm restructure)	% of farms * %percentage depopulation * Cost of restructuring farm building per median farm*number of RAUS farms in affected area * non-BIO % of RAUS
wbC dpC	50% of non-BIO RAUS farms depopulate totally (selling pigs light: loss of revenue)	% of farms * % depopulated * no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * % price reduction * farmgate price per pig AQ (90 kg)
wbC dpC	50% of non-BIO RAUS farms depopulate totally (Loss of revenue over the remaining production cycles)	(pigs cycles per year - 1)*no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * %percentage of farms * % depopulation * farmgate price per pig AQ (90 kg) * duration (years)

(Continues)

Impacts Map code	Indoor Only	
	Individual Cost	Formula
wbC dpC	50% of non-BIO RAUS farms depopulate totally (reduced variable cost)	$-1 * \% \text{ of farms} * \text{number of farms non-BIO RAUS farms affected} (= \text{no. of RAUS farms affected} * \text{non-BIO RAUS \%}) * \text{variable cost per pig} * \text{median farm size} * \% \text{ depopulated} * \text{duration (years)}$
wbC dpC	50% of non-BIO RAUS farms depopulate totally (opportunity costs for empty stables/fixed costs)	$\% \text{ of farms} * \text{no. of farms in affected area} (= \text{RAUS farms affected} * \% \text{non-BIO}) * \text{median farm size} * \text{fixed costs per pig per year} * \text{duration (years)}$
wbB dpB	50% of Bio pig farms move indoors: lose label (on remaining pigs - not depopulated) if > 3 months	$\% \text{ of farms} * \text{no. of BIO pig farms affected} * \text{avg. no. of BIO pigs per farm in that canton/region} * (1 - \% \text{ depopulated}) * \text{farmgate price difference between BIO and AQ per pig (standard)} * \text{number of pig cycles per year} * \text{duration (years)}$
wbB dpB	50% of Bio pig farms move indoors: 50% depopulation per farm (selling pigs light: loss of revenue)	$\% \text{ of farms} * \% \text{ depopulated} * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{ price reduction} * \text{farmgate price per pig BIO (90 kg)}$
wbB dpB	50% of Bio pig farms move indoors: 50% depopulation per farm (loss of revenue over the remaining production cycles)	$(\text{pigs cycles per year} - 1) * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{percentage of farms} * \% \text{ depopulation} * \text{farmgate price per pig BIO (90 kg)} * \text{duration (years)}$
wbB dpB	50% of Bio pig farms move indoors: 50% depopulation per farm (reduced variable cost)	$-1 * \% \text{ of farms} * \text{number of BIO farms affected} * \text{variable cost per pig} * \text{avg number of pigs per BIO farm} * \% \text{ depopulated} * \text{duration (years)}$
wbB dpB	50% of Bio pig farms move indoors: farm restructure	$\% \text{ of farms} * \% \text{percentage depopulation} * \text{Cost of restructuring farm building per avg BIO farm} * \text{number of BIO farms in affected area}$
wbC dpC	50% of BIO farms depopulate totally (selling pigs light: loss of revenue)	$\% \text{ of farms} * \% \text{ depopulated} * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{ price reduction} * \text{farmgate price per pig BIO (90 kg)}$
