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The economic impact of different foot-and-mouth disease control strategies in northwest Germany – a pilot study

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ABSTRACT

In case of an outbreak of foot-and-mouth disease (FMD) veterinary authorities have to decide whether a culling or a vaccination strategy shall be applied for controlling disease. In Germany, the last outbreak was in the late 80's and little is known about the economic consequences of different mitigation strategies. For this reason, a static epidemiological and economic model was created using geo-reference data on municipality level. The model needs epidemiological input about infected premises, the size of movement restriction zones and the duration of epidemic events. FMD epidemics for two animal dense regions in northwest Germany, the Jade-Weser region and the County of Grafschaft Bentheim, were simulated and its costs analysed. In collaboration with epidemiologists of the veterinary authorities, three different scenarios were designed for each of the two strategies and regions (a best case, a probable/medium case and a worst case). In the economic model part, the costs were estimated for farmers and for the animal disease fund (the authorities). Thereby, the costs were divided into the categories Direct Costs (DC), Direct Consequential Costs (DCC) and Indirect Consequential Costs (ICC). In addition, the compensation payments to farmers and possible losses of price reductions were pointed out.

The pilot study is not representative but reveals important tendencies. The cost analysis indicates that the animal type is one of the most influential factors on farmers' costs. For the vaccination strategy, DC of an epidemic will be much lower at the expense of consequential costs. A culling strategy leads to high DC but DCC and ICC are probably relatively low depending on the dimension of the epidemic. Additionally, the ICC are dependent on the regional structures of the processing industry. The results suggest that vaccination could be an economical strategy for the Grafschaft Bentheim. There, pig farmers would suffer less from price effects due to vaccination. Furthermore, there are no large export dependent processors in the area. In cattle dense regions like Jade-Weser vaccination could lead to high losses of cattle farmers if value losses for cattle and milk occur. Many dairies in the Jade-Weser region are export dependent and would be stricken by the export restrictions. If high value losses of products from vaccinated animals are likely, vaccination should be avoided. When applying a culling strategy, the animal disease fund has to bear most of the incurred costs. Using a vaccination-to-live strategy shifts the costs from the disease fund to the farmers, which may lead to conflicts.

CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

BRA	County of Wesermarsch
d	day
DC	Direct Costs
DCC	Direct Consequential Costs
DM	Deutsche Mark, German Mark
EC	European Commission
EEC	European Economic Community
EU	European Union
FMD	foot-and-mouth disease
FRI	County of Friesland
GeSeVo	*Gesellschaft für Seuchenvorsorge*, Company for Disease Prevention
GM	gross margin
GSV	*Geflügelseuchenvorsorge*, Poultry Disease Prevention
ha	hectare
ICC	Indirect Consequential Costs
IP	infected premises
NRW	North Rhine-Westphalia
Org.	Organisation
PZ	protection zone
SZ	surveillance zone
TSN	*Tierseuchennachrichten*, Notification and Crisis Management System
TSK	*Tierseuchenkasse,* Animal Disease Fund
UK	United Kingdom
USA	United States of America
WHV	City of Wilhelmshaven
WTM	County of Wittmund

1 INTRODUCTION

The 2001 epidemic in the UK showed plainly that foot-and-mouth disease (FMD) causes tremendous economic damages. Germany faced the last outbreak of FMD more than 25 years ago in 1988 and currently, Europe is free of FMD without vaccination. Nevertheless, the risk of introduction by tourism, groceries, feed or litter materials persists. In summer and autumn 2014, for example, many North African countries were affected by FMD epidemics and further trade controls entered into force (Commission Implementing Decision 2014/689/EC). In this context, there has been much discussion about adequate control strategies against highly contagious diseases like FMD, which occur seldom but cause a high damage (LAVES, 2013). For trade reasons, the EU uses a preventive depopulation strategy against FMD since 1992. When culling susceptible animals is not possible or eligible, depopulation may be combined with an emergency vaccination (AID E.V., 2001; Council Directive 2003/85/EC), whereas a vaccination-to-live strategy is generally seen to grant more aspects of animal welfare (MOURITS AND HUIRNE, 2005).

If FMD breaks out in an EU member state, in this case Germany, county and state veterinarians have to make choices regarding an adequate control strategy. These choices depend on the epidemiological and economic dimensions of an outbreak. In any of such cases, control measures have to be set quickly by the authorities and their decisions may have serious consequences for the degree of damage. Hence, they have to be prepared and need information for decision support. Computer models that are able to simulate disease outbreaks ex ante can serve this purpose. Such studies already exist for many concentrated livestock production areas, e.g. the Netherlands (BACKER ET AL., 2009), the USA (SCHOENBAUM AND DISNEY, 2003; PENDELL ET AL., 2007; WARD ET AL., 2009), Australia (GARNER AND BECKETT, 2005) and Spain (MARTÍNEZ-LÓPEZ ET AL., 2010). For Germany, the information in this regard is rather limited. Only WILLMS (2006) and KRÄMER (2010) calculated costs of an FMD outbreak with the help of geo-reference data but focussed on total cost calculations or compensation schemes only. However, a thorough comparison between depopulation-based and vaccination-based strategies on their economic impacts is still lacking.

For this reason, the aim of this study is to estimate the potential economic impact of different FMD control strategies for counties in northwest Germany. The focus is set on vaccination-to-live and culling scenarios and their Direct (DC), Direct Consequential (DCC), their compensation payments and Indirect Consequential Costs (ICC) for farmers in case of an outbreak. Northwest Germany has the highest livestock density of the country and is thus of special interest. The study is done in cooperation with the German-Dutch Interreg-Project "Economic vaccination", so that additional interest arises for the border area in the northwest. Two regions are analysed in this study: the Region of Jade-Weser, which has a high cattle density, and the County of Grafschaft Bentheim, which has both a high cattle and swine density. The structure differences allow a comparison of the affected farmers.

In relation to the aim, the most important research questions for this study are:

1) What important epidemiological and economic factors determine the economic impact of FMD? – E.g. regional agricultural structures, disease spread, affected animal product quantities, veterinary and carcass disposal organisation;

2) What are possible FMD outbreak scenarios for the two different counties in northwest Germany? – Particularly with regard to the different emergency vaccination and culling strategies, and best-, probable/medium and worst-case scenarios;

3) What is the economic impact for farmers in the FMD scenarios with respect to DC, DCC and compensation payments?

4) What are the ICC of market disruptions in different vaccination and non-vaccination strategies?

Specific farm data is necessary when using FMD-models. Due to secrecy obligations, however, such data is not publicly available in Germany. Alternatively, likely scenarios were created in cooperation with epidemiologists of the county's veterinary authorities. They have experience in forming realistic scenarios for disease exercises and have access to the German notification and crisis management system TSN (*Tierseuchennachrichten*; FLI, 2010). Together with them, *ex ante* disease simulations for the two regions were carried out. The scenarios differ in the number of infected farms, the radius of the movement restriction zones, and the duration.

For the cost analysis an economic model was developed in order to estimate the average DC, DCC and granted compensations for farmers in each control strategy. The model is based on agricultural census data of each municipality. That data are handled in a static epidemiological model first, for which the mentioned epidemiological input is necessary. Without individual farm data, the dynamics of disease cannot be modelled. The epidemiological dimension of an outbreak determines its market disruptions. The geo-reference data can be used additionally to derive the commodity volumes stricken by trade restrictions. Based on these volumes, ICC are estimated.

The paper starts with some general background on the topic. This chapter includes information on control strategies and their corresponding legislation, historical background and past epidemics as well as literature information on disease models and the cist categories. Next, the methodology of the study is described including the description of the census data, the explanation of the model and the created scenarios for the analysis. In the fourth chapter, the results of the cost estimation are presented with respect to the different scenarios and the cost categories. Afterwards, the methods and the results are discussed. Finally, the conclusions are drawn and the research questions are answered to summarise the report.

2 AGRICULTURAL BACKGROUND

FMD is a highly contagious viral disease, which affects all cloven-hoofed animals. In Germany, cattle, swine, sheep and goats are farm animals that are at risk. Important wild animals that can be affected are wild boars and deer. For humans, FMD is not dangerous (BÄTZA AND ROESICKE, 2001). Worldwide, seven serotypes of FMD are known and each has several subtypes (IBID.). The course of disease depends on the serotype and the animal type. The incubation period can be between 2 to 14 days but is usually 2 to 6 days. Typical clinical symptoms in animals are fever, blisters, skin fissures and lameness. In most outbreaks in livestock, disease spreads very fast and morbidity is almost 100%. Mortality is with less than 5% quite low but in offspring, mortality can be at about 50 to 70% (IBID.). The background gives an overview of FMD outbreaks, portrays the control strategies and presents literature review on epidemiological and economic studies.

2.1 Past FMD outbreaks

Until the second half of the 20th century, FMD was endemic in Europe and outbreaks in livestock were common. In the following an overview of the last outbreaks of FMD are presented with a focus on Europe but including important epidemics outside Europe, too.

Table 1 shows an overview about FMD epidemics in Europe and worldwide. Germany faced the last FMD cases in 1988, when four premises were infected. This was most likely caused by escaping FMD vires from a vaccine plant in Lower Saxony (ML NIEDER-SACHEN, 1988). During the 90's there were several minor and medium outbreaks in Greece and Italy (WILLMS, 2006).

Table 1: Outbreaks of FMD in Europe and worldwide
References: ANDERSON, 2008; EC, 2011; OIE, 2011; WILLMS, 2006; YANG ET AL., 1999

Year	Country	Infected premises (IP)
1988	Germany	4
1988; 1989; 1993	Italy	7; 74; 57
1994; 1996; 2000	Greece	95; 39; 14
1997	Taiwan	6,147
2001	UK, Netherlands, France, Ireland	2034; 26; 2; 1
2007	UK	8
2010-2011	Japan	292
2011	Bulgaria	11

In the end of the 90's and beginning of the new millennium, two major outbreaks occurred. In 1997 Taiwan was affected by FMD, which led to an epidemic with 6,147 infected pig farms. Four million pigs were culled or died of disease and financial costs of US$ 378.6 million arose plus additional export losses of US$ 1.6 billion for the Taiwanese pig industry (YANG ET AL., 1999).

In Europe, the 2001 FMD outbreak had huge consequences. In the UK, the disease lasted for 11 months and in total, 2,034 stocks were infected. FMD spread also to conti-

nental Europe and infected 26 premises in the Netherlands and two in France. During the epidemic, 4.077 million animals were culled for disease control and an extra 2.047 million animals were slaughtered for welfare reasons. The outbreak cost the British society more than £ 6 billion, not considering indirect costs of e.g. supplier industries. The government had costs of about £ 3 billion and paid £ 1.2 billion as compensation to farmers (ANDERSON, 2008), but still the sector faced a loss of £ 525 million. For the tourism sector, losses of £ 2.7 to £ 3.2 billion were estimated (THOMPSON ET AL., 2002).

Six years later another minor outbreak occurred in the UK, in which eight farms were infected. The epidemic had two waves and occurred after accidental releasing FMD from a research laboratory. It cost the government about £ 47 million (ANDERSON, 2008). The last FMD outbreak in Europe was 2011 in Bulgaria. Eleven premises were infected by wild boars crossing the border from Turkey to Bulgaria (EC, 2011).

2.2   Disease control in the EU and Germany

Until the end of 1991, the European Community applied a preventive vaccination as the main strategy against FMD. Since 1992, a stamping-out strategy is mandatory. The following sections give a closer description to the different control strategies.

2.2.1   Until 1992: preventive vaccination

From 1967 until the end of 1991, it was mandatory in West Germany to vaccinate all cattle older than four months. Before 1967, protection against FMD was federal state matter and different control strategies were used, which included vaccination and medication of infected animals. Often, farmers waited until the animals recovered and were immunised STROHMAIER AND STRAUB, 1995a). This practise was prohibited in 1966 and a mandatory protective vaccination against three types of FMD was introduced plus culling of infected livestock. In the following years, outbreaks were reduced from 15,933 in 1965, to 4,715 in 1966, 2,860 in 1967 and to 70 cases in 1,968. In 1970, only eight FMD cases were registered (IBID.).

It is not definitely known, which of the two control strategies (stamping-out or preventive vaccination) was most effective in eradicating FMD in Germany. STROHMAIER AND STRAUB (1995b) concluded that stamping out is more effective: between 1970 and 1988, 31 farms were infected and 20 of them occurred after vaccination campaigns and six close to vaccine producers. This argument is supported by a comparison between vaccinating and non-vaccinating countries. From 1967 until 1991, non-vaccinating countries had less outbreaks of FMD than vaccinating countries and even if an outbreak occurred, disease was often spread from a vaccinating country (IBID.). Additionally, there is evidence that a stamping out strategy is cheaper than a preventive vaccination strategy. In 1982, for example, the non-vaccinating Denmark paid DM 7.4 million consequential of FMD. Lower Saxony, in which animals were vaccinated, paid in the same year about DM 9 million for vaccination and outbreak cost. Most important cost factor remained the trade restrictions that non-vaccinating countries implemented (STROHMAIER AND STRAUB, 1995c).

2.2.2   After 1992: stamping out

The experiences of the vaccinating countries led to a change and a unification of control strategies in the European Economic Community (EEC). First, the legal situation is described. Afterwards, the disease control structures and strategies in Germany are explained.

2.2.2.1   Legal framework and OIE guidelines

Today, Germany is bound to the EU legislation in animal disease control. The first directives to abandon vaccination against FMD were established by the EEC in 1985 and

1990 (Council Directives 85/511/EEC and 90/423/EEC). Germany transposed the directive in 1992 with the "First Regulation to Change the FMD-Regulation" (*Erste Verordnung zur Änderung der MKS-Verordnung*). The latest version of the EU-legislation to control FMD is the Council Directive 2003/85/EC from 29th September 2003. Germany adopted the directive in the beginning of 2005 with the "Regulation for the Protection against Foot-and-Mouth Disease (FMD-Regulation)" (*Verordnung zum Schutz gegen die Maul- und Klauenseuche (MKS-Verordnung)*). In Germany, authorities of the federal states are responsible for the implementation of control measures in case of an FMD outbreak, which means that county and state veterinary officers are in charge of control measures.

Besides the FMD-Regulation, the Animal Health Act (*Tiergesundheitsgesetz*) needs to be considered for control measures. It gives general guidelines for the control of animal diseases and categorises FMD as a notifiable animal disease, which immediately has to be reported to the authorities if clinical symptoms are observed by farmers or veterinarians.

Many guidelines for disease control are prepared in cooperation with the World Organisation for Animal Health (OIE). Member countries have to report notifiable diseases to the OIE. The OIE informs other countries about the disease status of a country or area and confers the status "FMD free where vaccination is not practised", which leads to trade advantages due to more export opportunities (OIE, 2014a). The OIE and the EU also regulate the restrictions for export in case of an FMD outbreak. Regarding this, the concept of regionalisation is important: countries are divided into different FMD risk categorisations. First, EU export restrictions are likely to hit the whole country. After a while, those restrictions are only valid for risk regions. As an example, the restrictions of the 2007 UK outbreaks can be presented. In 2007, the last case was confirmed on 30 September. Until 19 November, no exports of animals or dairy were allowed. Then, the regionalisation set in and the country was divided in three zones: FMD Free Export Area, FMD Restricted Export Area (meat allowed but no live animals) and the FMD No Export Area. On 14 December, the FMD Restricted Export Area was lifted and on 31 December, all export restrictions were removed (ANDERSON, 2008). However, when a country applied vaccination, in order to regain the status "FMD free without vaccination", regionalisation persists until no outbreak has occurred in the previous 12 months (OIE, 2014b).

2.2.2.2   Disease control in Germany

The directives, acts and regulations mentioned above are the basis for FMD control in Germany. The FMD-Regulation gives the ultimate guidelines. In case of suspicion of FMD (§ 3, FMD-Regulation), the responsible veterinary authority takes viral samples of the suspicious animals. If these lead to evidence for FMD, the animals have to be culled immediately. In addition, further samples are taken from the suspicious premise and its traces are explored. No agricultural goods are allowed to leave the premise and disinfections at entrances, exits, and of clothes are mandatory. The same applies for dangerous contact premises, e.g. contact farms, abattoirs or dairies (§ 4). If there is a suspicious case, the competent authority determines a control zone around the premise for 72 hours (§ 5). During this stand still, no agricultural goods may be transported.

If viral tests finally confirm the occurrence of FMD, the infected livestock has to be culled within 24 hours. The assets have to be disinfected and agricultural products have to be destroyed or cleaned. The veterinary authority can implement the preventive culling of farms close to the infected premise (IP; e.g. in one kilometre radius). Around the IP, movement restriction zones (MRZ) will be established: a minimum three kilometres protection zone (PZ; red lines in Figure 1) and additionally a ten kilometres radius surveillance zone (SZ; blue line in Figure 1). The rules for the PZ and SZ are settled in § 9 to § 12 of the FMD-Regulation. However, since the regulations are compliant with EU law, the

EU will involve in disease control. Especially in severe diseases like FMD, it is likely that the MRZs orientate at municipality borders as it was e.g. in the classical swine fever epidemic in the Baltic States (Commission Implementing Decision 2014/709/EU).
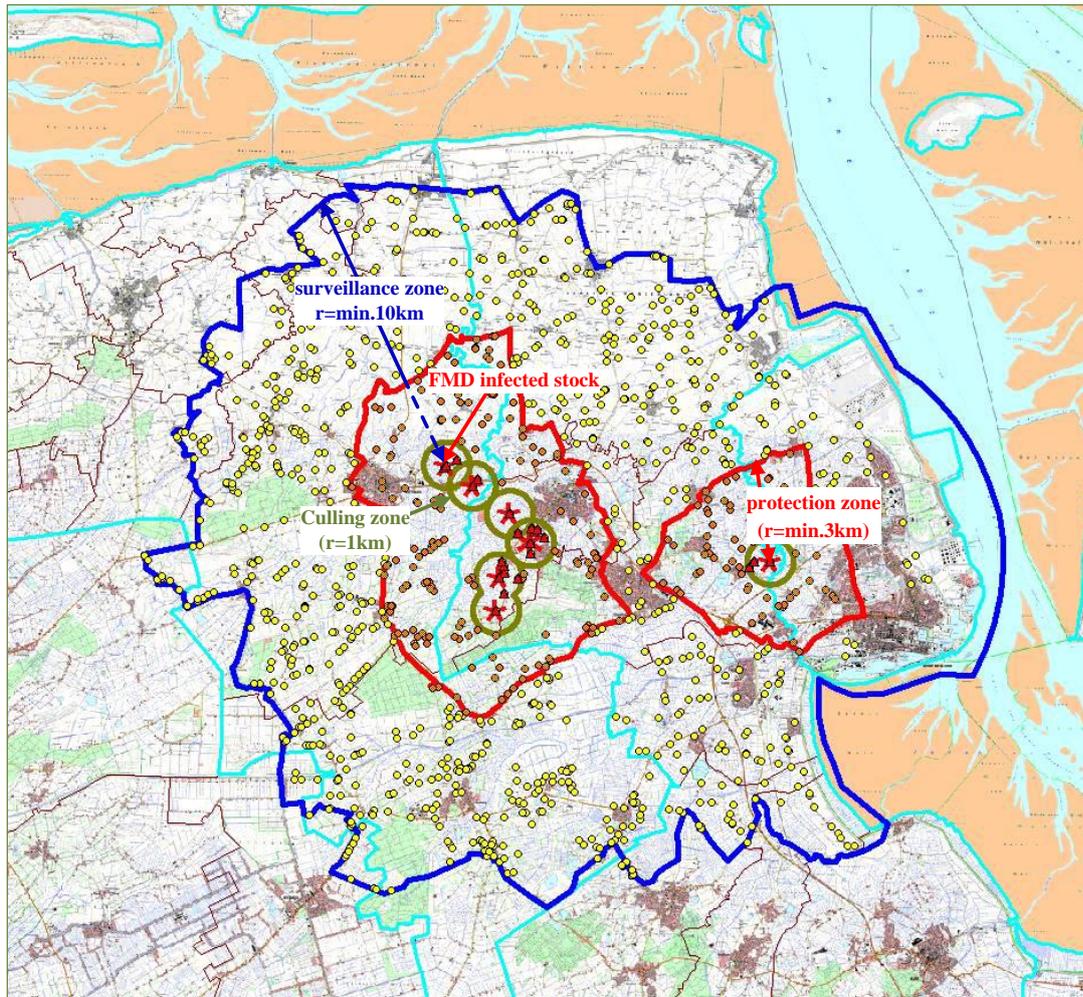
Figure 1: Sample map for the zoning in case of an FMD outbreak
Reference: modified image of VETERINARY OFFICE JADEWESER, 2013

In both zones, government veterinarians conduct investigations on farms and other agricultural premises. For all premises in the two zones, it is forbidden to place meat, milk, and other animal products of endangered species, processed within 21 days before the assumed introduction of the virus, on the market. Also, the transport of raw milk and manure is forbidden. For the PZ, however, the guidelines for protection and prevention of virus spread are more stringent: when endangered species are present, the veterinary authority forbids to transport feed, inseminate artificially and to drive cattle. This can even apply, when only non-endangered species are present, because they might spread the virus in their fur or else. In addition, animal markets and fairs have to be cancelled and persons having been in contact with cloven-hoofed animals in the infected holding are not allowed to take part in events with other people. All vehicles and equipment that was in contact with endangered species or affected premises have to be cleaned and disinfected.

In case of an outbreak, an emergency vaccination for a defined area can be applied if the European Commission (EC) agrees upon the plans. Table 2 shows the criteria that are relevant for the decision on vaccination. The veterinary officers of the VETERINARY OFFICE JADEWESER (2013) conclude in their FMD exercise report that the most striking argument for an emergency vaccination is the problem of the carcass disposal, because when it is not possible to burn or bury the carcasses the capacities of the carcass disposal plains could be

too low. According to § 16 of the FMD-regulation, two kinds of emergency vaccinations are allowed in Germany: the protection vaccination and the suppressive vaccination. The focus of this study is on the first. If the veterinary authority orders a protection vaccination, a specific vaccination zone has to be defined in advance. All vaccinated animals must get a special eartag with the lettering "*I.MKS*". The suppressive vaccination is only allowed on premises that are infected by FMD or in the culling radius. The animals have to be killed afterwards. For this reason, such a vaccination is interesting, when the capacities for carcass disposal are too small, but the country does not want to risk any trade restrictions because of vaccination.

Table 2: Criteria for the decision to apply protective vaccination
Reference: Council Directive 2003/85/EC

Criteria	Decision	
	For vaccination	Against vaccination
Population density of susceptible animals	High	Low
Predominant species clinically affected	Pigs	Ruminants
Movement of potentially infected animals or products out of the PZ	Evidence	No evidence
Predicted airborne spread of virus from infected holdings	High	Low or absent
Suitable vaccine	Available	Not available
Origin of outbreaks (traceability)	Unknown	Known
Incidence slope of outbreaks	Rising rapidly	Shallow or slow rise
Distribution of outbreaks	Widespread	Restricted
Public reaction to total stamping out policy	Strong	Weak
Acceptance of regionalisation after vaccination	Yes	No
Acceptance of regionalisation by third countries	Known	Unknown
Economic assessment of competing control strategies	If it is foreseeable that a control strategy without emergency vaccination would lead to significantly higher economic losses in the agricultural and non-agricultural sectors	If it is foreseeable that a control strategy with emergency vaccination would lead to significantly higher economic losses in the agricultural and non-agricultural sectors
It is foreseeable that the 24/48 hours rule cannot be implemented effectively for two consecutive days (1)	Yes	No
Significant social and psychological impact of total stamping out policy	Yes	No
Existence of large holdings of intensive livestock production in a non-densely populated livestock area	Yes	No

(1) 24/48 hours rule means:

(a) infected herds cannot be stamped out within 24 hours after the confirmation of the disease, and

(b) the pre-emptive killing of animals likely to be infected or contaminated cannot be safely carried out within less than 48 hours.

If emergency vaccination was applied, restrictions regarding trade with animal products and with possible contact goods come into force for a minimum of 30 days (§ 17). Animals have to be slaughtered in defined abattoirs and meat of vaccinated animals has to be isolated from other meat. For milk, similar restrictions apply. Most likely is milk processing to butter and skimmed milk powder, which can be stored quite long (VETERINARY OFFICE JADEWESER, 2013). Following the 30th day after vaccination, the veterinary authorities conduct clinical and serological examinations at all farms in the vaccination zone. If antibodies against non-structure proteins were found (which infected animals have), the authorities have to order the culling of the infected livestock and its destruction. If no antibodies could be found, the EC may determine freedom of FMD. Until this happens, the market and transport restrictions mentioned above remain (§ 21).

2.2.3   Culling and carcass disposal

In Lower Saxony, the culling process in case of animal diseases is put into execution by two corporations for disease prevention: the GeSeVo GmbH (*Gesellschaft für Seuchenvorsorge*, Company for Disease Prevention) and the Emsländische GSV GmbH (*Geflügelseuchenvorsorge,* Poultry Disease Prevention). The GSV is competent for culling infected animals in the Counties of Emsland and Grafschaft Bentheim, whereas the GeSeVo is competent for the other counties of Lower Saxony. The GeSeVo is officially only organising the culling of fowl and pigs but according to VETERINARY OFFICE JADEWESER (2013), they will take over the culling of infected cattle.

The corporations for disease prevention are financed by the animal disease funds and by the regional authorities as well as commercial operators being active in animal and meat business (GESEVO, 2014).

2.2.4   Compensation and animal disease fund (*Tierseuchenkasse*, TSK)

Compensations in case of a notifiable disease are regulated in part 6 of the Animal Health Act. Compensation payments are defined and organised by each federal state in animal disease funds (TSK). Typically, the compensation orientates at the value of the animals, which is dependent on current market prices. For special breeding animals, there are upper limits per animal species. Additionally, according to the Implementing Law of the Animal Health Act (*Ausführungsgesetz zum Tiergesundheitsgesetz*), the TSK pays the costs of carcass disposal, the culling of the animals, disinfection and other organisations.

The TSK in Lower Saxony is financed by contributions of the federal state and by yearly contributions of the animal keepers. In 2014, for example, for each cattle € 8 had to be spent (€ 15.6 respectively if they are infected by bovine herpes virus), € 0.7 had to be paid for each pig, € 1.2 for sheep and goats (NDS TSK, 2014a).

2.3   Studies on disease simulation with economic aspects

Many studies on FMD have been published in the present and past and FMD epidemics were simulated for many countries. International studies are presented first and afterwards, specific studies for Germany are described.

2.3.1   International FMD simulation studies

2.3.1.1   Europe

One of the first simulation studies was done by BERENTSEN ET AL. in 1992. They used a dynamic modelling approach, which integrates an epidemiological model, a disease control model and an export model. The model was used to compare the cost of preventive vaccination and stamping out strategies in the Netherlands and concluded that a stamping

out strategy would lead to lower costs. Another study for the Netherlands was done by BACKER ET AL. in 2009 analysing the current control strategies (stamping out and emergency vaccination). For low animal density areas, they concluded that the minimum strategy with culling only infected livestock is more cost effective. For high animal density areas, it is often cheaper to use a vaccination. In addition, GE ET AL. (2010) created a modelling approach for dynamic decision-making, in which they emphasised the value of flexibility in control options depending on the development of disease.

MORRIS ET AL. (2001) developed a spatial model of alternative control strategies for the 2001 FMD epidemic in the UK. They advised that the stamping out policy is best suited to eradicate the disease quickly and cost-efficient and to restore normal trade conditions. Emergency vaccination would lengthen the epidemic.

MARÍNEZ-LÓPEZ ET AL. (2010) developed a spatial stochastic model for InterSpread Plus that simulated outbreaks for six alternative control strategies for the Castile and Leon region in Spain. Compared to the minimum required mitigation measures, both protection vaccination and depopulation strategies are estimated to reduce the spread of FMD. However, vaccination will lengthen the time to regain the FMD-free status and for this reason, culling neighbour premises is more (cost)-effective.

2.3.1.2   USA

Several simulations were carried out for the USA, where the last FMD outbreak was in 1929 in California (PENDELL ET AL., 2007). In view of lacking disease data, modelling is important. SCHOENBAUM AND DISNEY (2003) used a stochastic simulation model (Monte Carlo) and analysed different mitigation strategies for three regions in the USA. It is concluded that ring-culling is more costly than pre-emptive culling of dangerous contact herds only. Vaccination is estimated to shorten the duration of outbreaks but to increase costs compared to culling. In fast spreading scenarios however, suppressive ring-vaccination (delayed culling) is estimated to be less costly. PENDELL ET AL. (2007) did a study on economic impacts of a FMD outbreak in southwest Kansas, a dense cattle area. However, they only calculated the potential economic damage and not the impact of different mitigation strategies. Another study simulated FMD spread in integrated livestock systems in Texas (WARD ET AL., 2009). An early detection in the index herd is most important regarding the epidemic dimension. This is likely to be true for every other region, too. Suppressive vaccination would not have advantages in disease control.

2.3.1.3   Asia and Oceania

YOON ET AL. (2006) modelled FMD for South Korea with help of InterSpread Plus. The simulation was based on a 2002 FMD epidemic in South Korea and the aim was to compare alternative control strategies to the reference strategy of stamping out pre-emptively. According to the authors, besides early detection, ring-vaccination combined with pre-emptive culling could be an adequate strategy to reduce the size of an epidemic.

For Australia, GARNER AND BECKETT (2005) described the stochastic spatial state-transition model AusSpread in their article and used FMD outbreaks in Queensland as an example epidemic.

2.3.1.4   General model analyses

DUBÉ ET AL. (2007) compared three FMD simulation models, namely AusSpread, InterSpread Plus and NAADSM. The models were used to simulate the same scenario in Australia (with AusSpread), New Zealand (InterSpread Plus), and North America (NAADSM). Despite significantly different results, those differences do not lead to another control strategy.

A general guide to build a model to simulate FMD was given by THORNLEY AND FRANCE in 2009. In their article, the single steps to construct a within-herd and a between-herd model are described and used for an example epidemic (UK 2001). They conclude that the "within-farm infectivity […] is, in one sense, not an important parameter for FMD epidemiology" (THORNLEY AND FRANCE, 2009, p. 153), because already one infected animal leads immediately to a depopulation of the whole farm.

2.3.2   German FMD simulation studies

In recent years – besides the epidemic exercises on FMD – two dissertations were done about simulated FMD outbreaks. WILLMS (2006) analysed the costs of an FMD outbreak for the County of Osnabrück. For this purpose, a farmer was asked for assistance and served as an index farm. He wrote down all visits to his farm and all contacts with other farmers (e.g. farmers visiting him, trucks of abattoirs or feed mills etc.). On this contact basis, 76 different scenarios could be simulated. All outbreaks are directly related to the index farm. In the best case, 10,000 pigs had to be culled, in the worst case 150,000 pigs. Respectively, 400 and 8,500 cattle would have to be culled. The total costs are predicted to be between € 33 and € 134 million with a median of € 74.5 million. Compensations would be in the best case about € 1.5 million and in the worst case € 19 million.

The other study was done by KRÄMER in 2010. He developed an agent-based model to explore the costs for farmers for FMD epidemics in the Counties of Schwandorf (Bavaria) and Steinfurt (North Rhine-Westphalia, NRW). After compensation to farmers, an average financial damage of about € 4 million was calculated, which could rise to € 5 million if only culled animals would be compensated. The study focuses very much on the behaviour of farmers in case of an outbreak. In this context, premature and delayed trading behaviour is explored.

2.4   Economics on FMD and other animal diseases

When analysing animal diseases economically, it is wise to structure the different cost categories for better comparison. For this purpose, LONGWORTH ET AL. (2014a; 2014b) developed a general framework that classified costs into four categories depending on where the costs incurred. Thereby, a category has several cost components. The categories are Direct Costs, Direct Consequential Costs, Indirect Costs and Aftermath Costs. Aftermath Costs are hard to determine, because they occur after eradication of disease and after lifting all trade restrictions. Therefore they will be left out in this study. Using a given framework has the advantage that different epidemics can be compared easily and consistently. A description of the categories is given below.

2.4.1   Direct Costs

Direct Costs (DC) incur at disease control measures that aim to eradicate the disease. They include the total organisational costs of control (veterinary staff, facilities, etc.) and the costs of actions that are decided to combat a disease (culling of infected livestock, culling of dangerous contact stock, cleansing and disinfection and cost of vaccination if practised). Compensation payments also belong to this category. The major driver of DC is the number of affected farms. For farmers, the DC of an outbreak might be relatively low, because most the DC is compensated by the government or the animal disease funds. It should be mentioned, however, that the compensation could be lower than the real market price (LONGWORTH ET AL., 2014a; 2014b).

2.4.2   Direct Consequential Costs

Direct Consequential Costs (DCC) are caused by direct control measures. They arise from measures that are applied to prevent further transmission to yet uninfected livestock. They incur at all holdings in the MRZs not affected by the virus or already empty because of depopulation measures. Due to the MRZs, such holdings are unable to carry out daily business. For this reason, they face idle production, reduced turnover or cashflow, value losses of milk and animals as well as welfare slaughter of animals for space reasons. In contrast to DC, most of the DDC (except for welfare slaughter) are losses instead of expenditures. The major epidemiological factors of DCC are the size and duration of an epidemic (LONGWORTH ET AL., 2014a; 2014b).

2.4.3   Indirect Consequential Costs

Indirect consequential costs (ICC) are related to market effects during disease. The major influence is the duration and the type of control strategies. On the one hand, they can incur because of disruptions on livestock commodity markets. Disruptions are linked to the applied measures of the authorities to control FMD. Supply shocks will occur due to reduced production. Demand shocks could be caused by, e.g., publishing culling or carcass-burning videos. These shocks lead to different prices and change the gross margin and revenue of farmers outside the MRZs. On the other hand, business sectors other than agriculture can be affected by an epidemic, e.g. tourism or transport (LONGWORTH ET AL., 2014a; 2014b). Especially tourism suffers from MRZs in the countryside and the bad image of a region because of news coverage. For example, THOMPSON ET AL. (2002) estimated for example the cost of the tourism sector in the 2001 epidemic in the UK and ranged them between £ 2.7 and £ 3.205 billion with additional indirect effects for upstream businesses of the tourism sector of £ 1.835 to £ 2.180 billion. This shows that it is very difficult to give exact values for ICC even after an epidemic occurred. In this study, the focus is on a strategy's costs for farmers and for this reason, ICC are only estimated for agriculture.

3   METHODOLOGY

The first research question about what important epidemiological and economic factors determine the economic impact of FMD will be answered by literature research and by the economic model. The results and the census data can be used to identify the most striking factors with respect to the geographical differences of the regions.

For the second question about possible FMD epidemics in the two regions, epidemiologists of the counties' veterinary authorities were consulted to create likely scenarios. Particularly with regard to emergency protection vaccination and culling strategies, best-case, probable/medium and worst-case scenarios were estimated. The veterinarians have experience in forming realistic scenarios for disease exercises and access to the German notification and crisis management system TSN. Together with them, ex ante disease simulations were done. The scenarios differ in disease development, the number of infected farms, the radius of the MRZs and the duration. The MRZs are given as a percentage share of each single municipality (e.g. 50% is in PZ, 50% is in SZ).

In order to analyse the FMD epidemics and their costs, a static epidemiological and economic model was created in Microsoft Excel 2010. The model estimates the impact on farmers with respect to DC, DCC and compensation payments (third research question). It is based on geo-reference data of the agriculture census 2010 and on the previously created epidemiological scenarios. If the census data is available, the model could be calibrated for every county in Germany. The model consists of four sheets. Two of them are specific for a simulation ("Model CountyName" and "Results", two are general input (the census data and the average gross margins of animal production systems: sheets "County Data" and "Gross margins"). The first two sheets are important for running a simulation.

A schematic description of the methodology is presented in Figure 2. Two models were created, one for each region. The sheet 'Model CountyName' is divided into three main parts. First, the control strategy has to be selected. Four different strategies were chosen and given in the model, but not all strategies will be analysed in detail:

 1) EU minimum (only culling of infected premises)
 2) Culling 1km (culling with 1km radius around infected premises
 3) German vaccination plan (0.5km radius culling plus 0.5 − 3km radius vaccination)
 4) Vaccination zone 3km (PZ)

The strategies culling in 1km radius and vaccination in 3km radius are compared in this report. After the selection of the control strategy, the epidemiological model has to be calibrated with respect to the created scenario (step 2 in Figure 2). This part is divided into the areas: infected premises (IP), protection zone (PZ), surveillance zone I (SZ I), and the surveillance zone II (SZ II; which is the merged PZ and SZ I). Affected municipalities have to be checked according to the created scenario and additionally, the number of IP and the share of each municipality in the MRZs have to be specified. Infected farm types (e.g. cattle or pig farmers) in the beginning are selected randomly by pressing a keyboard combination. Next, the costs of an epidemic with respect to the selected strategy are estimated. Several cost categories are given and again split in four areas (IP, PZ, SZ I, and SZ II; step 3 in Figure 2). Below, the costs for each area are summarised and categorised by DC and DCC. The compensation payments and costs for farmers and for the TSK/organisation are displayed separately. By pressing a key combination depending on the control strategy and

the county, a Monte Carlo simulation is applied, so that in each run different infected farm types are calculated, and the total costs are summarised in the separate sheet "Results".
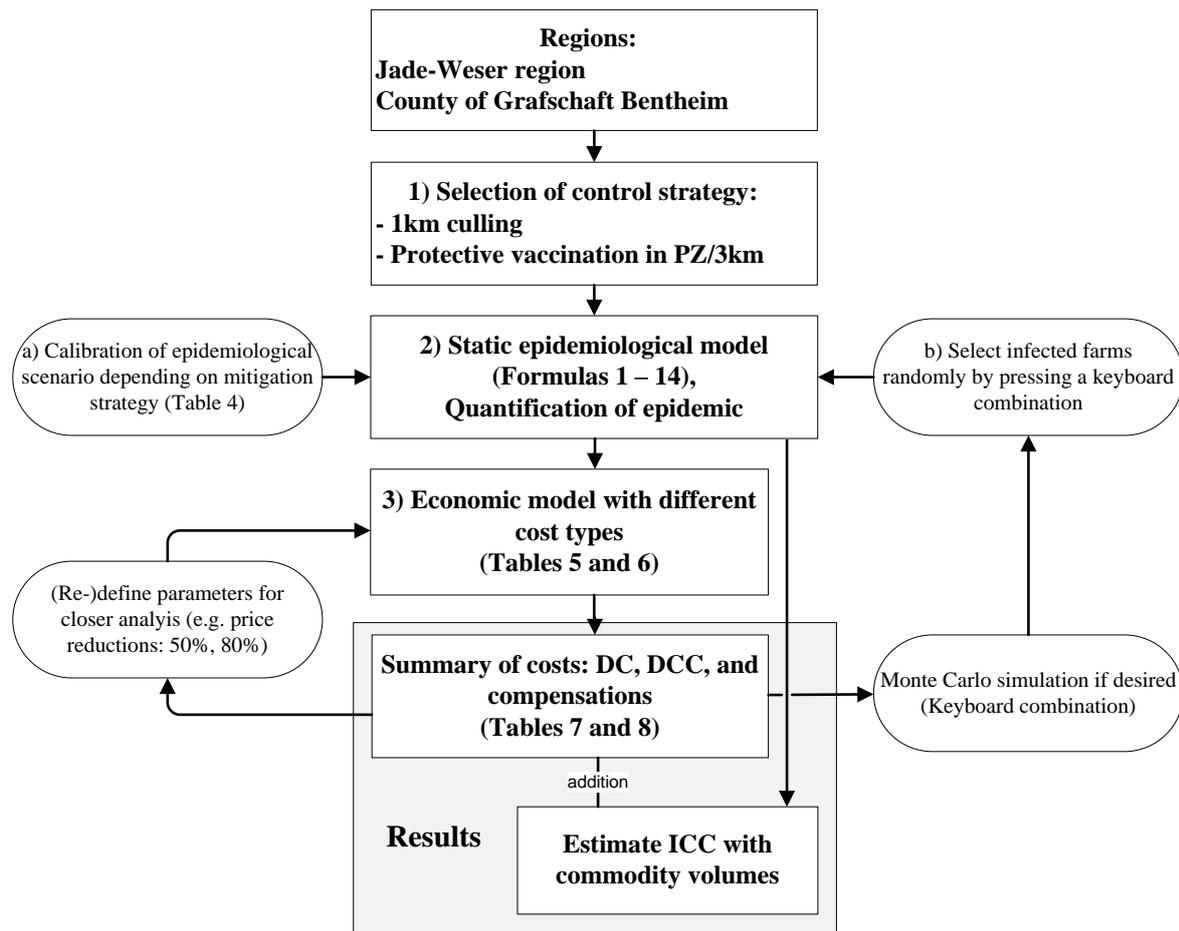
Figure 2: Schematic description of the methodology

The fourth research question about the ICC will be analysed separately, because it is hard to give a reasoned estimate of market disruptions outside the MRZ. The starting point of this analysis also is the epidemiological dimension of an outbreak. The market disruptions are on the one hand determined by commodity volumes that are affected by trade restrictions. Those volumes can be derived from the census data and the additional estimates that were done. Such a decrease can lead to higher commodity prices outside the MRZ. For the analysis of those changes price elasticities can be used. On the other hand, demand decrease inside and outside Germany may result in lower prices, which could affect the whole country in case that trade export restrictions.