wbC dpC	50% of BIO farms depopulate totally (Loss of revenue over the remaining production cycles)	$(\text{pigs cycles per year} - 1) * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{percentage of farms} * \% \text{ depopulation} * \text{farmgate price per pig BIO (90 kg)} * \text{duration (years)}$
wbC dpC	50% of BIO farms depopulate totally (reduced variable cost)	$-1 * \% \text{ of farms} * \text{number of BIO farms affected} * \text{variable cost per pig} * \text{avg number of pigs per BIO farm} * \% \text{ depopulated} * \text{duration (years)}$
wbC dpC	50% of BIO farms depopulate totally (opportunity costs for empty stables/fixed costs)	$\% \text{ of farms} * \text{no. of BIO farms affected} * \text{avg BIO farm size} * \text{fixed costs per pig per year} * \text{duration (years)}$
Impacts Map Code	Fencing Only	
	Individual Cost	Calculation Formula
wbF dpF	50% of non-BIO RAUS farms build fence	$\% \text{ of farms} * \text{no. of non-BIO RAUS farms affected} (= \text{no. of RAUS farms affected} * \text{non-BIO RAUS \%}) * \text{Avg cost of fence per farm per year}$
wbG dpG	40% of non-BIO RAUS farms depopulate totally (selling pigs light: loss of revenue)	$\% \text{ of farms} * \% \text{ depopulated} * \text{no. of non-BIO RAUS farms affected} (= \text{no. of RAUS farms affected} * \text{non-BIO RAUS \%}) * \text{median number of pigs per farm} * \% \text{ price reduction} * \text{farmgate price per pig AQ (90 kg)}$
wbG dpG	40% of non-BIO RAUS farms depopulate totally (loss of revenue over the remaining production cycles)	$(\text{pigs cycles per year} - 1) * \text{no. of non-BIO RAUS farms affected} (= \text{no. of RAUS farms affected} * \text{non-BIO RAUS \%}) * \text{median number of pigs per farm} * \% \text{percentage of farms} * \% \text{ depopulation} * \text{farmgate price per pig AQ (90 kg)} * \text{duration (years)}$
wbG dpG	40% of non-BIO RAUS farms depopulate totally (reduced variable cost)	$-1 * \% \text{ of farms} * \text{number of farms non-BIO RAUS farms affected} (= \text{no. of RAUS farms affected} * \text{non-BIO RAUS \%}) * \text{variable cost per pig per year} * \text{median farm size} * \% \text{ depopulated} * \text{duration (years)}$
wbG dpG	40% of non-BIO RAUS farms depopulate totally (opportunity costs for empty stables/fixed costs)	$\% \text{ of farms} * \text{no. of farms in affected area} (= \text{RAUS farms affected} * \% \text{non-BIO}) * \text{median farm size} * \text{fixed costs per pig per year} * \text{duration (years)}$
wbF dpF	40% of BIO farms build a fence	$\% \text{ of farms} * \text{Avg cost of fence per farm per year} * \text{avg. no of BIO farms in affected area}$
wbG dpG	10% of BIO farms depopulate totally (selling pigs light: loss of revenue)	$\% \text{ of farms} * \% \text{ depopulated} * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{ price reduction} * \text{farmgate price per pig BIO (90 kg)}$