3.1   Data and description of the counties

The data for the model are from the Agriculture Census 2010 (*Landwirtschaftszählung*) in Lower Saxony (Table 3). It was collected and published on municipality and county level but not on single farm level. Data of three animal types is used: cattle, sheep and swine. Cattle data is published in the categories "all cattle" and "cows". Therefore, it can be calculated how many calves, heifers, steers and bulls are in each municipality but it remains unknown what kind of distribution they have. Sheep data was summarised in one category and it is unknown how many lambs and how many ewes or rams there are. For the calculations, it is assumed that the share is equal at 50% ewes/rams and 50% lambs. Swine were collected in the categories "sows", "piglets" and "other" including mainly fat-

tening pigs but also boars. The category piglet includes all piglets until a weight of 20kg. Heavier piglets are listed in the other-category. For the cost estimation in the model, it is assumed that all other pigs are fattening pigs, because the share of boars should be small.

Data about animal keepers is completely available but for some municipalities, data for some animal types is not stated. In this case, the value was estimated on the grounds of the total numbers of animals per type and per county. The difference between the total animal number and the given data per municipality is equal to the missing data per county. The missing data per county was then divided by the number of the animal keepers without stated data in order to get an average value per farm in the specific counties. In the case of the City of Wilhelmshaven, no county level data for the data generation is available. Therefore, the missing data was generated by using the average and the average share of cows, sows and piglets compared to the average number of all cattle and swine. For the Jade-Weser region, there was sometimes hardly any swine data available due to its minor importance. The exact way of estimation in this case can be seen in appendix I.

Data about livestock keepers is on farm basis, so that no stocks outside the main premise are listed. This is for example often the case in pig husbandry, when a farm leases pigsties of farmers that have given up agriculture. Therefore, the number of farmers is lower than the number of actual livestock and of places where animals are kept. Next to cattle, sheep and pig farms, the number of fowl and solid hoofed farms is given in the census data. Adding up all farm types, the share of each type can be calculated and additionally the share of farms that keep two animal types. Hereby, it is assumed that farms do not keep more than two animal types. This is important for the calculations of IP in the beginning of the epidemic.

3.1.1   Jade-Weser region

The Counties of Friesland, Wesermarsch, Wittmund and the City of Wilhelmshaven have a veterinary cooperation called *Zweckverband Veterinäramt JadeWeser* (Special-purpose Association Veterinary Office JadeWeser) in order to control and combat animal diseases. For this reason, the mentioned counties will be seen as one in what concerns animal diseases. Three islands belong to the region. They will be left out in the model, because they are irrelevant for livestock husbandry and isolated from the mainland so that an outbreak is unlikely.

The counties show the typical characteristics of (East) Frisia. The largest part of the marshes in this coastal region is used as permanent grassland. Consequently, ruminants have the highest share in this region. Besides cows and other cattle, the share of sheep is – compared to most other regions in Germany – quite high (Table 3). In total, the region of Jade-Weser has about 113,500 cows. When assuming an average milk production of 22 kg per cow and day, about 2.5 million kg are produced in the region per day.

3.1.2   County of Grafschaft Bentheim

The County of Grafschaft Bentheim is situated in the west of Lower Saxony close to the Dutch border. Most of the agricultural lands are arable land. Permanent grassland has a share of 14%. The county has a high animal density and a high share of cattle as well as pig farms. On 981km² are more than 400,000 pigs and about 100,000 cattle. Sheep have only minor importance. Compared to Jade-Weser, farmers keep more often more than one animal species (Table 3).

A bit less than one-third of the cattle are cows, which produce on average 660,000 kg per day (at 22 kg per cow). The share of other cattle is higher compared to Jade-Weser, so that a greater share of bull fattening can be assumed. However, there are no concrete data about this available and therefore, the assumption of 50% calves and 50% bulls is

maintained. In the swine-category, about half of the pigs are piglets that are born by more than 50,000 sows. In addition, more than 150,000 fattening pigs are kept in this county.

Table 3: Description and characteristics of the analysed counties
Reference: LSKN, 2012

Region/county		Lower Saxony	Jade-Weser				Grafschaft Bentheim
Category			Wilhelms-haven	Friesland	Weser-marsch	Wittmund	
Area (km²)		47,614	107	604	822	624	981
agri. land (ha)		2,577,017	3,575	42,593	56,822	43,124	57,410
Farms		41,730	51	634	845	772	1,327
Farms with livestock		32,736	43	560	810	699	1,195
Cattle	farms	21,093	32	466	725	611	836
	all animals	2,484,629	5,209	81,163	120,607	75,101	98,907
	cows: farms	13,161	30	390	576	514	585
	cows: animals	769,283	2,068	33,483	48,161	29,752	30,153
Sheep	Sheep: farms	2,480	7	56	143	44	56
	Sheep: animals	205,569	2,226	8,849	20,213	2,187	2,210
Swine	farms	10,990	2	34	26	89	534
	all animals	8,428,731	1,073	33,550	7,445	38,637	408,652
	Piglets: farms	4,703	0	17	10	48	337
	Piglets: animals	2,455,891	0	11,190	4,366	16,353	204,083
	Breeding sows: farms	4,070	1	9	12	44	336
	Breeding sows:	596,735	62	1,371	1,121	3,836	51,287
	Other swine: farms	10,367	2	32	22	77	489
	Other swine: animals	5,376,105	1,011	20,989	1,958	18,448	153,282
Other	Fowl: farms	5,612	8	64	72	117	189
	Solid-hoofed: farms	6,958	11	111	153	113	162
Sum of farm types		47,133	60	731	1,119	974	1,777
Average number species/farm		1.44	1.40	1.31	1.38	1.39	1.49
Share Cattle		64%	74%	83%	90%	87%	70%
Share Sheep		8%	16%	10%	18%	6%	5%
Share Swine		34%	5%	6%	3%	13%	45%
Cattle (Share1)		50%	70%	79%	73%	74%	45%
Swine (Share2)		26%	4%	6%	3%	11%	29%
Sheep (Share3)		6%	15%	9%	14%	5%	3%
Cattle & swine (Share4)		13%	2%	2%	1%	6%	19%
Cattle & sheep (Share5)		3%	7%	3%	8%	3%	2%
Swine & sheep (Share6)		2%	0%	0%	0%	0%	1%
Sum		100%	100%	100%	100%	100%	100%

3.2 Epidemiological input

First, this section describes how the census data is used in the model and how the affected farms and animals are calculated. Afterwards, the epidemics that were simulated by the epidemiologists are presented. The epidemics are presented as a number of infected farms plus percentage shares of a municipality that are likely to be in the MRZ. Those numbers and shares have to be entered manually into the epidemiological part of the model in order to estimate affected farms and animals. However, since a lot of regulation in case of an outbreak of a notifiable animal disease is done on EU level, the zoning is geared to

municipality borders or at least to district borders (see also section 2.2). This means that often whole municipalities are in a zone, which makes an estimate of the zoning easier.

3.2.1 Data usage in the model

The model is divided into the zones IP, PZ, SZ I, and SZ II, whereat SZ II is a merger of PZ and SZ I. In the following, the estimation of the animals and farms in each zone is explained.

3.2.1.1 Infected premises (IP)

The most relevant animal species for FMD in Germany are cattle and swine. In some grassland regions, some sheep are kept too. Those three species will be included in the model, whereat only a few farmers keep more than two animal types. For this reason, six different farm types f will be included in the epidemiological part of the model and serve as IP. Those farm types are:

If f =   1 = Cattle only   4 = Cattle and swine
                2 = Swine only   5 = Cattle and sheep
                3 = Sheep only   6 = Swine and sheep

On these farm types, six different animal types a are kept:

If a =   1 = Cows   4 = Sows
                2 = Other Cattle   5 = Piglets
                3 = Sheep   6 = Fattening pigs

Each analysed region has m municipalities with $j = 1,\dots,m$. By checking a municipality in the model, the dummy value $D = 1$ is allocated, when a municipality is not checked, it has the dummy value 0. Of each j, ten farms n_{ji} (with $i = 0,\dots,10$) can be infected by FMD. The exact number of IP in each municipality has to be entered manually. Since it is unknown, which farm is the index case, what the local conditions are and what the spatial distributions are, the farm types are selected randomly according to their frequency:

$$(1) \quad Farmtype\ f = If\left(n_i/n_{ji} * D \leq 1\right),\ then: D * If\left(Rand(0,1) \leq Share1,\right.$$

$$then: 1, If\left(Rand(0,1) \leq Share1 + Share2,\ then: 2, If\left(Rand(0,1) \leq\right.\right.$$

$$Share1 + Share2 + Share3, then: 3, If\left(Rand(0,1) \leq Share1 + Share2 +\right.$$

$$Share3 + Share4, then: 4, If\left(Rand(0,1) \leq Share1 + Share2 + Share3 +\right.$$

$$\left.\left.\left.\left.\left.Share4 + Share5, then: 5, If\left(Rand(0,1) \leq, then: 6,\ else: 0\right)\right)\right)\right)\right)\right) \quad \forall j\ \forall_i$$

Share1 to Share6 are the shares of each farm type f = 1,…, 6 in each municipality (Table 3). The number of infected animals on all infected farms in j is then:

$$(2) \quad Animaltype\ a_{inf_j} = \sum_{i=1}^{10}\left(If\left(and\left(n_{ji} = 1,4,5\right), then: \bar{a}_j, else: 0\right)\right) \forall j$$

For cows at the first infected farm in municipality j, this is for example calculated by:

$$cows_{inf_j} = If\left(and(n_{1\,1} = 1,4,5), then: \overline{cows}_j, else: 0\right) + If\left(and(n_{1\,2} = \right.$$
$$1,4,5), then: \overline{cows}_j, else: 0\right) + \cdots + If\left(and(n_{1\,10} = 1,4,5), then: \overline{cows}_j, else: 0\right)$$

3.2.1.2 Protection zone (PZ)

The percentage of each municipality in the PZ has to be entered into the model manually. The number of farms with cloven-hoofed animals in the PZ can then be estimated with the census data:

(3) $Farms_{PZ_j} =$

$If\left(sharePZ_j > 0, then: D_j * \left(-n_{ji} + sharePZ_j * Farms_{cloven_j}\right), else: 0\right) \quad \forall j$

with:

(4) $Farms_{cloven_j} = Farms_{livestock_j} - \dfrac{Farms_{fowl_j} + Farms_{solid_j}}{Farms_{\Sigma alltypes_j}} * P(single)_j *$

$Farms_{livestock_j} \forall j$

Animals on affected farms in the PZ in municipality j are calculated by using average values, in contrast to the IP. An exact per farm-calculation would be very extensive.

(5) $a_{PZ_j} = If\left(sharePZ_j > 0, then: Max\left(0, sharePZ_j * a_j - a_{inf_j}\right), else: 0\right)$

The maximum formula is necessary to get only positive numbers. Otherwise, the animal numbers in the PZ could be negative if too many infected animals are present.

The farms that are in the culling zones can be estimated by using and the circle area formula. In order to prevent too many culled farms, the radius, however is reduced to 750m if more than 5 farms are infected in one municipality (see overlapping circles in Figure 1).

(6) $Farms_{culling_j} =$

$If\Bigg(n_{ji} > 0, then: If(Strategy = culling\ 1km,$

$then: \dfrac{\sum_{i=1}^{10} n_{ji}}{(\Sigma f_{cattle} \Sigma f_{sheep} \Sigma f_{swine})/(\sum_{j=1}^{m} \sum_{i=1}^{10} n_{ji})} * \dfrac{Farms_{cloven_j}}{area_j} * 1^2 * \pi,$

$else: If\Bigg(and(Strategy = culling\ 1km, n_{ji} > 5),$

$then: \dfrac{\sum_{i=1}^{10} n_{ji}}{(\Sigma f_{cattle} \Sigma f_{sheep} \Sigma f_{swine})/(\sum_{j=1}^{m} \sum_{i=1}^{10} n_{ji})} * \dfrac{Farms_{cloven_j}}{area_j} * 0.75^2 * \pi,$

$else: If\Bigg(Strategy = German\ vacc.\ plan,$

$then: \dfrac{\sum_{i=1}^{10} n_{ji}}{(\Sigma f_{cattle} \Sigma f_{sheep} \Sigma f_{swine})/(\sum_{j=1}^{m} \sum_{i=1}^{10} n_{ji})} * \dfrac{Farms_{cloven_j}}{area_j} * 0.5^2 * \pi\Bigg), \ else: 0)\Bigg)\Bigg) \forall j$

If a vaccination strategy is chosen, all animals in the PZ have to be vaccinated except for the strategy "German vaccination plan". In this case, animas in a 500m radius have to be culled and those need to be subtracted from the animals in the PZ. The denominator accounts for farms with more than one animal type.

3.2.1.3 Surveillance zone I and II (SZ I and SZ II)

The SZ changes over time and merges with the PZ. For this reason, the SZs are split into two zones. SZ I is the zone that was established directly in the beginning. SZ II lasts 15 days before the restrictions are lifted, but this value may be adapted in the model. The percentage of each municipality in the SZ has to be entered manually, too. The calculation for the affected number of farms is similar to the PZ-formula above:

(7) $Farms_{SZI_j} =$

$\quad If\left(shareSZI_j > 0, then: \left(-n_{ji} + shareSZI_j * Farms_{cloven_j}\right), else: 0\right) \forall j$

Together, $sharePZ_j$ and $shareSZI_j$ should not be above 100%, because then some farms would be counted twice. The animals in SZ I are calculated in the same way as in the PZ:

(8) $a_{SZI_j} = If\left(shareSZI_j > 0, then: Max\left(0, shareSZI_j * a_j - a_{inf_j}\right), else: 0\right) \forall j$

The farms and animals in SZ II are the sum of the PZ and SZ I minus the culled animals and the animals that were already slaughtered for welfare reasons. Welfare slaughtering is applied for other cattle, piglets and fattening pigs. Cows, sheep and sows are exempted, because enough room in the stables is assumed. Welfare slaughtering of an animal type is calculated by:

(9) $Welfare\ slaughter_{a_j} = \dfrac{a_j}{2} * \dfrac{t_{epidemic_j}}{t_{raising}} \forall j$

Culled animals have to be subtracted from a_j. For other cattle, however, only 50% of the animals are counted, because the housing problems are less urgent. $t_{epidemic}$ is the duration of the epidemic in municipality j and $t_{raising}$ is the average time to raise the specific animals. For other cattle, it is set at 650 days and for fattening pigs 160 days, which is quite high but some upward leeway for the raising period is assumed. For piglets, it is the minimum of the formula above at 80 days and the total number of piglets plus the number of sows times ½ * 26.5/2.35 (live piglets/sow / litters/sow) (for welfare slaughtering, see also MEUWISSEN ET AL., 1999).

3.2.1.4 Duration of the MRZs

The total time of each zone is different for each municipality and depends on the IPs per municipality (n_{ji}) and the duration of epidemic events in the affected counties. The latter information is from the epidemiologists and is presented in the following section. The time differs for each of the four affected zones IP, PZ, SZ I, and SZ II. Overall, the duration of the zoning is only a vague estimation and very difficult to determine, because it is uncertain, in which intervals and where the infections occur at the farms. This cannot be simulated in the static model. The differences in the zoning are due to the assumption that disease spreads further and migrates to other municipalities. During this process, some municipalities are supposed to be again free of FMD whereas others just face it.

The quarantine duration for IP is has a minimum of 30 days by law. For this study, 32 days are assumed until all examinations are finished as a minimum value until restocking. If the time of the PZ is longer, this value will be used, because the IP will then be part of the PZ and faces the transport restrictions.

(10) $t_{IP_j} = Max\left(t_{PZ_j}, 32\ days\right) \forall j$

The time of the PZ in municipality j differs with respect to the type of control strategy and is defined as:

(11) $t_{PZ_j} = If\Bigg(and(strategy = cullling, sharePZ_j > 0), then: \dfrac{t_{events}}{\log_{n_{ji}} t_{events}} +$

$\quad 30days,\ If\Bigg(and(strategy = vaccination, sharePZ_j > 0), then: \dfrac{t_{events}}{\log_{n_{ji}} t_{events}} +$

$\quad 7days + 40days, else: 0\Bigg)\Bigg) \forall j$

whereat t_{events} is the duration of epidemic events. This information is given by epidemiologists. 30 days are supposed to be the general time of a PZ. Actually, this is higher than the time given in legislation but necessary until all examinations on farms are finished. The logarithm results in a denominator that gets smaller with decreasing ratio with rising number of IP in a municipality. This leads to larger time intervals at the beginning of the epidemic (at few IP) but to shorter intervals when more farms are infected. The reason for this is that a regional spread is assumed and thus the MRZ only grows a little for every additional outbreak (Figure 1). Zero or one IP are changed into two due to mathematical matters. For the vaccination strategies, 7 days are supposed to adjust some delay until vaccination is applied and 40 days are the duration of the control zone.

The duration of the SZ I is equal to the duration of the PZ at 0 infected farms. Equality is assumed when parts of a municipality are both in the PZ and SZ.

$$(12)\, t_{SZI_j} = If\left(and\left(shareSZI_j > 0, t_{PZ_j} > 0 \right), then: t_{PZ_j},\; If\left(shareSZI_j > 0, \right.\right.$$

$$then:, \left(and(strategy = cullling, sharePZ_j > 0), then: \frac{t_{events}}{\log_2 t_{events}} + 30 days, \right.$$

$$If\left(and(strategy = vaccination, sharePZ_j > 0), then: \frac{t_{events}}{\log_2 t_{events}} + 7 days + \right.$$

$$\left.\left.\left. 40 days, else: 0 \right) \right) else: 0 \right)\right) \forall j$$

The logarithm is in this case always two due to the if-clause explained above. SZ II only applies for municipalities that were already in the PZ and/or SZ I. It is defined to last 15 days, which is similar to the duration of the SZ after merging PZ and SZ in the UK in the epidemic 2007 (ANDERSON, 2008).

$$(13)\, t_{SZII_j} = If\left((sharePZ_j + shareSZ_j) > 0, then: 15 days, else: 0 \right) \forall j$$

The total time of restrictions in municipality j is then the sum of the duration of SZ II and time of the PZ or SZ respectively:

$$(14)\, t_{epidemic_j} = Max\left(t_{PZ_j}, t_{SZI_j} \right) + t_{SZII_j} \forall j$$

3.2.2   Epidemiological scenarios

Table 4 shows the FMD epidemics that were simulated by the epidemiologists. The table gives all information that is necessary to run a simulation in the model. Maps for better orientation can be seen in appendix II. In total, six possible epidemics will be analysed closely for each region, three for the strategy "1km culling" and three for the "3km vaccination"-strategy. In these scenarios, vaccination-to-live is done in the PZ. The relevant information for a simulation includes the number of infected farms, the municipalities in which the infected farms are settled, the municipalities that are in the PZ and SZ respectively and the time of epidemiological events. The latter is the time span from the first detection to the last detection of FMD on a farm. Of course, the quarantine time is added to this, as shown above. For the municipalities that are in the MRZs, a share can be given, for example 50%. When no share is given, the whole municipality is located in the zone.

Table 4: Simulated epidemics and model input

Simulated epidemics for Jade-Weser and Grafschaft Bentheim

Region/County	Dimension	1km culling Best	1km culling Probable/medium	1km culling Worst	3km vaccination Best	3km vaccination Probable/medium	3km vaccination Worst
Jade-Weser	Infected farms	7	40	150	7	25	100
	Affected municipalities	FRI: 4 Jever, 1 Schortens; WTM: 2 Wittmund	WHV: 1; FRI: 23; WTM: 1 Dunum, 5 Friedeburg, 1 Stedesdorf 1 Werdum, 6 Wittmund; BRA: 2 Jade;	WHV, FRI, WTM, BRA (except Berne & Lemwerder)	FRI: 4 Jever, 1 Schortens; WTM: 2 Wittmund	WHV: 1; FRI: 16; WTM: 4 Friedeburg, 4 Wittmund	WHV: 3; FRI: 50; WTM:1 Blomberg, 3 Dunum, 2 Esens, 10 Friedeburg, 1 Holtgast, 2 Moorweg, 1 Neuharl, 3 Stedesdorf 2 Werdum, 10 Wittmund; BRA: 6 Jade, 3 Ovelgönne, 3 Stadland
	Municipalities in protection zone	1/3 WHV, Jever, Schortens, 1/10 Wangerland, 1/10 Friedeburg, 1/3 Wittmund	see above plus 1/2 Neuharlingersiel 1/2 Ovelgönne, 1/2 Stadland	see above plus Berne and Lemwerder	1/3 WHV, Jever, Schortens, 1/10 Wangerland, 1/10 Friedeburg, 1/3 Wittmund	see above plus Jade	WHV, FRI, WTM except Eversmeer, Nenndorf Schweindorf, Westerholt, Utarp. BRA except Berne and Lemwerder
	Municipalities in surveillance zone	2/3 WHV, Bockhorn, Sande, 9/10 Wangerland, Zetel, Dunum, 9/10 Friedeburg, 1/2 Neuharlingersiel, Stedesdorf Werdum, 2/3 Wittmund	Blomberg, Esens, 1/2 Holtgast, Moorweg, 1/2 Neuharlingersiel, 1/2 Ovelgönne, 1/2 Stadland	-	2/3 WHV, Bockhorn, Sande, Varel, 9/10 Wangerland, Zetel, Dunum, 9/10 Friedeburg, Neuharlingersiel, Stedesdorf Werdum, 2/3 Wittmund	Blomberg, Dunum, Esens, Holtgast, Moorweg, Neuharlingersiel, Neuschoo, Ochtersum, Stedesdorf, Werdum, Ovelgönne, Stadland	Eversmeer, Nenndorf Schweindorf, Utarp, Westerholt, Berne, Lemwerder
	Duration of epidemic events	7 days	105 days	135 days	7 days	49 days	90 days
Grafschaft Bentheim	Infected farms	7	40	150	7	25	100
	Affected municipalities	7 Nordhorn	7 Bad Bentheim, 5 Engden, 4 Isterberg, 8 Nordhorn, 1 Ohne, 3 Quendorf, 5 Samern, 1 Schüttorf, 2 Suddendorf 4 Wietmarschen	Grafschaft Bentheim except Wielen	7 Nordhorn	4 Bad Bentheim, 3 Engden, 4 Isterberg, 6 Nordhorn, 1 Ohne, 3 Quendorf, 2 Samern, 1 Schüttorf 1 Suddendorf	Grafschaft Bentheim except Getelo, Itterbeck and Wielen
	Municipalities in protection zone	3/4 Nordhorn	Bad Bentheim, Engden, Isterberg, Nordhorn, Ohne, Quendorf Samern, Schüttorf Suddendorf Wietmarschen	Grafschaft Bentheim	3/4 Nordhorn	Bad Bentheim, Engden, Isterberg, Nordhorn, Ohne, Quendorf Samern, Schüttorf Suddendorf 1/2 Wietmarschen	Grafschaft Bentheim except Getelo, Itterbeck, Laar and Wielen
	Municipalities in surveillance zone	2/3 Engden, Isterberg Lage, Neuenhaus, 1/4 Nordhorn, 3/4 Osterwald, Wietmarschen	Esche, Georgsdorf, Gölenkamp, Halle, Hoogstede, Lage, Neuenhaus, Osterwald, Uelsen	-	1/10 Bad Bentheim, Engden, Esche, Georgsdorf Halle, Lage, Neuenhaus, 1/4 Nordhorn, Osterwald, Wietmarschen	Esche, Georgsdorf, Gölenkamp, Halle, Hoogstede, Lage, Neuenhaus, Osterwald, Uelsen, 1/2 Wietmarschen	Getelo, Itterbeck, Laar and Wielen
	Duration of epidemic events	7 days	105 days	135 days	7 days	49 days	90 days

In the timely run of an FMD outbreak, it is assumed that the index case is in the centre of the Jade-Weser region, thus in the Counties of Friesland and Wittmund in the municipalities Jever, Schortens, Sande or Wittmund. The exercise 2013 serves an index scenario (VETERINARY OFFICE JADEWESER, 2013). From this starting point, disease spreads to the other areas in the four counties. For the Grafschaft Bentheim, the index scenario is located in the middle of Nordhorn.

The numbers of IP were defined together with the epidemiologists. They and the duration of epidemic events are equal for both regions in order to allow a comparison. The structure does influence the epidemic course of events but since it is hard to give a profound estimate of FMD in Germany, many scenarios are possible. For the veterinary authorities and farmers, one IP is already the worst case.

The starting point of the analysis is the case of seven infected farms located in three municipalities. This is the same scenario as in the exercise 2013 and roughly the minimum of infected farms for an application of the vaccination strategy (see Table 2 in section 2.2). This scenario is the same for both strategies, only the SZ is a bit smaller for the culling-strategy, because of a ten kilometre SZ has to be established around the vaccination zone. Generally, the best-case scenario is one IP. However, this could never be a case for the vaccination strategy, because ere vaccination can be used, a specific number of farms or animals have to be infected.

For the probable/medium case using culling, 40 infected farms are stated and for the vaccination strategy 25 farms. In the worst-case, 150 farms may be infected when using the 1km culling strategy and 100 farms when using the 3km vaccination strategy. In all worst-case scenarios, all municipalities are affected by disease. In Jade-Weser, the worst-case culling scenario, all municipalities even contain IP, except for Berne and Lemwerder, which are a bit disconnected due to the River Hunte and are somewhat more oriented to the Oldenburg region. In the Grafschaft Bentheim, only the municipality of Wielen is exempted by IP but in the PZ anyway. For the worst-case vaccination scenario, it is assumed that disease can be controlled faster and therefore some municipalities at the outer border areas contain no IP. Still, those municipalities will lie in the SZ.

3.3 Economic model

The economic model is linked to the epidemiological model and the agricultural census data. In this section, first the model's assumptions and the different cost types are described and explained. A summary of this is given in Table 5 and Table 6. Afterwards, the allocation of the cost types and the structure of the cost categories are addressed. This is outlined in Table 7 and Table 8.

3.3.1 Model input

The epidemiological input and model is the basis for the economic model. The economic model is also divided into IP, PZ, SZ I, and SZ II. Table 5 and Table 6 give an overview of the cost types that are included in the model's calculations, separated according to the six animal types. The categories taxation, weight and gross margin are general assumptions in the model that are contained in the other cost types. The column "place of incurrence" shows, in which area the costs arise. The column to the right gives the source of the supposed values. Further, Table 7 shows to which one of the cost categories (DC and/or DCC) the cost types belong and additionally, for which cost types the farmers will get compensation. The cost categories are subdivided into the groups Organisation, Cattle, Sheep and Swine.

Table 5: Cost types and assumptions in the economic model

Cost type		Unit	Cattle: cows	Cattle: other cattle	Sheep	Swine: sows	Swine: piglets	Swine: fattening	Place of incurrence	Reference
Taxation	10.7%								-	-
Weight	Weight of animals	kg/animal	650	(50+700)/2=375	55	250	(1.5+20)/2=10.75	(20+130)/2=75	-	-
Gross margin	GM per animal and year	€/animal*a	1,220	197	47	367	-	68	-	Pigs & Cattle: LfL (2014), Agrarmarkt NRW (2014); Sheep: LKSH (2014), Landwirtschaft BW (2014)
	GM/animal*d	€/animal*d	3.34	0.54	0.13	1.00	0.00	0.19		
Organisation cost per epidemic	Fixed cost for mobile control centre	€/d			2,500				IP	Veterinary Office JadeWeser (2013)
	variable cost for mobile control centre	€/epidemic			223,000					
Clinical examination & screening	Clinical examination & screening	€/farm			408.45 (204.23 for SZ respectively)				IP, PZ, SZI, SZII	Hop et al (2014)
Tracing	Tracing	€/farm			501.68				IP	Longworth et al. (2014b). Value for poultry farms
Culling & slaughtering	Culling capacity (culling teams: 3)	animals/d	150*3=450	(50+15)/2*10*3=975	80*10*3=2,400	30*10*3=900	200*10*3=6,000	80*10*3=2,400	IP, PZ	Willms (2006)
	Culling capacity	t/d	450*650/1,000=294	975*375/1,000=366	72,400*55/1,000=132	900*250/1,000=225	6,000*10.75/1,000=65	2,400*75/1,000=180		
	Cost of culling per animal	€/animal	40	33	25	25	5	25		Saatkamp et al. (forthcoming)
Welfare slaughtering	Cost of culling per animal	€/animal	40	33	25	25	5	25	PZ, SZI, SZII	-
Transport & destruction (culling & welfare slaughter)	20m²=t Container €0.11/l; 20,000 l €0.11/l	€/t			110				IP, PZ, SZI, SZII	NDS TSK 2014b
Cleansing & disinfection	Fixed part cleansing & disinfection	€/farm			1,000				IP, PZ	Willms (2006)
	Variable part per animal €0.11/m²	m²/animal	4.0	4.0	2.0	2.0	0.5	1.5		
Indemnification	Price	€/kg sw/animal	2.57	(3.52+2.54)/2=3.03	(4.84+0.86)/2=2.85	1.29	30.00	1.40	IP, PZ, SZI, SZII	Agrarmarkt NRW (2014); LKSH (2014) for sheep Brand (2004)
	Slaughter utilisation	%	50%	65%	42%	70%	-	75%		
	Average final weight	kg/animal	325	244	23	175	-	56		
	Indemnification/Worth	€/animal	925	818	73	250	33	87		

Table 6: Cost types and assumptions in the economic model (continued)

Cost type		Unit	Cattle: cows	Cattle: other cattle	Sheep	Swine: sows	Swine: piglets	Swine: fattening	Place of incurrence	Reference
Losses due to empty housing	Reduction of GM/d due to empty housing	%	100%						IP, PZ, SZI, SZII	-
Losses due to destruction of milk & feed	Average kg of milk/cow*day	kg/d	22							from gross margins
	Milk price	€/kg	0.32						IP, PZ	Agrarmarkt NRW (2014)
	Days of which milk has to be destroyed	d	1							-
	Value of destroyed feed per animal	€/animal	44	30	1.6	33	included in sows	3.7		Meuwissen et al. (2004)
Losses in milk production	Milk price reduction in PZ/SZ due to FMD	%	0, 50, 80	-	-	-	-	-	PZ, SZI, SZII	-
Losses due to prohibition of artificial insemination	animals that cannot be inseminated	animals	live cows$_j$*1/2* t.zone/365	-	-	live sows$_j$*1/2 *t.zone/365/2.35	-	-	PZ	own caclulations
Losses due to lower prices for products of MRZs directly after epidemic	Animals that have to be slaughtered after lifting transport restrictions	animals	-	1/2*Σ(live animals$_j$ *t.zone/650)	1/1.5*Σ(live animals$_j$ *t.zone$_j$/85)	-	Σ(live animals$_j$ *t.zone$_j$/80)	Σ(live animals$_j$ *t.zone$_j$/160)		-
	Meat price reduction in culling scenarios	%	-	0, 50, 80	0, 50, 80	-	0, 50, 80	0, 50, 80	SZII	-
	Meat price reduction in vaccination scenarios	%	0, 50, 80	0, 50, 80	0, 50, 80	0, 50, 80	0, 50, 80	0, 50, 80		-
Protection vaccination	Vaccination doses	€/animal			1.99					Saatkamp et al. (forthcoming)
	Labour cost for applications	€/animal			1				PZ	*lump-sum*
	Other materials	€/farm			45.4					Longworth et al. (2014b).
	Labour cost for preparations	€/farm			230.1					Value for poultry farms
Monitoring protection vaccination	Monitoring	€/farm			408.45					Hop et al. (2014)
	Cost per sample	€/sample			9				PZ, SZI, SZII	Willms (2006)
	Samples per farm	samples/farm			30					
Suppressive vaccianion	Carcass disposal capacity	t/d		630			560			Laves (2012)
	Vaccination doses	€/animal	1.99							Saatkamp et al. (forthcoming)
	Labour cost for applications	€/animal	1.00						IP, PZ	*lump-sum*
	Other materials	€/farm	45.40							Longworth et al. (2014b).
	Labour cost for preparation	€/farm	230.10							Value for poultry farms

The type "organisational cost per epidemic" includes the costs for the mobile control centre. Animals are on the one hand culled in case they are infected (or other animals on the farm) or on the other hand due to space reasons in animal housing (welfare slaughtering). The costs for both of the categories are supposed to be the same but for welfare slaughtering there is no capacity limit. The cost type "Transport & destruction" is divided into culling and welfare slaughtering. It is assumed that the costs are the same at € 110/t with 1m³ = 1t. Cleansing and disinfection is only done after culling on IP and on preventively culled farms. After welfare slaughtering, no disinfection is undertaken. Both slaughtering reasons are indemnified. In case of culling, this is listed on the DC. In case of welfare slaughtering, compensation is listed on the DCC. The prices for the indemnification orientate at current market prices. For other cattle and sheep, the exact specification of the animals remains unknown. For other cattle, prices for bulls and calves were taken and weighted equally. For sheep, prices of lambs and ewes were taken.

Losses due to empty housing after culling or slaughtering are 100% of the daily gross margin. Therefore, all zones suffer from this. Feed and milk has to be destroyed on IP and additionally on those premises that are culled preventively. At the other farms, it is assumed that the dairies still collect the milk that is produced and that a price is paid. Three different price reduction categories are analysed: 0% reduction, 50% reduction and 80% reduction. An 80% price reduction was used according to a tuberculosis case in Bavaria, where the dairies paid 20% of the price and a milk support fund paid 80% (HEIN, 2013). However, the volume of such a fund is not likely to be able to bear the costs of larger epidemics. For this reason, it is assumed that only 20% are paid. Also, cows and sows cannot be inseminated artificially in case of an outbreak. Those animals have a reduced production in the future due to later pregnancy. The animals that should be inseminated averagely during the epidemic are multiplied by the time and the daily gross margin.

Directly after an epidemic, many animal keepers will have to sell their animals. This counts especially for piglets, fattening pigs, lambs and other cattle and could lead to price reduction, either due to increased supply or due to the simple fact that the products are from MRZs and therefore buyers reluctant. Cows and sows are supposed to stay on the farms. If a vaccination strategy is applied, all animals are vaccinated. Therefore, all animals from the PZ would be labelled as vaccinated and consequently, buyers are reluctant against all vaccinated animals. The price categories for reduction are 50 and 80%, too.

The costs for vaccination can be seen in Table 6 as well. For the 3km vaccination strategy, only farms in the PZ are affected. All farms that are vaccinated are monitored twice: first, in the PZ and secondly, in SZ II. The model also has the possibility that a suppressive vaccination has to be applied if the capacities for culling are not at hand. However, this is hardly the case, because it is calculated on an average basis.

3.3.2   Allocation and summary of cost types

As mentioned above, the costs are analysed with respect to the DC, the DCC, the compensation payments and the ICC. The ICC however will be addressed separately taking into account the quantities that are taken out of further production or processing. Table 7 shows a summary of the different cost types and their categorisation in DC and DCC. Additionally, it can be seen, what kinds of losses are compensated for. Those losses are both the value of culled or welfare slaughtered animals as well as the value of destroyed milk and feed at infected or preventively culled farms.

Losses due to lower prices for products of the MRZs (milk, animals and meat) could be listed as both DCC and ICC. The changeover between the two consequential cost types is a grey zone and has to be defined more precisely to avoid confusion. In this study, all losses that incur within the MRZ (the PZ and SZ) are listed as DCC. Price effects outside the

MRZ or after lifting the MRZ but with export restrictions still in force are listed as ICC. Both farmers and processors could have to bear the costs of price reductions for products of the MRZ. In the in-depth analysis of this study, it is supposed that processors transfer the lower prices to farmers. Those losses are thus DCC for farmers.

In Table 8, the allocation of the net costs is shown per group. On the one hand, the Organisation/the TSK is responsible for all costs that incur for disease control plus the organisation of welfare slaughtering. In addition, the value of culled and slaughtered animals as well as destroyed feed and milk are indemnified. On the other hand, Cattle, Sheep and Swine farmers suffer from empty housing, prohibition of artificial insemination and lower prices.

Table 7: Occurrence of costs sorted by DC, DCC and compensation

Direct Costs	Direct Consequential Costs	Of which Compensation
Organisational costs per epidemic		
Clinical examination & screening		
Tracing		
Culling & slaughtering		
	Welfare slaughtering	
Transport & destruction (culling)	Transport & destruction (welfare slaughtering)	
Cleaning & disinfection		
Indemnification (culling)	Indemnification (welfare slaughtering)	X
	Losses due to empty housing	
Losses due to destruction of milk & feed		X
	Losses in milk production	
	Losses due to prohibition of artificial insemination	
	Losses due to lower prices for products of MRZs after epidemic	
Protection vaccination		
Monitoring protection vaccination		
Suppressive vaccination		

Table 8: Allocation of net costs to authorities and livestock keepers

Organisation/TSK	Animal keepers Cattle | Sheep | Swine
Organisational cost per epidemic	Losses due to empty housing
Clinical examination & screening	Losses in milk production
Tracing	Losses due to prohibition of artificial insemination
Culling & slaughtering	Losses due to lower prices for products of MRZs after epidemic
Welfare slaughtering	
Transport & destruction (culling)	
Transport & destruction (welfare slaughtering)	
Indemnification (culling)	
Indemnification (welfare slaughtering)	
Losses due to destruction of milk & feed	
Cleaning & disinfection	
Protection vaccination	
Monitoring protection vaccination	
Suppressive vaccination	

4 RESULTS

After explaining the structure of the model and the scenarios for the Jade-Weser region and the Grafschaft Bentheim, the results of the simulations are presented. The chapter is divided according to the severity of the scenarios starting with the best-case scenarios. Each scenario has three different assumptions. The initial assumption is that no price reductions occur for agricultural products of the MRZs (left column of the result tables). This assumption is changed to a 50% reduction and finally to an 80% reduction (see section 3.3.1). The DC stay the same but the DCC increase at such a change. The additional costs of price reductions are outlined in the middle and right columns of the tables in this chapter.

Each simulation varies a bit in the height of the costs depending on the farm types that are infected. In each section, one specific outbreak is analysed. Those outbreaks have costs around the mean and the median. In the tables of this chapter, the results for the culling strategy are presented in the upper part of the tables, the vaccination results can be seen in the lower part. For the simulations without any price effects, this variation is analysed closer by a Monte Carlo simulation and can be seen in appendix III. In each run, the types of the index farms are selected randomly. After that, the ICC are explored.

4.1 Best-case scenarios

4.1.1 Jade-Weser region

Both best-case scenarios are almost equal. Seven farms in three municipalities are infected by FMD. The PZ has in both the culling strategy and the vaccination strategy the same size, only the SZ is a bit larger for the vaccination strategy. In this section, one average best-case scenario is analysed. Six cattle farms are infected plus one pig farm. Table 9 gives a summary of this scenario. In addition, Table A20 in appendix III summarises the results of 100 iterations of the best-case scenario without price effects. The scenario in Table 9 was chosen according to the mean values and median of the Monte Carlo results of Table A20. In the different iterations, the standard deviation of the total costs is € 60,000 for the culling strategy and € 92,000 for vaccination.

The total costs for the culling strategy are with € 6.2 million about € 200,000 higher than the costs for the vaccination strategy. About two-thirds in the culling scenario are DC and one-third DCC. The predominant part of both DC and DCC is originated from cattle farming, which is no surprise when considering the agricultural structure of Jade-Weser. The costs for sheep farmers are low, because no farm is infected with FMD in the scenario at hand. In total, farmers get € 4.6 million compensation payments, of which € 3 million originate from culling of infected animals and about € 1.6 million from welfare slaughtering. Concerning the latter, pig farmers suffer from relatively high losses compared to cattle farmers, because even in small and short time epidemics, quite a lot of piglets and fattening pigs need to be slaughtered. In total, the TSK and authorities have to pay for about € 5.9 million. Farmers have losses of € 340,000.

When applying the 3km vaccination strategy, the costs shift from DC to DCC. DCC are with € 3.4 million more than half of all costs compared to DC of € 2.6 million. Both DC and DCC incur stronger in the category Organisation/TSK. However, farmers get with € 3.5 million fewer compensation payments. For culling on IPs, € 870,000 has to be spent.

Additionally, € 2.6 million have to be paid for welfare slaughtering, which is due to the larger zoning and the longer transport restrictions. For the TSK and other authorities, the total net costs are € 220,000 lower than in the culling-scenario. Farmers, on the other hand, suffer from higher losses, due to the longer and larger zoning.