(Continues)

Impacts Map Code	Fencing Only Individual Cost	Calculation Formula
wbG dpG	10% of BIO farms depopulate totally (Loss of revenue over the remaining production cycles)	(pigs cycles per year - 1)*no. of BIO RAUS farms affected * avg number of pigs per BIO farm * %percentage of farms * % depopulation * farmgate price per pig BIO (90 kg) * duration (years)
wbG dpG	10% of BIO farms depopulate totally (reduced variable cost)	-1 * % of farms * number of BIO farms affected* variable cost per pig * avg number of pigs per BIO farm* % depopulated * duration (years)
wbG dpG	10% of BIO farms depopulate totally (opportunity costs for empty stables/fixed costs)	% of farms * no. of BIO farms affected * avg BIO farm size* fixed costs per pig per year * duration (years)
Impacts Map code	Indoor and/or Fencing Individual Cost	Calculation Formula
wbJ dpJ	30% of non-BIO RAUS farms build fence	% of farms * no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) *Avg cost of fence per farm per year
wbK dpK	30% of non-BIO RAUS farms move indoors (50% depopulation per farm) (selling pigs light: loss of revenue)	% of farms * % depopulated * no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * % price reduction * farmgate price per pig AQ (90 kg)
wbK dpK	30% of non-BIO RAUS farms move indoors (50% depopulation per farm) Loss of revenue over the remaining production cycles	(pigs cycles per year - 1)*no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * %percentage of farms * % depopulation * farmgate price per pig AQ (90 kg)*duration (years)
wbK dpK	30% of non-BIO RAUS farms move indoors (50% depopulation per farm) (reduced variable cost)	-1 * % of farms * number of farms non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * variable cost per pig * median farm size* % depopulated * duration (years)
wbK dpK	30% of non-BIO RAUS farms move indoors (farm restructure)	% of farms * %percentage depopulation * Cost of restructuring farm building per median farm*number of RAUS farms in affected area * non-BIO % of RAUS
wbL dpL	30% of non-BIO RAUS farms depopulate totally (selling pigs light: loss of revenue)	% of farms * % depopulated * no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * % price reduction * farmgate price per pig AQ (90 kg)
wbL dpL	30% of non-BIO RAUS farms depopulate totally (Loss of revenue over the remaining production cycles)	(pigs cycles per year - 1)*no. of non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * median number of pigs per farm * %percentage of farms * % depopulation * farmgate price per pig AQ (90 kg) * duration (years)
wbL dpL	30% of non-BIO RAUS farms depopulate totally (reduced variable cost)	-1 * % of farms * number of farms non-BIO RAUS farms affected(= no. of RAUS farms affected*non-BIO RAUS %) * variable cost per pig * median farm size* % depopulated * duration (years)
wbL dpL	30% of non-BIO RAUS farms depopulate totally (opportunity costs for empty stables/fixed costs)	% of farms * no. of farms in affected area (= RAUS farms affected *%non-BIO) * median farm size* fixed costs per pig per year * duration (years)
wbJ dpJ	40% of BIO farms build a fence	% of farms * Avg cost of fence per farm per year * avg. no of BIO farms in affected area
wbK dpK	5% of Bio pig farms move indoors: lose label (on remaining pigs - not depopulated) if > 3mths	%of farms* no. of BIO pig farms affected * avg. no of BIO pigs per farm in that canton/region* (1-%depopulated)*farmgate price difference between BIO and AQ per pig (standard)*number of pig cycles per year * duration (years)
wbK dpK	5% of Bio pig farms move indoors: 50% depopulation per farm (selling pigs light: loss of revenue)	% of farms * % depopulated * no. of BIO farms affected* avg number of pigs per BIO farm * % price reduction * farmgate price per pig BIO (90 kg)
wbK dpK	5% of Bio pig farms move indoors: 50% depopulation per farm (Loss of revenue over the remaining production cycles)	(pigs cycles per year - 1)*no. of BIO farms affected * avg number of pigs per BIO farm * %percentage of farms * % depopulation * farmgate price per pig BIO (90 kg) * duration (years)

(Continues)

Impacts Map code	Indoor and/or Fencing Individual Cost	Calculation Formula
wbK dpK	5% of Bio pig farms move indoors: 50% depopulation per farm (reduced variable cost)	$-1 * \% \text{ of farms} * \text{number of BIO farms affected} * \text{variable cost per pig} * \text{avg number of pigs per BIO farm} * \% \text{ depopulated} * \text{duration (years)}$
wbK dpK	5% of Bio pig farms move indoors: farm restructure	$\% \text{ of farms} * \% \text{percentage depopulation} * \text{Cost of restructuring farm building per avg BIO farm} * \text{number of BIO farms in affected area}$
wbL dpL	5% of BIO farms depopulate totally (selling pigs light: loss of revenue)	$\% \text{ of farms} * \% \text{ depopulated} * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{ price reduction} * \text{farmgate price per pig BIO (90 kg)}$
wbL dpL	5% of BIO farms depopulate totally (Loss of revenue over the remaining production cycles)	$(\text{pigs cycles per year} - 1) * \text{no. of BIO farms affected} * \text{avg number of pigs per BIO farm} * \% \text{percentage of farms} * \% \text{ depopulation} * \text{farmgate price per pig BIO (90 kg)} * \text{duration (years)}$
wbL dpL	5% of BIO farms depopulate totally (reduced variable cost)	$-1 * \% \text{ of farms} * \text{number of BIO farms affected} * \text{variable cost per pig} * \text{avg number of pigs per BIO farm} * \% \text{ depopulated} * \text{duration (years)}$
wbL dpL	5% of BIO farms depopulate totally (opportunity costs for empty stables/fixed costs)	$\% \text{ of farms} * \text{no. of BIO farms affected} * \text{avg BIO farm size} * \text{fixed costs per pig per year} * \text{duration (years)}$

Abbreviations: CONR: Control region, OR: Observation region, PZ: Protection zone, SZ: Surveillance zone, BIO: Organic farms, RAUS: farms that are part of the RAUS subsidy scheme, which requires a minimum amount of outdoor-access for animals, WB: wild boar, DP: domestic pigs.