In a next step, possible price reductions are taken into account. For the culling scenario, an additional € 10.1 million add up to the DCC at a 50% reduction. At 80% price reduction, € 16.2 million would arise. Lower animal prices are responsible for € 1.6 and € 2.5 million respectively. Especially pig farmers would suffer from reduced meat or animal prices. Nevertheless, the major burden of the costs has to be borne by cattle farmers, who, in the scenario at hand, lose € 9.6 million at 50% price reduction and € 15.4 million at 80% (assuming a milk price of 35ct/kg incl. tax). For the vaccination strategy, those additional losses increase to € 27.4 million at a 50% price reduction for agricultural products and to € 43.8 million at 80%. A bit less than half of these amounts (€ 12.8 and 20.5 million respectively) would be due to lower animal prices, the rest is due to losses in milk production. That would be additional net DCC for farmers without indemnification.

The reasons for the difference are the higher value losses for animals and meat in case of vaccination and the longer duration of the MRZs, which are up to 67 days in some municipalities. In the vaccination scenarios, it is assumed that all animals will be vaccinated and that the price reductions count for all animals, too. Therefore, also cows, sows and ewes face a decrease in value. At a culling strategy, only those animals are decreased in value that have to be sold directly after the epidemic, which are piglets, fattening pigs, lambs and some cattle. Additionally, the losses in milk production increase when using vaccination, because farmers face for a longer time lower prices.

4.1.2 Grafschaft Bentheim

In the Grafschaft Bentheim best-case scenario, all seven infected farms lie in the area of the Town of Nordhorn. In the average scenario at hand, two cattle farms, four pig farms and one sheep farms are infected. If a depopulation strategy is used, 21 farms are culled preventively, five more than in Jade-Weser, because of the higher farm density. Almost 370 farms are in the MRZ, which in reality would be higher, because the SZ is also partly in the Netherlands and in the County of Emsland.

The costs of this epidemic can be seen in Table 10. Without any price effects the total cost distribution does not change much compared to Jade-Weser. Overall, the costs are slightly higher. However, in Grafschaft Bentheim, the pig farmers have a higher share of costs and they increase the DCC due to more welfare slaughtering of piglets and fattening pigs. This can also be seen in the higher compensation payments for welfare slaughtering.

With price reductions included the costs for the culling strategy are lower compared to the vaccination strategy (total costs of € 10.1 million at 50% and 12.8 million at 80%). When vaccinating the total costs rise to € 16.4 million and € 22.5 million respectively. At the culling strategy, cattle and pig farmers face similar losses because of price reductions. In contrast, vaccination leads to twice as high losses for cattle farmers since the animals are worthier and even cows have to be sold with price reduction. However, compared to Jade-Weser with the very high cattle share, the losses from price effects are much lower in Grafschaft Bentheim. This is why the differences between the strategies are relatively small.

Table 9: Best-case scenarios in the Jade-Weser region for the strategies 1km culling and 3km vaccination Jade-Weser (best-case scenarios), in millions of Euros

	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
Cost category	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
1km culling															
Total direct cost (DC)	4.06	1.06	2.86	0.01	0.14	4.06	1.06	2.86	0.01	0.14	4.06	1.06	2.86	0.01	0.14
Compensation for farmers	3.01	-	2.86	0.01	0.14	3.01	-	2.86	0.01	0.14	3.01	-	2.86	0.01	0.14
Net DC for TSK/authorities	4.06	1.06	2.86	0.01	0.14	4.06	1.06	2.86	0.01	0.14	4.06	1.06	2.86	0.01	0.14
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	2.13	0.24	1.42	0.00	0.47	12.25	0.24	11.02	0.13	0.86	18.32	0.24	16.79	0.21	1.09
Compensation for farmers (welfare slaughtering)	1.55	-	1.09	0.00	0.45	1.55	-	1.09	0.00	0.45	1.55	-	1.09	0.00	0.45
Net DCC for TSK/authorities	1.79	0.24	1.09	0.00	0.45	1.79	0.24	1.09	0.00	0.45	1.79	0.24	1.09	0.00	0.45
Net DCC for farmers	0.34	-	0.32	0.00	0.02	0.34	-	0.32	0.00	0.02	0.34	-	0.32	0.00	0.02
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	10.12	-	9.61	0.13	0.38	16.19	-	15.37	0.21	0.61
Total gross cost of epidemic with …% price effects	6.19	1.30	4.28	0.01	0.61	16.31	1.30	13.88	0.14	0.99	22.38	1.30	19.65	0.22	1.22
Total net cost of epidemic with ….% price effects	6.19	5.85	0.32	0.00	0.02	16.31	5.85	9.93	0.13	0.40	22.38	5.85	15.69	0.21	0.63
3km vaccination															
Total direct cost (DC)	2.60	1.73	0.81	0.00	0.06	2.60	1.73	0.81	0.00	0.06	2.60	1.73	0.81	0.00	0.06
Compensation for farmers	0.87	-	0.81	0.00	0.06	0.87	-	0.81	0.00	0.06	0.87	-	0.81	0.00	0.06
Net DC for TSK/authorities	2.60	1.73	0.81	0.00	0.06	2.60	1.73	0.81	0.00	0.06	2.60	1.73	0.81	0.00	0.06
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	3.42	0.42	2.12	0.00	0.87	30.81	0.42	28.38	0.37	1.64	47.25	0.42	44.13	0.60	2.10
Compensation for farmers (welfare slaughtering)	2.58	-	1.75	0.00	0.84	2.58	-	1.75	0.00	0.84	2.58	-	1.75	0.00	0.84
Net DCC for TSK/authorities	3.00	0.42	1.75	0.00	0.84	3.00	0.42	1.75	0.00	0.84	3.00	0.42	1.75	0.00	0.84
Net DCC for farmers	0.41	-	0.38	0.00	0.04	0.41	-	0.38	0.00	0.04	0.41	-	0.38	0.00	0.04
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	27.40	-	26.26	0.37	0.77	43.83	-	42.01	0.60	1.23
Total gross cost of epidemic with …% price effects	6.02	2.15	2.94	0.00	0.93	33.42	2.15	29.19	0.37	1.70	49.86	2.15	44.95	0.60	2.16
Total net cost of epidemic with ….% price effects	6.02	5.61	0.38	0.00	0.04	33.42	5.61	26.63	0.37	0.81	49.86	5.61	42.39	0.60	1.27

Culling: 7 infected farms (6 cattle and 1 pig keepers, about 1,565 infected animals of which 871 cattle), 166 farms in PZ (16 farms culled preventively with 3,222 cloven-hoofed animals), 622 farms in SZ I, longest duration of MRZs in municipality j: 50 days, shortest: 47 days

Vaccination: 7 infected farms (6 cattle and 1 pig keepers, about 1,565 infected animals of which 871 cattle), 166 farm in PZ and vaccinated farms with about 33,000 cloven-hoofed animals, 782 farms in SZ I, longest duration of MRZs in municipality j: 67 days, shortest: 64 days

Table 10: Best-case scenarios in the Grafschaft Bentheim for the strategies 1km culling and 3km vaccination

Grafschaft Bentheim (best-case scenarios), in millions of Euros

1km culling

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
Total direct cost (DC)	4.05	1.01	1.83	0.01	1.19	4.05	1.01	1.83	0.01	1.19	4.05	1.01	1.83	0.01	1.19
Compensation for farmers	3.03	-	1.83	0.01	1.19	3.03	-	1.83	0.01	1.19	3.03	-	1.83	0.01	1.19
Net DC for TSK/authorities	4.05	1.01	1.83	0.01	1.19	4.05	1.01	1.83	0.01	1.19	4.05	1.01	1.83	0.01	1.19
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	2.74	0.41	0.50	0.00	1.83	6.05	0.41	2.42	0.01	3.21	8.04	0.41	3.58	0.01	4.04
Compensation for farmers (welfare slaughtering)	2.03	-	0.37	0.00	1.66	2.03	-	0.37	0.00	1.66	2.03	-	0.37	0.00	1.66
Net DCC for TSK/authorities	2.44	0.41	0.37	0.00	1.66	2.44	0.41	0.37	0.00	1.66	2.44	0.41	0.37	0.00	1.66
Net DCC for farmers	0.30	-	0.13	0.00	0.17	0.30	-	0.13	0.00	0.17	0.30	-	0.13	0.00	0.17
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	3.31	-	1.92	0.01	1.38	5.29	-	3.08	0.01	2.20
Total gross cost of epidemic with …% price effects	6.79	1.42	2.33	0.01	3.03	10.10	1.42	4.25	0.02	4.40	12.08	1.42	5.41	0.02	5.23
Total net cost of epidemic with …% price effects	6.79	6.48	0.13	0.00	0.17	10.10	6.48	2.06	0.01	1.55	12.08	6.48	3.21	0.01	2.37

3km vaccination

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
Total direct cost (DC)	1.87	1.26	0.22	0.00	0.38	1.87	1.26	0.22	0.00	0.38	1.87	1.26	0.22	0.00	0.38
Compensation for farmers	0.61	-	0.22	0.00	0.38	0.61	-	0.22	0.00	0.38	0.61	-	0.22	0.00	0.38
Net DC for TSK/authorities	1.87	1.26	0.22	0.00	0.38	1.87	1.26	0.22	0.00	0.38	1.87	1.26	0.22	0.00	0.38
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	4.36	0.66	0.74	0.00	2.95	14.52	0.66	7.82	0.03	6.01	20.62	0.66	12.06	0.04	7.85
Compensation for farmers (welfare slaughtering)	3.37	-	0.64	0.00	2.73	3.37	-	0.64	0.00	2.73	3.37	-	0.64	0.00	2.73
Net DCC for TSK/authorities	4.03	0.66	0.64	0.00	2.73	4.03	0.66	0.64	0.00	2.73	4.03	0.66	0.64	0.00	2.73
Net DCC for farmers	0.32	-	0.10	0.00	0.23	0.32	-	0.10	0.00	0.23	0.32	-	0.10	0.00	0.23
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	10.16	-	7.08	0.03	3.06	16.26	-	11.33	0.04	4.90
Total gross cost of epidemic with …% price effects	6.23	1.93	0.96	0.00	3.33	16.39	1.93	8.04	0.03	6.39	22.49	1.93	12.29	0.05	8.23
Total net cost of epidemic with …% price effects	6.23	5.90	0.10	0.00	0.23	16.39	5.90	7.18	0.03	3.29	22.49	5.90	11.42	0.04	5.12

Culling: 7 infected farms (2 cattle and 4 pig farms, 1 sheep farm, about 4,818 infected animals of which 250 cattle), 98 farms in PZ (21 farms culled preventively), 270 farms in SZ I, longest duration of MRZs in municipality j: 52 days, shortest: 47 days

Vaccination: 7 infected farms (2 cattle and 4 pig farms, 1 sheep farm, about 4,818 infected animals of which 250 cattle), 98 vaccinated farms with about 55,000 cloven-hoofed animals, 372 farms in SZ I, longest duration of MRZs in municipality j: 69 days, shortest: 64 days

4.2   Probable/medium scenarios

4.2.1   Jade-Weser region

For the probable scenarios, 40 farms are supposed to be infected using a culling strategy and 25 farms using the vaccination strategy. 1,267 farms are in the MRZ using culling and 1,320 using vaccination. Table 11 shows the results of an average outcome with the price reduction categories. In the culling scenario, 30 cattle farms, six pig farms and four sheep farms are infected. The maximum time of restrictions per municipality is 85 days and the minimum for municipalities that are only in the SZ 61 days. Of the 25 farms that are infected in the vaccination scenario 20 farmers keep cattle, three keep pigs and two have sheep. The minimum time for municipalities that are only in the SZ is 71 days and the maximum is with 79 days slightly higher for municipalities with several IPs.

The total costs for the culling strategy are more than € 32 million. The major part of this (24.2 million) are DC, € 7.9 million are DCC. Most of the costs again incur at cattle farms. For organisational purposes and culling, a gross of about € 4.2 million arises at the TSK and the authorities. Additionally, € 23.6 million (20.46 plus 3.18 million) have to be paid for compensations and therefore, the net costs for the TSK are at about € 28 million. More than € 4.2 million, or 13.1%, of the total costs are losses of farmers without compensation.

For the vaccination scenario without price effects, the total costs are with € 16.5 million only about half as high as in the culling scenario. The DC sum up to € 9.6 million and the DCC up to 6.9, which is twice as much compared to the best-case scenario. Most of the net costs are paid by the TSK (€ 14million). Farmers have to spend € 2.4 million – a share of 15% but absolutely lower compared to culling.

Including 50% or 80% price reductions for agricultural products at the culling strategy, the total costs increase to € 54.2 and € 67.5 million respectively (additional € 20.1 or € 35.4 million). Cattle farmers again suffer from the major part of the losses but sheep and pig farmers lose also almost € 1.3 or € 1.9 million. Altogether, losses in meat prices account for € 3.3 and € 5.2 million respectively of the DCC. When looking at the vaccination strategy with price effects the DCC increase much stronger compared to culling. At 50% price reduction, additional losses of about € 87 million incur and at 80% reduction, even losses of € 139 million are estimated. Losses in animal prices are € 64 million and € 102.4 million. Cattle farmers have to bear the major parts: in the region, 202,000 mainly cattle have to be vaccinated and are affected by the price reduction. Pig and sheep farmers face losses of € 2.4 and € 3.8 million respectively. Although sheep and pig keepers seem to have relatively small losses even at strong price reductions, the low share of those should be taken into account. In the County of Friesland, only 6% of the all livestock farmers keep swine. In the County of Wittmund, the share is with 13% higher but still small.

Table A21 in appendix III shows that the deviations in each iteration increase. The standard deviation is for the culling scenarios 379,000 and for vaccination 252,000. The higher differences in each simulation result from more IPs and their different farm types. However, without price effects, vaccination will always have a cost advantage. Including price effects that are stronger than a few per cent, culling should be preferred.

4.2.2   Grafschaft Bentheim

The results of the Grafschaft Bentheim can be seen in Table 12 and Table A24. From the 40 infected farms in the culling scenario, 22 keep cattle, 19 pigs and four keep sheep. In total are 735 farms in the MRZ, which last municipality-dependent from 61 to 92 days. 115 farms have to be culled preventively, which is more than in Jade-Weser. The total costs are without price effects € 31.7 million, whereat the major part is DC. Compared to

Table 11: Probable/medium scenarios in the Jade-Weser region for the strategies 1km culling and 3km vaccination

Jade-Weser (probable/medium scenarios), in millions of Euros

	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
Cost category	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
1km culling															
Total direct cost (DC)	24.21	3.76	19.44	0.11	0.91	24.21	3.76	19.44	0.11	0.91	24.21	3.76	19.44	0.11	0.91
Compensation for farmers	20.46	-	19.44	0.11	0.91	20.46	-	19.44	0.11	0.91	20.46	-	19.44	0.11	0.91
Net DC for TSK/authorities	24.21	3.76	19.44	0.11	0.91	24.21	3.76	19.44	0.11	0.91	24.21	3.76	19.44	0.11	0.91
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	7.88	0.49	6.30	0.01	1.09	30.00	0.49	27.36	0.38	1.77	43.26	0.49	40.00	0.60	2.18
Compensation for farmers (welfare slaughtering)	3.18	-	2.29	0.00	0.89	3.18	-	2.29	0.00	0.89	3.18	-	2.29	0.00	0.89
Net DCC for TSK/authorities	3.67	0.49	2.29	0.00	0.89	3.67	0.49	2.29	0.00	0.89	3.67	0.49	2.29	0.00	0.89
Net DCC for farmers	4.22	-	4.01	0.01	0.20	4.22	-	4.01	0.01	0.20	4.22	-	4.01	0.01	0.20
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	22.11	-	21.06	0.37	0.68	35.38	-	33.70	0.59	1.09
Total gross cost of epidemic with …% price effects	32.10	4.24	25.74	0.12	2.00	54.21	4.24	46.81	0.48	2.68	67.48	4.24	59.44	0.70	3.09
Total net cost of epidemic with …% price effects	32.10	27.88	4.01	0.01	0.20	54.21	27.88	25.07	0.38	0.88	67.48	27.88	37.71	0.60	1.29
3km vaccination															
Total direct cost (DC)	9.62	6.34	2.97	0.02	0.29	9.62	6.34	2.97	0.02	0.29	9.62	6.34	2.97	0.02	0.29
Compensation for farmers	3.28	-	2.97	0.02	0.29	3.28	-	2.97	0.02	0.29	3.28	-	2.97	0.02	0.29
Net DC for TSK/authorities	9.62	6.34	2.97	0.02	0.29	9.62	6.34	2.97	0.02	0.29	9.62	6.34	2.97	0.02	0.29
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	6.86	0.59	5.06	0.00	1.20	93.87	0.59	89.77	0.73	2.78	146.08	0.59	140.59	1.17	3.73
Compensation for farmers (welfare slaughtering)	3.85	-	2.77	0.00	1.08	3.85	-	2.77	0.00	1.08	3.85	-	2.77	0.00	1.08
Net DCC for TSK/authorities	4.44	0.59	2.77	0.00	1.08	4.44	0.59	2.77	0.00	1.08	4.44	0.59	2.77	0.00	1.08
Net DCC for farmers	2.42	-	2.30	0.00	0.12	2.42	-	2.30	0.00	0.12	2.42	-	2.30	0.00	0.12
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	87.01	-	84.70	0.73	1.58	139.22	-	135.52	1.17	2.53
Total gross cost of epidemic with …% price effects	16.49	6.93	8.04	0.02	1.49	103.50	6.93	92.74	0.76	3.07	155.71	6.93	143.56	1.19	4.02
Total net cost of epidemic with …% price effects	16.49	14.07	2.30	0.00	0.12	103.50	14.07	87.00	0.73	1.70	155.71	14.07	137.82	1.17	2.65

1km culling: 40 infected farms (30 infected cattle, 6 pig, 4 sheep keepers, 11,069 infected animals of which 4,681 cattle), 1105 farms in PZ (106 farms culled preventively 22,500 animals), 162 farms in SZ I, longest duration of MRZs in municipality j: 85 days, shortest: 61 days

3km vaccination: 25 infected farms (20 cattle, 3 pig and 2 sheep keepers 6,916 infected animals of which 3,255 cattle), 925 farms in PZ (202,000 animals vaccinated), 395 farms in SZ I, longest duration of MRZs in municipality j: 79 days, shortest: 71 days

Table 12: Probable/medium scenarios in the Grafschaft Bentheim for the strategies 1km culling and 3km vaccination Grafschaft Bentheim (probable/medium scenarios), in millions of Euros

1km culling

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organ-isation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organ-isation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organ-isation	Farmers Cattle	Farmers Sheep	Farmers Swine
Total direct cost (DC)	22.88	4.26	11.87	0.04	6.70	22.88	4.26	11.87	0.04	6.70	22.88	4.26	11.87	0.04	6.70
Compensation for farmers	18.62	-	11.87	0.04	6.70	18.62	-	11.87	0.04	6.70	18.62	-	11.87	0.04	6.70
Net DC for TSK/authorities	22.88	4.26	11.87	0.04	6.70	22.88	4.26	11.87	0.04	6.70	22.88	4.26	11.87	0.04	6.70
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	8.81	1.02	2.52	0.00	5.27	17.01	1.02	8.14	0.03	7.82	21.92	1.02	11.51	0.05	9.35
Compensation for farmers (welfare slaughtering)	4.60	-	0.95	0.00	3.65	4.60	-	0.95	0.00	3.65	4.60	-	0.95	0.00	3.65
Net DCC for TSK/authorities	5.63	1.02	0.95	0.00	3.65	5.63	1.02	0.95	0.00	3.65	5.63	1.02	0.95	0.00	3.65
Net DCC for farmers	3.18	-	1.57	0.00	1.61	3.18	-	1.57	0.00	1.61	3.18	-	1.57	0.00	1.61
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	8.20	-	5.62	0.03	2.55	13.11	-	8.99	0.04	4.08
Total gross cost of epidemic with …% price effects	31.69	5.28	14.39	0.04	11.97	39.88	5.28	20.01	0.07	14.52	44.80	5.28	23.38	0.09	16.05
Total net cost of epidemic with …% price effects	31.69	28.50	1.57	0.00	1.61	39.88	28.50	7.19	0.03	4.16	44.80	28.50	10.56	0.05	5.70

3km vaccination

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organ-isation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organ-isation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organ-isation	Farmers Cattle	Farmers Sheep	Farmers Swine
Total direct cost (DC)	6.36	3.74	1.45	0.00	1.17	6.36	3.74	1.45	0.00	1.17	6.36	3.74	1.45	0.00	1.17
Compensation for farmers	2.62	-	1.45	0.00	1.17	2.62	-	1.45	0.00	1.17	2.62	-	1.45	0.00	1.17
Net DC for TSK/authorities	6.36	3.74	1.45	0.00	1.17	6.36	3.74	1.45	0.00	1.17	6.36	3.74	1.45	0.00	1.17
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	8.52	1.29	1.74	0.00	5.49	37.40	1.29	23.32	0.06	12.73	54.73	1.29	36.27	0.10	17.08
Compensation for farmers (welfare slaughtering)	5.82	-	1.17	0.00	4.65	5.82	-	1.17	0.00	4.65	5.82	-	1.17	0.00	4.65
Net DCC for TSK/authorities	7.11	1.29	1.17	0.00	4.65	7.11	1.29	1.17	0.00	4.65	7.11	1.29	1.17	0.00	4.65
Net DCC for farmers	1.41	-	0.57	0.00	0.84	1.41	-	0.57	0.00	0.84	1.41	-	0.57	0.00	0.84
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	28.89	-	21.58	0.06	7.24	46.22	-	34.53	0.09	11.59
Total gross cost of epidemic with …% price effects	14.88	5.03	3.19	0.00	6.66	43.77	5.03	24.77	0.06	13.90	61.10	5.03	37.72	0.10	18.25
Total net cost of epidemic with …% price effects	14.88	13.47	0.57	0.00	0.84	43.77	13.47	22.15	0.06	8.08	61.10	13.47	35.10	0.10	12.43

1km culling: 40 infected farms (22 cattle 19 pig, 4 sheep keepers, 27,690 infected animals of which 2,685 cattle), 432 farms in PZ (115 are culled preventively, 64,000 animals), 303 farms in SZ I, longest duration of MRZs in municipality j: 92 days, shortest: 61 days

3km vaccination: 25 infected farms (13 cattle, 12 pig and 1 sheep keepers, 15,558 infected animals of which 1,612 cattle), 397 farms in PZ and vaccinated (229,000 animals), 353 farms in SZ I, longest duration of MRZs in municipality j: 85 days, shortest: 71 days

Jade-Weser, the DCC are again higher by almost one million due to the higher share of swine. Direct compensations are lower in Grafschaft Bentheim since fewer cattle are infected. Direct consequential compensations, on the other hand, are 1.6 million higher, because more pigs and piglets have to be slaughtered for welfare reasons.

If price effects are ignored, vaccination is only half as expensive as culling. The reasons are fewer compensation payments and less infected farms. In the vaccination scenario, 13 farms keep cattle, 12 keep pigs and one farm has sheep. 750 farms are in MRZ and 397 have to be vaccinated with 229,000 animals. The restrictions last from 71 to 85 days.

In the scenarios with price effects, the costs for culling increase to € 39.9 and 44.8 million. Vaccination cost rise up to € 43.8 million and € 61.1 million at 80% reduction (22.9 and 36.7 million due to lower meat prices). Once more, it becomes apparent that the costs are quite similar. In Jade-Weser, the difference between the two strategies was at 80% price reduction about € 90 million and in Grafschaft Bentheim, this is only € 16.3 million.

4.3   Worst-case scenarios

4.3.1   Jade-Weser region

In the worst-case culling scenario, 150 infected farms are assumed. For the vaccination strategy, 100 farms are supposed in the estimates. Table 13 presents the results of one simulation that has mean and median values. Table A22 shows the results of 100 iterations with different farm types of infected farms. In the culling scenario, 117 farms keep cattle, 25 pigs and 11 keep sheep. Using the vaccination strategy, 81 farms keep cattle, 12 keep pigs and seven farms have sheep. For both strategies, the maximum closure of affected municipalities is as well 108 days.

With € 108.4 million, the total costs of the culling strategy are – without any price effects – about thrice as high as the € 38.5 million of the vaccination strategy. Almost € 87 million are DC. Only 20% of the total costs are DCC when culling. Total compensation payments sum up to € 80.7 million (76.14 plus 4.51 million). The TSK has the highest total net costs with almost € 92 million. Farmers face losses of about € 16.5 million, which incur mostly at cattle keepers. For the worst-case vaccination scenario, about two thirds of the total costs without price effects are DC and one third are DCC. This shows a shift from DC to DCC. Compensations for culling and welfare slaughtering are up to € 18.4 million. Farmers lose € 8 million of which € 420,000 incur at sheep and pig farms. About € 30.5 million has to be paid by the TSK and the authorities.

When assuming 50% or 80% price reductions of agricultural products, the reverse situation is the case. For vaccination, farmers would have to bear additional losses of € 144.5 million and 231.3 million respectively due to losses in milk production and decrease in animal values (107 and 171 million due losses in animal value). In total, about 270,000 living cattle are in the MRZ (after culling infected ones). Many of them are vaccinated and since they have a high monetary value, this leads to very high losses for cattle farmers.

Again, it can be seen that the share of DCC is higher in the vaccination strategy. The TSK and the authorities, on the other hand, face lower costs when vaccinating, because less compensations need to be paid. When no price effects occur, this is no problem for farmers, because despite a higher share, the total net costs stay lower for them. With price effects, however, farmers suffer from very high value losses of the animals, especially cattle.

Table 13: Worst-case scenarios in the Jade-Weser region for the strategies 1km culling and 3km vaccination Jade-Weser (worst-case scenarios), in millions of Euros

1km culling

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
Total direct cost (DC)	86.74	10.60	72.62	0.57	2.95	86.74	10.60	72.62	0.57	2.95	86.74	10.60	72.62	0.57	2.95
Compensation for farmers	76.14	-	72.62	0.57	2.95	76.14	-	72.62	0.57	2.95	76.14	-	72.62	0.57	2.95
Net DC for TSK/authorities	86.74	10.60	72.62	0.57	2.95	86.74	10.60	72.62	0.57	2.95	86.74	10.60	72.62	0.57	2.95
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	21.61	0.64	19.27	0.08	1.63	54.52	0.64	50.87	0.74	2.28	74.27	0.64	69.83	1.13	2.67
Compensation for farmers (welfare slaughtering)	4.51	-	3.52	0.00	0.99	4.51	-	3.52	0.00	0.99	4.51	-	3.52	0.00	0.99
Net DCC for TSK/authorities	5.15	0.64	3.52	0.00	0.99	5.15	0.64	3.52	0.00	0.99	5.15	0.64	3.52	0.00	0.99
Net DCC for farmers	16.46	-	15.75	0.08	0.63	16.46	-	15.75	0.08	0.63	16.46	-	15.75	0.08	0.63
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	32.91	-	31.60	0.66	0.65	52.66	-	50.56	1.05	1.05
Total gross cost of epidemic with …% price effects	108.35	11.23	91.89	0.65	4.57	141.26	11.23	123.49	1.31	5.23	161.01	11.23	142.45	1.71	5.62
Total net cost of epidemic with …% price effects	108.35	91.89	15.75	0.08	0.63	141.26	91.89	47.35	0.74	1.29	161.01	91.89	66.31	1.13	1.68

3km vaccination

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
Total direct cost (DC)	23.73	11.28	11.37	0.05	1.03	23.73	11.28	11.37	0.05	1.03	23.73	11.28	11.37	0.05	1.03
Compensation for farmers	12.45	-	11.37	0.05	1.03	12.45	-	11.37	0.05	1.03	12.45	-	11.37	0.05	1.03
Net DC for TSK/authorities	23.73	11.28	11.37	0.05	1.03	23.73	11.28	11.37	0.05	1.03	23.73	11.28	11.37	0.05	1.03
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	14.79	0.84	12.19	0.01	1.76	159.33	0.84	153.65	1.19	3.65	246.05	0.84	238.52	1.90	4.79
Compensation for farmers (welfare slaughtering)	5.94	-	4.59	0.00	1.35	5.94	-	4.59	0.00	1.35	5.94	-	4.59	0.00	1.35
Net DCC for TSK/authorities	6.78	0.84	4.59	0.00	1.35	6.78	0.84	4.59	0.00	1.35	6.78	0.84	4.59	0.00	1.35
Net DCC for farmers	8.01	-	7.60	0.01	0.41	8.01	-	7.60	0.01	0.41	8.01	-	7.60	0.01	0.41
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	144.54	-	141.46	1.18	1.90	231.26	-	226.33	1.89	3.03
Total gross cost of epidemic with …% price effects	38.52	12.12	23.56	0.06	2.78	183.06	12.12	165.02	1.24	4.68	269.78	12.12	249.90	1.95	5.82
Total net cost of epidemic with …% price effects	38.52	30.51	7.60	0.01	0.41	183.06	30.51	149.05	1.19	2.30	269.78	30.51	233.93	1.90	3.44

1km culling: 150 infected farms (117 cattle, 25 pig, 11 sheep keepers, 36,629 infected animals of which 17,933 cattle), 1,569 farms in PZ (399 culled preventively, 87,000 animals), 100 farms in SZ I, longest duration of MRZs in municipality j: 108 days, shortest: 64 days

3km vaccination: 100 infected farms (81 cattle, 12 pig, 7 sheep keepers, 25,609 infected animals of which 12,453 cattle), 1,565 farms in PZ to vaccinate (339,000 animals), 153 farms in SZ I, longest duration of MRZs in municipality j: 108 days, shortest: 76 days

Table 14: Worst-case scenarios Grafschaft Bentheim for the strategies 1km culling and 3km vaccination Grafschaft Bentheim (worst-case scenarios), in millions of Euros

Cost category	Without price effects in MRZs					With price effects in MRZs (-50%)					With price effects in MRZs (-80%)				
	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine	Total	TSK Organisation	Farmers Cattle	Farmers Sheep	Farmers Swine
1km culling															
Total direct cost (DC)	84.27	12.29	51.32	0.10	20.55	84.27	12.29	51.32	0.10	20.55	84.27	12.29	51.32	0.10	20.55
Compensation for farmers	71.98	-	51.32	0.10	20.55	71.98	-	51.32	0.10	20.55	71.98	-	51.32	0.10	20.55
Net DC for TSK/authorities	84.27	12.29	51.32	0.10	20.55	84.27	12.29	51.32	0.10	20.55	84.27	12.29	51.32	0.10	20.55
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	17.86	1.03	8.50	0.01	8.33	25.28	1.03	13.91	0.04	10.31	29.74	1.03	17.16	0.05	11.50
Compensation for farmers (welfare slaughtering)	4.31	-	0.95	0.00	3.37	4.31	-	0.95	0.00	3.37	4.31	-	0.95	0.00	3.37
Net DCC for TSK/authorities	5.34	1.03	0.95	0.01	3.37	5.34	1.03	0.95	0.00	3.37	5.34	1.03	0.95	0.00	3.37
Net DCC for farmers	12.52	-	7.55	0.01	4.96	12.52	-	7.55	0.01	4.96	12.52	-	7.55	0.01	4.96
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	7.42	-	5.42	0.02	1.98	11.87	-	8.66	0.04	3.17
Total gross cost of epidemic with …% price effects	102.13	13.32	59.82	0.12	28.88	109.55	13.32	65.23	0.14	30.86	114.00	13.32	68.48	0.16	32.05
Total net cost of epidemic with …% price effects	102.13	89.61	7.55	0.01	4.96	109.55	89.61	12.97	0.04	6.94	114.00	89.61	16.22	0.05	8.13
3km vaccination															
Total direct cost (DC)	18.08	8.03	5.96	0.02	4.07	18.08	8.03	5.96	0.02	4.07	18.08	8.03	5.96	0.02	4.07
Compensation for farmers	10.06	-	5.96	0.02	4.07	10.06	-	5.96	0.02	4.07	10.06	-	5.96	0.02	4.07
Net DC for TSK/authorities	18.08	8.03	5.96	0.02	4.07	18.08	8.03	5.96	0.02	4.07	18.08	8.03	5.96	0.02	4.07
Net DC for farmers	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00
Total direct consequential cost (DCC)	15.68	2.00	4.29	0.00	9.38	69.49	2.00	48.12	0.07	19.30	101.78	2.00	74.41	0.11	25.25
Compensation for farmers (welfare slaughtering)	8.64	-	1.92	0.00	6.73	8.64	-	1.92	0.00	6.73	8.64	-	1.92	0.00	6.73
Net DCC for TSK/authorities	10.64	2.00	1.92	0.00	6.73	10.64	2.00	1.92	0.00	6.73	10.64	2.00	1.92	0.00	6.73
Net DCC for farmers	5.03	-	2.37	0.00	2.66	5.03	-	2.37	0.00	2.66	5.03	-	2.37	0.00	2.66
+ Net DCC for farmers due to price effects in MRZs	0.00	-	0.00	0.00	0.00	53.82	-	43.83	0.07	9.92	86.10	-	70.12	0.11	15.87
Total gross cost of epidemic with …% price effects	33.76	10.03	10.25	0.02	13.45	87.58	10.03	54.08	0.09	23.37	119.87	10.03	80.38	0.13	29.32
Total net cost of epidemic with …% price effects	33.76	28.73	2.37	0.00	2.66	87.58	28.73	46.20	0.07	12.57	119.87	28.73	72.50	0.11	18.52

1km culling: 150 infected farms (81 cattle, 71 pig, 12 sheep keepers, 86,015 infected animals of which 9,425 cattle), 925 farms in PZ (489 are culled preventively, 212,000 animals), longest duration of MRZs in municipality j: 108 days, shortest: 64 days

3km vaccination: 100 infected farms (55 cattle, 44 pig, 10 sheep keepers, 54,509 infected animals of which 6,608 cattle), 813 farms in PZ and vaccinated (392,000 animals), 162 farms in SZ I, longest duration of MRZs in municipality j: 108 days, shortest: 76 days

4.3.2   Grafschaft Bentheim

Table 14 above and Table A25 in the appendix show the worst-case results for the Grafschaft Bentheim. For the culling scenario, there are 81 cattle livestock, 71 pig and 12 sheep stocks infected with together 86,000 animals. 925 farms are in the PZ and 487 farms are culled preventively, which are an additional 212,000 animals. The total costs are almost equal to Jade-Weser and even the distribution between DC and DCC are similar. However, direct compensations are again somewhat lower and direct consequential compensation higher compared in Grafschaft Bentheim.

In the vaccination scenario, 55 cattle, 44 pig and 10 sheep stocks are infected by FMD. 813 farms are in the PZ and have to be vaccinated with 392,000 animals. Another 162 farms are in SZ I. For vaccination, the total costs are € 5 million lower than in Jade-Weser although more animals have to be vaccinated and twice as many animals are infected. Total compensations are similar to Jade-Weser but with a higher share of compensations at DCC.

With price effects, the costs of culling rise from € 102 million to € 110 and € 114 million. Once more, the increase is quite small compared to Jade-Weser. For vaccination, the costs increase from € 34 to € 88 and to € 120 million at 80% reduction. Therefore, vaccination can be an economical alternative to culling for the Grafschaft Bentheim if the price effects are not too high. However, if no indemnification is paid, farmers have to come up for the value losses. At 50% reduction, cattle farmers would face losses of about € 46.2 million and pig keepers an additional € 12.6 million. Using the culling strategy, this would only be € 13 million for cattle and € 7 million for pig farmers. At 80% reduction, the losses for farmers would of course be higher. Those losses could lead to many bankruptcies of cattle farms especially.

4.4   Interim summary of DC, DCC and compensations

Figure 3 and Figure 4 summarise the results that were presented in detail above. The results of Jade-Weser are presented in Figure 3, the results of Grafschaft Bentheim in Figure 4. On the left side of each figure the costs for the culling strategy are presented, on the right side the costs for vaccination. Each bar triple represents the results of one strategy. To which strategy the bars refer is written below each triple. The red bars show the total DC and DCC without possible price effects. The blue colour shows the costs for the TSK and green are costs for farmers. The middle bar of each triple represents the net costs divided by farmers and the TSK. Without the upper two parts of the middle bar (the possible losses of price reductions), it has the same height as the bar left to it. The right bar of the triples is the amount of compensation payments to farmers that has to be paid by the TSK and is therefore coloured blue.

When price effects are ignored, the vaccination scenarios have always lower total costs compared to culling. DC are much higher for the culling strategies, the share of DCC increases when using a vaccination strategy. For Jade-Weser, the inclusion of price effects would lead to a cost advantage for the culling strategy in all three scenarios for both 50 and 80% price reduction. In the Grafschaft Bentheim, the losses for farmers increase less when price reductions are included. For the probable scenario, at 50% reduction, the costs between the strategies are similar. At 80% reduction, vaccination has an advantage. In the worst case, vaccination has an advantage at 50% reduction but at 80%, culling should be preferred.
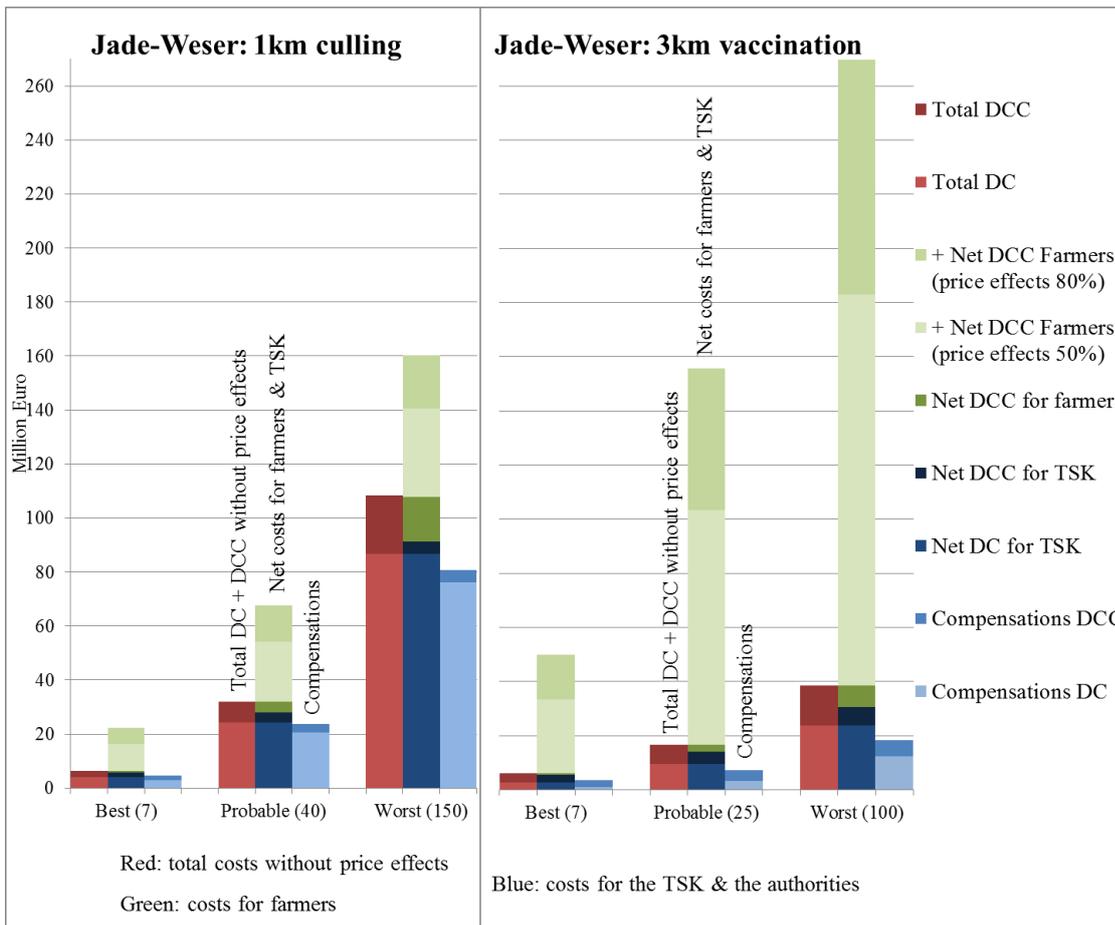
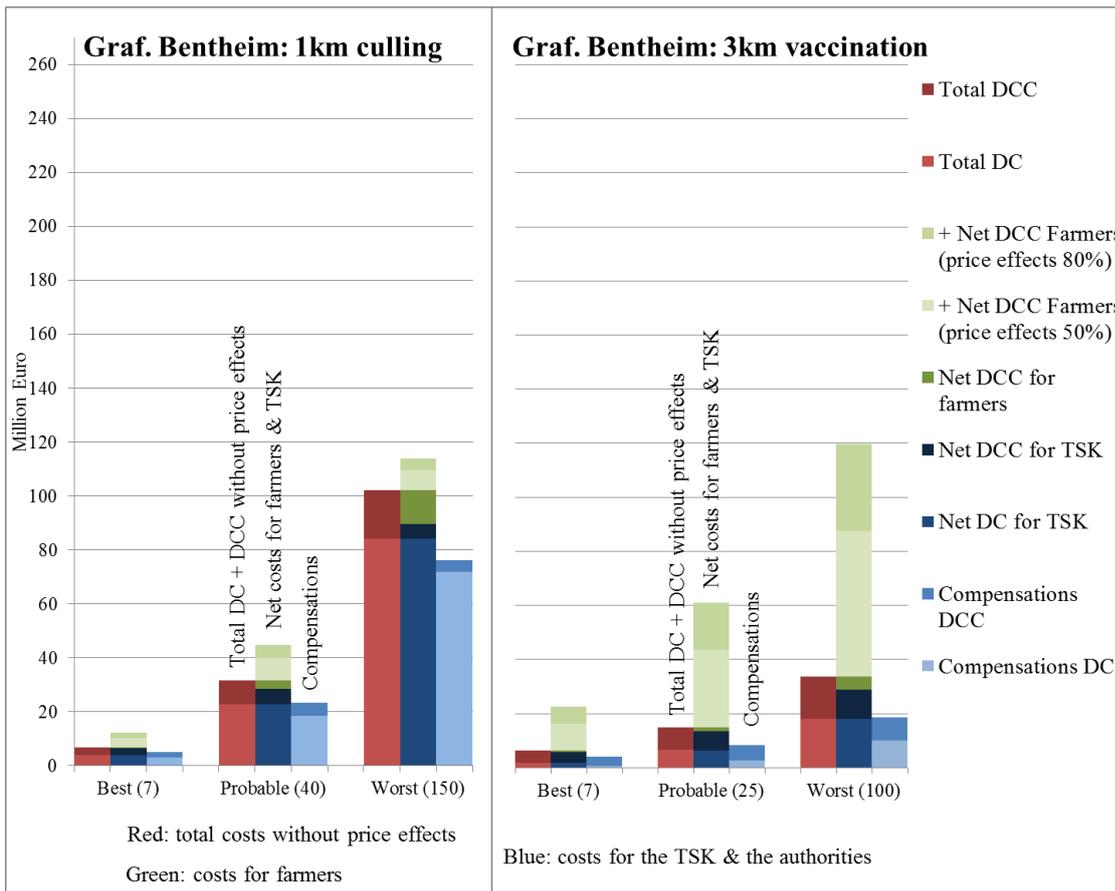**Figure 3: Result's summary of the Jade-Weser region**

Figure 4: Result's summary of Grafschaft Bentheim

4.5   Indirect Consequential Costs (ICC)

In addition to DC and DCC, ICC occur in regions outside the MRZs. This cost category is hard to determine, because it remains unknown how demand and supply on the markets develop. Approximations of the demand changes will be left out, but the results of the model give estimates of agricultural products that are missing on the market. For milk, such changes are analysed using the price elasticity of supply, which is supposed to be 0.45 (HEMME ET AL., 2005). Additionally, the absolute numbers give also an estimate of how many buyers are affected by trading restrictions, for example in piglet sells.

Next to changes on the German market, export problems and export restrictions would enter into force. In accordance with the UK 2007 outbreak (section 2.2.2.1), EU export restrictions could last for the MRZs for as long as three months after the last detection. For vaccination this could even take up to one year. For the surrounding regions, it could be about 2 ½ months and for Germany, this could take 1 ½ months after the last detection.

According to UN COMTRADE DATABASE (2015), Germany exported in 2013 dairy products of about € 8.446 billion (at an average exchange rate of € 1 = US$ 1.328 (EUROSTAT, 2015)) and imported dairy products of € 5.457 billion. If equal exports over the year existed, a one-month export ban would affect products with a value of € 704 million.[1] Live animal exports and meat exports of pork, beef and sheep or goats were in 2013 at € 9.035 billion and monthly at € 753 million (yearly imports of € 6.769 billion). Although those volumes are not equal to possible losses in case of an epidemic, they show the importance of the export market for the German agriculture. In addition, as the dairy volumes above show, not all products could be sold on the German market, especially since many imported products are deli food like cheese and curd (€ 3.271 billion). During an epidemic, processors will have to produce non-perishable products like milk powder, butter, pickled meat or frozen products. After disease, those products may be sold with price reduction. For example, if they have to be sold at 25% price decrease, a three months export ban for Germany could cost the dairy industry sales losses of about 390 million even when products destined for export (without cheese) can be sold on the German market. For the meat sector, when assuming that all export destined products can be sold on the German market, a three months export stop would have minimum costs of € 140 million.

4.5.1   Jade-Weser region

Table 15 summarises the affected quantities in the worst-case scenarios for the Jade-Weser region. The table shows the total German milk production and the milk production of Lower Saxony. The German milk production is reduced by 3.1% in both scenarios, because the MRZs have the same size. When assuming an elasticity of 0.45 the initial milk price of € 0.32/kg increases only by € 0.004/kg outside the MRZ – if disease does not spread further. This does not even take into account the connections to European trade partners. For this reason, an increase in milk prices is unlikely. Only when assuming a more widespread epidemic, a regional market and/or a higher elasticity, it is likely that the milk price will rise.

For both strategies, regionalisation will be introduced to allow non-affected regions to export but for the vaccination-to-live strategy, the export ban will take much longer. This could have serious consequences for dairies (and therefore for farmers) in and around the Jade-Weser region, because many of them depend highly on export. For example, the DMK exports more than 40% of its production and has a dairy at Strückhausen in the County of Wesermarsch, at which milk powders are produced (DMK, 2015a; 2015b). The

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[1] The German MILCHINDUSTRIE-VERBAND E.V. (2014) even published exports of € 9.45 billion, which would increase the affected trade volumes.

Ammerland Dairy states that 49% of its productions are exported to 55 countries (MOLKEREI AMMERLAND, 2015). The dairy processor Rücker declares to export to 60 countries. Three-fifth of its production is cheese, one-fifth milk powder and one-fifth butter (RÜCKER, 2015).

Besides milk, piglets and fattening pigs are affected. However, Jade-Weser has only a minor importance in pig production. The 42,500 affected fattening pigs are unlikely to increase pork prices. Nevertheless, some pig fatteners outside the MRZ may face procurement problems of piglets if they would order piglets from farmers in the MRZ. If farmers order piglet sections of 250, 170 sales would be concerned (of which several farmers are affected in multiple ways). In the probable and best-case scenario are of course fewer piglets affected (about 28,500 and 20,000).

Table 15: Quantities affected in Jade-Weser by FMD in the worst-case scenarios
[1] WOHLFARTH ET AL. (2014); data of 2010; in 2013: 25,049 t/d
[2] HEMME ET AL. (2005)

External effects: quantities & effects on ICC (Jade-Weser worst-case)							
	Parameters for ICC		**Price (€/kg, excl tax)**	**Reduction of prod. due disease**	**Price elasticity of supply**[2]	**Increase of price**	**New price (€/kg)**
1km culling	Infected animals	36,629					
	Cloven-hoofed animals at IP & in MRZ	399,472					
	Cattle at IP and in MRZ	282,080					
	Milk production per day at IP & in MRZ (22kg/cow*d)	2,486,882					
	Milk production per day in Germany[1]	79,660,274	0.320	3.122%	0.450	1.405%	**0.324**
	Milk production per day in Lower Saxony[1]	13,662,466	0.320	18.202%	0.450	8.191%	**0.346**
	Piglets at IP & in MRZ	34,249					
	Fattening pigs at IP & in MRZ	42,793					
3km vaccination	Infected animals	25,609					
	Cloven-hoofed animals at IP and in MRZ	396,260					
	Cattle at IP and in MRZ	282,080					
	Milk production per day at IP & in MRZ (22kg/cow*d)	2,486,882					
	Milk production per day in Germany[1]	79,660,274	0.320	3.122%	0.450	1.405%	**0.324**
	Milk production per day in Lower Saxony[1]	13,662,466	0.320	18.202%	0.450	8.191%	**0.346**
	Piglets at IP & in MRZ	31,909					
	Fattening pigs at IP & in MRZ	42,406					

4.5.2 Grafschaft Bentheim

The most important quantities affected by FMD for the Grafschaft Bentheim worst-case scenarios are presented in Table 16. More than twice as many animals are infected by FMD compared to Jade-Weser and there are as well more animals in the zones because of the higher swine share. Despite more affected animals, the cattle and cow share is smaller

in this case. Thus, milk price increases due to shortages on the dairy markets can be excluded

The effects on the pig markets are more interesting. In both worst-case scenarios, piglet stocks of 205,000 are affected and in total, there are 51,287 sows in the Grafschaft Bentheim, according to the census data. Those reductions on the piglet market would concern many pig fatteners outside the MRZ and increasing demand could lead to an increase of piglet prices at the expense of fatteners. Sow managers, on the other hand, could profit. If pork prices will increase from such a development too, depends on the overall dimension of disease and demand reactions of consumers.

According to the DAIRY INDUSTRY ASSOCIATION LOWER SAXONY (2015) no dairy is directly situated in Grafschaft Bentheim. Dairies in the closer area are e.g. the DMK in the County of Emsland or DOC Kaas in Hoogeveen (Netherlands). The DMK produces milk powder but also coffee creamer and the like (DMK, 2015b) and could be affected by regionalisation. The most important abattoirs of the region are Westfleisch in Schöppingen and Coesfeld (NRW; WESTFLEISCH, 2015) and Weidemark in Sögel (County of Emsland; WEIDEMARK, 2015). If FMD is focussed only on the Grafschaft Bentheim, those abattoirs could possibly be spared of regionalisation.

Table 16: Quantities affected by FMD in Grafschaft Bentheim worst-case scenarios
[1] WOHLFARTH ET AL. (2014); data of 2010; in 2013: 25,049 t/d
[2] HEMME ET AL. (2005)

External effects: quantities & effects on ICC (Grafschaft Bentheim worst-case)							
	Parameters for ICC		**Price (€/kg, excl. tax)**	**Reduction of prod. due disease**	**Price elasticity of supply[2]**	**Increase of price**	**New price (€/kg)**
1km culling	Infected animals	86,015					
	Cloven-hoofed animals at IP & in MRZ	510,430					
	Cattle at IP and in MRZ	98,959					
	Milk production per day at IP & in MRZ (22kg/cow*d)	662,005					
	Milk production per day in Germany[1]	79,660,274	0.320	0.831%	0.450	0.374%	**0.321**
	Milk production per day in Lower Saxony[1]	13,662,466	0.320	4.845%	0.450	2.180%	**0.327**
	Piglets at IP & in MRZ	204,573					
	Fattening pigs at IP & in MRZ	153,282					
3km vaccination	Infected animals	54,509					
	Cloven-hoofed animals at IP & in MRZ	510,430					
	Cattle at IP and in MRZ	98,959					
	Milk production per day at IP & in MRZ (22kg/cow*d)	662,005					
	Milk production per day in Germany[1]	79,660,274	0.320	0.831%	0.450	0.374%	**0.321**
	Milk production per day in Lower Saxony[1]	13,662,466	0.320	4.845%	0.450	2.180%	**0.327**
	Piglets at IP & in MRZ	204,573					
	Fattening pigs at IP & in MRZ	153,282					

5   DISCUSSION

Protective vaccination and depopulation strategies were analysed in this pilot study. The estimates were processed by using a static modelling approach. The numeric results should not be taken as definite since they depend on many changeable assumptions. The tendencies, however, reveal important findings that should be considered when using a control strategy.

5.1   Discussion of methodology

5.1.1   Epidemiology

The most exact way of analysing animal diseases in advance is to use epidemiological models like InterSpread (see section 2.3.1). Those models are based on geo-reference data of single farms, which enables the consideration of many different epidemiological characteristics and timely spread. Because of German secrecy obligations, such farm data is not publicly available. For this reason, an alternative approach had to be used. In order to deal with the problem of farm data access, the spread of disease was estimated by expert assessments. Those assessments give only the final spread of disease, so that the dynamics of the epidemic are left out. This problem was attempted to tackle to some extent; for example, the duration of the zoning was set shorter than the total time of epidemic events (section 3.2.1.4). Hereby, it is assumed that the disease spreads from municipality to municipality, so that some areas are affected later by FMD, and that the MRZs established first are lifted earlier.

Three scenarios were estimated for each control strategy, which is only a small variety of possibilities. In addition, those scenarios were created by few experts. The scenarios are based on knowledge of the spatial characteristics of the regions but not on epidemiological features. Therefore, they are not representative and in reality such fictive outbreaks will not occur. The range of the best, possible and worst case is not based on an underlying principle and depends itself on many factors. For example, when farmers and veterinarians are on alert to FMD, the best-case scenario could already be the most likely scenario (France and Ireland had in 2001 also only few IPs). The probable vaccination scenario is comparable to the epidemic in the Netherlands in 2001. The worst-case scenarios are based on the assumption of a widespread epidemic in Germany. In the 2001 UK epidemic, 2030 farms were infected in the whole country. Therefore, $100 - 150$ farms in each region could be a realistic basis for the analysis. However, for this pilot study the idea of the classification was rather to get a range of affected animals and farms as a basis for the economic model. This is sufficient to compare the approximate consequences of an epidemic.

Regarding the created scenarios, the differences between the culling and vaccination strategies seem to be somewhat odd in the first place. For example, the simulations of BACKER ET AL. (2009) for the Netherlands tend to have less IPs when a culling strategy is applied. On the other hand, HUIRNE ET AL. (2001) analysed the epidemic in the Netherlands in detail and concluded that for controlling disease vaccination in 2km radius or a combination of culling and vaccination is the most effective in animal dense regions. The faster disease control with vaccination is in line with the created scenarios of the experts. The difference can be justified by low culling capacities so that it takes longer to combat disease. In contrast, vaccination can be applied quickly, once the vaccine is provided. If vac-

cinating, this will start at the outer borders of the PZ so that a protection circle is drawn around the IPs. The aim is that disease cannot escape from the PZ. The better control is also reflected in the duration of epidemiological events, which is longer for the probable/medium and worst-case culling scenarios.

Many average and estimated values were used in order to calculate the affected animals and farms. The dealing with those inaccuracies is described in Chapter 3. However, the overall influence on the height of the cost should be small, since for most scenarios the zoning geared to municipality borders and therefore it is known, how many farms and animals are affected in one municipality. Thereby, it should also be mentioned that the data of the agricultural census is already four to five years old. The veterinary authorities noted that the livestock numbers of the census are smaller than in reality. Partly, this is because hobby and small-scale farmers are left out of the census. But more important, some livestock numbers increased in the last years, e.g. the number of pigs in the County of Grafschaft Bentheim. This could lead to fewer culled, vaccinated and welfare slaughtered animals in the model and thus, to lower estimated costs.

In order to create a more realistic assessment, the model could be expanded to a greater region. With the data of the Agriculture Census 2010, a model for the whole Weser-Ems region or even Lower Saxony would be possible. Unfortunately, data of NRW was incomplete, so that this federal state cannot be included. Doing so, the epidemic could spread further in the model or isolated cases outside the core could be considered. In addition, the MRZs could expand into other counties.

5.1.2 Economic model

The economic model is based on many assumptions about the cost types. The assumptions can be varied in the model manually and the different results could be analysed further. However, there are many dependencies and the value added of changing the assumptions seems to be not very high. If for example higher milk prices will be assumed in the model, how would the input prices develop for the gross margin calculations? Changing one assumption would lead to new assumptions in this case, which makes it very vague and complex.

In order to evaluate the validity of the economic model, costs of past FMD outbreaks (section 2.1) and the studies from the literature review (section 2.3) can be used to compare the results. WILLMS (2006) calculated in his model for the County of Osnabrück costs between € 33 and € 134 million for the culling strategy including compensations of € 1.5 to € 19 million. The county has a similar size to the Jade-Weser region but more pig farmers. For Jade-Weser, costs in the best-case culling scenario amount to € 6 or 22 million respectively (with 80% price reductions). In the worst-case culling scenario, costs amount up to € 108 and 161 million respectively. For Grafschaft Bentheim, the costs are between € 7 in the best case without price reduction and 114 million in the worst case at 80% reduction. The costs of the two study areas have therefore a similar range. KRÄMER (2010) estimated an average financial damage to farmers of about € 4 million after compensation. This value is comparable to the probable scenario of Jade-Weser, in which compensations of € 4.2 million were calculated for the culling strategy. For the Grafschaft Bentheim, the damage is lower at about € 3.2 million.

The costs of real outbreaks are often higher than the model results. Reasons are the focus on one single region in the model and not all of Lower Saxony or Germany. Additionally, the created results concentrate on farmers and organisational costs but leave out costs for upstream and downstream sectors like feed production, animal transporters, abattoirs or dairies. In the 2007 FMD epidemic in the UK, the government and the animal health fond had to spend £ 47 million (ANDERSON, 2008). For Jade-Weser, costs are in the

best-case culling scenario € 6 million, in the probable scenario € 28 million and in the worst-case scenario € 92 million were to be paid by the authorities. For the Grafschaft Bentheim, the costs are similar. However, the 2007 epidemic had two waves of infections and lasted quite long although only eight premises were infected (the epidemic events took 58 days). Thus, the personnel costs were higher and are hardly comparable.

The 2001 outbreak in the Netherlands with a vaccination-to-cull strategy cost about € 500 million for agricultural enterprises, € 120 million for the animal disease fund, € 140 million for the government and € 90 million for the EU according to HUIRNE ET AL. (2002). In the probable vaccination-to-live scenario of the model, the costs are about € 156 million for Jade-Weser and € 61 for Grafschaft Bentheim with price effects plus additional ICC of probably several hundred million. For Jade-Weser, the 156 million leave out additional costs for culling and include only 80% of the animal value. At 100% price reduction for meat in the model, the costs would increase by an additional 25 million. However, in the Netherlands, animal keepers suffered an income loss of € 230 million, which is higher than the results indicate.

5.2   Discussion of results

The major aim of this study was to compare economic consequences of protective emergency vaccination and culling strategies to control FMD. Thereby, the costs as well as the compensations were outlined for both farmers and the TSK. Despite the mainly numerical analysis in Chapter 4, the aim was not only to give concrete monetary values but to achieve a general understanding of the costs that may occur and to evaluate the most important factors influencing the height of the costs.

For the Jade-Weser region, vaccination has an advantage in total costs for larger outbreaks if price effects are excluded. In the best case both strategies generate similar total costs. However, including price effects results to a reverse situation, because vaccination leads to higher losses in milk production due to the larger and sometimes longer zoning, in addition to very high losses in animal values. For the Grafschaft Bentheim, without price effects the costs are similar to Jade-Weser. Differences occur when price effects are included: in the probable/medium scenario, the costs are at 50% equal but at 80% in favour of culling. In the worst case, vaccination has an advantage at 50% reduction but culling at 80%. This shows that the structural conditions of a region (the animal type being kept and the farm and animal density) are one of most important factors for deciding for a control strategy. This supports the appraisal of the EC and their criteria for the decision to apply a vaccination or non-vaccination strategy (Table 2).

The results can be compared to the FMD epidemic in the Netherlands in 2001. The Netherlands are in their agricultural structure the most similar to northwest Germany. In 2001, most outbreaks occurred in the provinces Gelderland and Overijssel, which are regions with a generally high density of cloven-hoofed animals. HUIRNE ET AL. (2001) concluded with an economic point of view that vaccination-to-live is more expensive due to the long trade restrictions. This was also concluded in this study, but the costs of the trade restrictions depend to a large extend? on the regional structures (are export dependent companies in the region?) and on the application of regionalisation. For Jade-Weser, the restrictions would be more striking and vaccination could be more expensive. In the Grafschaft Bentheim, it is possible that export dependent companies are not affected from regionalisation, so that export losses could be lower compared to Jade-Weser.

6   CONCLUSION

The created static model is able to estimate the costs of an FMD epidemic for farmers and the TSK and authorities respectively. Two control strategies were analysed with the model and results for two regions were presented. For each region, costs of one best-case, probable/medium and worst-case scenario were calculated in order to get an idea about possible costs in case of an FMD outbreak depending on the mitigation strategy. Costs were only analysed in-depth for farmers and the TSK inside the MRZ. For a final decision for a control strategy, improvement and extension of the epidemic simulations is essential, which could partly be done with the created model.

This pilot study analysed culling and vaccination-to-live strategies to control FMD from an economic point of view. The results are not representative but show important tendencies. DC are higher for the culling strategy, because of the large compensations that have to be spent for indemnifying the animal values. A vaccination strategy leads to lower DC but relatively higher DCC, although in absolute numbers, vaccination could still be more cost-efficient than culling if price effects are ignored. However, including price reductions for farmers of the MRZ resulted in higher absolute DCC if vaccination was used. Additionally, ICC are higher for a vaccination strategy, especially when export dependent processors suffer from export restrictions.

Altogether, the model results indicate that vaccination could be an economical alternative to the culling strategy, but the affected region should be analysed in-depth. Some regional preconditions are necessary to keep the consequential costs within reasonable limits. The most important cost determining factors that were unfolded in this pilot study are the affected animal type and prices for products of the MRZ. In cattle dense regions like Jade-Weser, a vaccination-to-live could lead to high losses when both milk and cattle lose in value. This would mean very high DCC for farmers that could exceed the costs of a culling strategy. In addition, many export dependent companies would suffer from export restrictions. Hereby, it would be important to gain further insight into the likelihood of price reductions for products of the MRZ.

In regions with a higher swine share like the Grafschaft Bentheim, the model results indicate that costs for vaccination could be below those of the culling strategy. Losses due to price effects are lower (DCC), because reductions in milk and animal value are less striking since a higher share of animals has to be slaughtered for welfare reasons and is therefore indemnified on the assumptions of this study. In addition, at minor outbreaks exporters could not be affected by longer export bans and ICC may be relatively low. Nonetheless, for a final statement in favour of vaccination-to-live, the possibilities for a regionalisation and the effects on surrounding regions like the Counties of Emsland, Borken and Steinfurt should be taken into account precisely. Furthermore, when deciding for vaccination-to-live, farmers will suffer from higher losses if they do not get additional support. This could lead to antipathies against vaccination, which can be countered by establishing an extra support fund.

7 SUMMARY

In order to summarise the most important results of this pilot study, the four research questions presented in the introduction can be answered.

1) What important epidemiological and economic factors determine the economic impact of FMD?

The model has many different assumptions that influence the costs of an epidemic. Disease specific factors can hardly be included in the static model, because it is only based on geo-reference data. Serotype, wind, temperature and geography influence the spread of FMD. Some of the most important factors that can be derived from the model are:

- Affected animal types: cattle, swine or sheep; in general it can be stated that the more cattle are infected, the higher the costs. A higher share of infected sheep and pig farms lead to lower costs of an epidemic.
- Animal and farm density, farm size: Both regions have high densities, so that vaccination could be adequate for controlling disease. Grafschaft Bentheim has a higher animal density than Jade-Weser but has a smaller area and in total fewer farms. With price effects excluded, the costs are nevertheless similar.
- Prices, control costs and market structure: the higher the current commodity prices for agricultural products, the higher the costs of an epidemic. Compensations have to be larger and consequential losses will be higher. The same is true for export markets: the higher the dependencies on exports, the larger the consequential losses. Price reductions for agricultural products of the MRZ and therefore higher consequential losses can dominate all other impacts, in particular for dairy cows.
- Contact structures (can be influenced by geography, e.g. rivers): the River Hunte isolates the municipalities of Berne and Lemwerder from the rest of Jade-Weser (lower risk of infection if disease spreads from Jade-Weser).
  Contact structures also influence the number of IPs and the animal types that are infected. Cattle farmers are more likely to infect other cattle farms due to more direct contact. Such contact structures were not included in the model but random infected farm types were chosen since it is unknown what kind of farm is first infected and what the contact structures are.

2) What are possible FMD outbreak scenarios for the two different counties in northwest Germany?

Best-case, probable and worst-case scenarios were presented in Section 3.2.2. For both regions, seven farms are infected in the best case for both the culling and the vaccination scenario. Of course, one infected farm is generally the best case, but then only the culling strategy is going to be applied. In a probable/medium scenario, 25 farms are infected using a vaccination strategy and 40 using a culling strategy. In the worst case, 100 farms are in-fected using a vaccination and 150 using a culling strategy. In the latter, all municipalities are settled in a MRZ. Generally, the epidemiologists assume that vaccination can control disease faster than culling. Culling needs large disposal capacities and takes more time. Vaccination can be applied rapidly once the vaccine is provided.

3) What is the economic impact for farmers in the FMD scenarios with respect to DC, DCC and compensation payments?

The DC, DCC and compensation payments were presented in detail in Chapter 4. When looking at the total DC only, vaccination has clear advantages in all scenarios (Figure 3 and Figure 4). If price effects are ignored for products of the MRZ, DCC can be lower too in absolute numbers although their share of the total costs is higher.

The costs are distributed in a different way depending on the strategy used. In the culling scenarios, DC are far higher than DCC because of the very high indemnifications to farmers. When vaccinating, DC and DCC have an almost equal share and compensations are clearly lower. Net costs for the TSK are therefore higher in the culling scenarios. Farmers have higher net costs, too, due to more empty houses when culling in a 1km radius.

Despite looking at single regions and not at the whole country, price reductions lead to higher losses in case of vaccination in Jade-Weser (Figure 3), because animals and products would suffer more from the price reductions. For the Grafschaft Bentheim, the picture is somewhat different: price effects are smaller since the region has fewer cattle and for this reason, vaccination with price effects is less expensive (Figure 4). In the worst case, vaccination could even have an advantage when price effects are taken into account (at 50%).

However, price reductions would be additional losses for farmers without indemnification. From the perspective of the TSK, a vaccination strategy should be preferred for this reason. Farmers, on the other hand, should prefer a culling strategy when they fear price effects, although they partly finance the TSK.

4) What are the ICC of market disruptions in different vaccination and non-vaccination strategies?

The results-chapter indicates how difficult it is to evaluate market disruptions and its costs or benefits soundly. Disruptions are highly dependent on the dimension of disease, the reactions of trade partners, consumption behaviour and the trade restrictions by the EU. Via export volumes of agricultural products, it can be seen, what commodity values are at risk. Unfortunately, it is not possible to get export data from single regions in Germany. This could help to estimate the losses of a regionalisation in case of an outbreak. A nationwide export stop – even if a sales substitution to the German market was possible – could cost processors and producers more than half a billion at 25% price reduction. However, since Germany has an export surplus, many products will not be able to be sold on the German market. Consumers, on the other hand, could profit from this, when supply on the German markets increases and prices fall.

ICC will be higher for regions, where export dependent processors are settled. This would be the case for the Jade-Weser region. There, some processors export about 50% of their production. When those companies cannot export for about one year, this could lead to bankruptcies. For epidemics in regions without export dependent processors, the ICC will be lower, especially when regionalisation does not affect those companies. This could e.g. be the case for smaller outbreaks in Grafschaft Bentheim.

8 ACKNOWLEDGEMENTS

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2014/709/EU, Commission Implementing Decision of 9 October 2014 concerning animal health control measures relating to African swine fever in certain Member States and repealing Implementing Decision 2014/178/EU.

2014/689/EC, Commission Implementing Decision of 29 September 2014 on measures to prevent the introduction into the Union of the foot-and-mouth disease virus from Algeria, Libya, Morocco and Tunisia.

2003/85/EC, Council Directive of 29 September 2003 on Community measures for the control of foot-and-mouth disease repealing Directive 85/511/EEC and Decisions 89/531/EEC and 91/665/EEC and amending Directive 92/46/EEC.

90/423/EEC, Council Directive of 26 June 1990 amending Directive 85/511/EEC introducing Community measures for the control of foot-and-mouth disease.

85/511/EEC, Council Directive of 18 November 1985 introducing community measures for the control of foot-and mouth disease.

Animal Health Act = Gesetz zur Vorbeugung vor und Bekämpfung von Tierseuchen (Tiergesundheitsgesetz - TierGesG) (2013), Germany.

First Regulation to Change the FMD-Regulation = Erste Verordnung zur Änderung der MKS-Verordnung (1992), Germany.

FMD-Regulation: Regulation for the Protection against Foot-and-Mouth Disease = Verordnung zum Schutz gegen die Maul- und Klauenseuche (MKS-Verordnung) (2005), Germany.

Implementing Law of the Animal Health Act = Ausführungsgesetz zum Tiergesundheitsgesetz, AGTierGesG (2014), federal law of Lower Saxony, Germany.

APPENDIX

APPENDIX I: DATA ESTIMATION IN JADE-WESER

Some census data had to be estimated. The estimations are not exact, because they orientate themselves at mean values and how much data is missing. However, in view of the low swine numbers, this is thought to be acceptable, because that is more relevant for the model. In the following, the estimation is explained for the counties in Jade-Weser.

Table A17: County of Friesland data

	Swine farms	Swine animals	Av. swine / farm	Piglets: farms	Piglets: animals	Av. piglets/ farm	Breeding sows: farms	Breeding sows: animals	Av. breeding sows/ farm	Swine Other: farms	Other swine: animals	Av. other swine/ farm
Friesland without islands	34	33,550		17	11,190		9	1,371	1,371	32	20,989	
Rest (Sum Friesl. – given data)	0	2,175		0	6552	655	0	724	181	0	4,865	
Bockhorn	2	594	363	0	0	0	0	0		2	594	363
Jever	3	1,728	363	1	655	655	1	181	181	3	892	84
Sande	0	0	0	0	0	0	0	0		0	0	0
Schortens	1	297	363	0	0	0	0	0		1	297	363
Wangerland	12	12,534	1045	6	3,931	655	1	181	181	11	7,978	725
Varel	11	13,431	1221	7	4,638	663	5	647	129	11	8,146	741
Zetel	5	5,410	1082	3	1,966	655	2	362	181	4	3,082	771

The municipalities Bockhorn, Jever and Schortens have no information about swine animal numbers except for zero piglets and sows. This means that all swine belong to the category other animals. Zetel and Wangerland have information on all animals and only partly on other animals. All swine are calculated by adding the other three groups. The average numbers (red and bold averages) were calculated by:

Average piglets/farm = 655 = 6,552 / (1 + 6 + 3)

Average breeding sows/farm = 181 / (1 + 1 + 2)

Average other swine = 297 = (4,865 – 3,082) / (2 + 3 + 1)

The value of 3,082 other swine for Zetel is calculated differently, because for this municipality, data is for all swine animals is available. The estimations are not exact. Overall, 444 animals in the category all swine are excessive in the calculations. However, this category is not directly used in the model and therefore the excessive pigs do not occur in the calculations.

Table A18: County of Wesermarsch data

	Swine farms	Swine animals	Av. swine / farm	Piglets: farms	Piglets: animals	Av. piglets/ farm	Breeding sows: farms	Breeding sows: animals	Av. breeding sows/ farm	Swine Other: farms	Other swine: animals	Av. other swine/ farm
Wesermarsch	**26**	**7,445**		**10**	**4,366**		**12**	**1,121**		**22**	**1,958**	
Rest (Sum Weser. – given data)	**0**	**3,895**		**0**	**3,085**	**513**	**0**	**1,111**	**123**	**0**	**1,958**	**193**
Berne	7	2,169	310	3	1,281	427	4	494	123	6	394	66
Brake (Unterweser)	2	683	341	0	0	0	1	123	123	2	385	193
Butjadingen	2	1,196	598	1	513	513	1	123	123	2	385	193
Elsfleth	1	917	917	1	513	513	1	123	123	1	193	193
Jade	3	29	10	1	5	5	3	10	3	2	14	7
Lemwerder	0	0	0	0	0	0	0	0		0	0	0
Nordenham	1	917	917	1	513	513	1	123	123	1	193	193
Ovelgönne	8	1,352	169	2	1,027	513	1	123	123	7	202	29
Stadland	2	793	397	1	513	513	0	0		1	193	193

Brake, Butjadingen, Elsfleth, Nordenham and Stadland have no animal numbers available. Again, those values were calculated by adding up the other three types of swine. Missing piglet numbers were estimated by using the average:

Piglets: animals = 513 = (3085 – 5) / (1 + 1 + 1 + 2 +1)

Jade has only half of the necessary information, but that is sufficient for a separate estimation of the piglet numbers, which are subtracted above.

Piglets (Jade) = 5 ~ (29 / 6) * 1 (6 farm types)

The average breeding sows and other swine were estimated by:

Av. breeding sows/farm = 123 = 1111 / (4 + 1 + 1 + 1 + 1 + 1)

Av. other swine/farm = 193 = (1958 − 394 − 14 − 202) / (4 + 1 + 1 + 1 + 1 + 1)

For Berne, Jade and Ovelgönne, the data was partly available. For this reason, the average other swine/farm were estimated in a different way:

Av. other animals (Berne) = 394 = 2,169 − 1,281 − 494

Av. other animals (Jade) = 14 = 29 − 5 − 10

Av. other animals (Övelgönne) = 202 = 1,352 − 1,027 − 123

County of Wittmund data

Some municipalities had no available data. For Eversmeer and Ochtersum, the missing data was estimated in the following way:

Eversmeer: Piglets = 6 ~ (35 / 11) * 2 (11 farm types) | Breeding sows = 10 ~ (35 / 11) * 3

Ochtersum: Piglets = 5 ~ (26 / 5) * 1 (5 farm types) | Breeding sows = 5 ~ (26 / 5) * 1

And for the other municipalities, where data was partly available:

Av. other animals (Blomberg) = 3,214 = 5,537 − 1,950 − 373

Av. other animals (Neuharlingersiel) = 2,458 = 3,838 − 1,006 − 373

Av. other animals (Ochtersum) = 16 = 26 − 5 − 5

Av. other animals (Stedesdorf) = 195 = 1,792 − 1,317 − 28

For the municipalities without data it was done in the same way as above:

Av. piglets/farm = 335 = (5,715 − 6 − 5) / (2 + 4 + 2 + 3 + 1 + 3 + 1 + 1)

Av. breeding sows/farm = 93 = (1,975 − 10 − 5) / (4 + 2 + 3 + 3 + 1 + 4 + 1 + 3)

Av. other swine/farm = 364 = (9,891 − 3,214 − 2,458 − 16 − 195) / (2+2+4 + 1 + 2 + 2 + 2)

In total, 663 animals in the category all swine are excessive in the calculations. Again, this category is not directly used in the model and therefore, the excessive pigs do not occur in the calculations.

Table A19: County of Wittmund data

	Swine farms	Swine animals	Av. swine / farm	Piglets: farms	Piglets: animals	Av. piglets/ farm	Breeding sows: farms	Breeding sows: animals	Av. breeding sows/farm	Swine Other: farms	Other swine: animals	Av. other swine/ farm
Wittmund	**89**	**38,637**		**48**	**16,353**	**16,353**	**44**	**3,836**		**77**	**18,448**	
Rest	**0**	**7,388**		**0**	**5,715**	**335**	**0**	**1,975**	**93**	**0**	**9,891**	**364**
Blomberg	5	5,537	1,107	3	1,950	650	4	373	93	4	3,214	804
Dunum	11	6,906	628	10	4,592	459	9	1,309	145	10	1,005	101
Esens, Stadt	4	872	218	2	671	335	2	187	93	4	14	4
Eversmeer	7	35	5	2	6	3	3	10	3	6	19	3
Friedeburg	13	2,857	220	4	1,342	335	3	280	93	11	571	52
Holtgast	2	1,400	700	2	671	335	0	0		2	729	364
Moorweg	4	1,308	327	3	1,006	335	3	280	93	3	21	7
Nenndorf	2	1,158	579	1	335	335	1	93	93	2	729	364
Neuharlingersiel	5	3,838	768	3	1,006	335	4	373	93	4	2,458	615
Neuschoo	2	793	397	1	335	335	1	93	93	1	364	364
Ochtersum	3	26	9	1	5	5	1	5	5	3	16	5
Schweindorf	0	0	0	0	0	0	0	0		0	0	0
Stedesdorf	4	1,792	448	3	1,317	439	3	280	93	4	195	49
Utarp	2	729	364	0	0	0	0	0		2	729	364
Werdum	2	1,064	532	1	335	335	0	0		2	729	364
Westerholt	2	729	364	0	0	0	0	0		2	729	364
Wittmund	21	10,258	488	12	2,779	232	10	552	55	17	6,927	407

APPENDIX II: MAPS OF THE ANALYSED COUNTIES

Map sources: WIKIPEDIA, 2015

Figure A5: County of Wittmund (WTM)

Figure A6: County of Friesland (FRI)

Figure A7: County of Wesermarsch (BRA)

Figure A8: County of Grafschaft Bentheim

APPENDIX III: RESULTS OF THE MONTE CARLO SIMULATION

Jade-Weser region

Table A20: Results of 100 simulations of the best-case scenarios without price effects

Analysis of 100 iterations of the Jade-Weser best-case scenario

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
1km culling	**Total direct cost (DC)**	**4,053,857**	**3,869,909**	**4,113,586**	**4,014,021**	**4,061,472**	**4,102,357**	**53,198**
	Compensation for farmers	2,996,034	2,834,825	3,058,871	2,962,179	3,005,427	3,035,635	50,116
	Net DC for TSK/authorities	4,053,857	3,869,909	4,113,586	4,014,021	4,061,472	4,102,357	53,198
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**2,132,988**	**2,099,463**	**2,152,171**	**2,126,433**	**2,133,035**	**2,140,411**	**12,390**
	Compensation for farmers (welfare slaughtering)	1,549,306	1,527,334	1,560,092	1,546,546	1,550,772	1,553,345	7,891
	Net DCC for TSK/authorities	1,790,618	1,761,424	1,804,725	1,786,738	1,792,666	1,796,220	10,477
	Net DCC for farmers	342,370	332,473	348,232	340,305	343,529	344,584	3,886
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**6,186,844**	**6,004,956**	**6,261,734**	**6,148,019**	**6,193,169**	**6,239,079**	**59,970**
	Total netto cost of epidemic without price effects	**6,186,844**	**6,004,956**	**6,261,734**	**6,148,019**	**6,193,169**	**6,239,079**	**59,970**
3km vaccination	**Total direct cost (DC)**	**2,580,250**	**2,363,133**	**2,749,138**	**2,526,251**	**2,603,342**	**2,650,522**	**78,629**
	Compensation for farmers	850,877	636,883	992,312	800,124	874,362	929,483	77,484
	Net DC for TSK/authorities	2,580,250	2,363,133	2,749,138	2,526,251	2,603,342	2,650,522	78,629
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**3,421,678**	**3,364,518**	**3,448,946**	**3,407,255**	**3,424,062**	**3,448,946**	**21,553**
	Compensation for farmers (welfare slaughtering)	2,588,067	2,551,095	2,602,515	2,582,250	2,587,496	2,600,429	12,181
	Net DCC for TSK/authorities	3,012,955	2,963,931	3,031,456	3,005,153	3,012,752	3,029,183	16,005
	Net DCC for farmers	408,723	382,195	423,388	402,849	411,310	419,763	9,697
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**6,001,929**	**5,753,581**	**6,178,060**	**5,945,232**	**6,022,516**	**6,099,468**	**91,787**
	Total net cost of epidemic without price effects	**6,001,929**	**5,753,581**	**6,178,060**	**5,945,232**	**6,022,516**	**6,099,468**	**91,787**

Table A21: Results of 100 simulations of the probable/medium scenarios without price effects

Analysis of 100 iterations of the Jade-Weser probable/medium scenario

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
1km culling	**Total direct cost (DC)**	**24,192,475**	**23,372,766**	**24,744,070**	**23,989,635**	**24,274,086**	**24,471,905**	**348,593**
	Compensation for farmers	20,440,528	19,682,555	20,958,748	20,237,352	20,481,858	20,682,321	321,322
	Net DC for TSK/authorities	24,192,475	23,372,766	24,744,070	23,989,635	24,274,086	24,471,905	348,593
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**7,886,964**	**7,750,533**	**7,979,854**	**7,855,109**	**7,889,731**	**7,913,570**	**42,362**
	Compensation for farmers (welfare slaughtering)	3,179,872	3,116,350	3,224,893	3,164,102	3,181,714	3,194,209	21,019
	Net DCC for TSK/authorities	3,666,126	3,580,055	3,726,139	3,645,978	3,668,211	3,685,594	27,925
	Net DCC for farmers	4,220,838	4,149,257	4,271,151	4,198,713	4,225,204	4,244,323	30,033
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**32,079,439**	**31,198,711**	**32,690,399**	**31,823,910**	**32,142,285**	**32,367,720**	**378,996**
	Total net cost of epidemic without price effects	**32,079,439**	**31,198,711**	**32,690,399**	**31,823,910**	**32,142,285**	**32,367,720**	**378,996**

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
3km vaccination	**Total direct cost (DC)**	9,589,139	9,078,745	10,025,724	9,439,533	9,589,532	9,741,431	226,082
	Compensation for farmers	3,252,753	2,810,940	3,709,977	3,091,090	3,254,423	3,406,400	217,465
	Net DC for TSK/authorities	9,589,139	9,078,745	10,025,724	9,439,533	9,589,532	9,741,431	226,082
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	6,865,057	6,772,364	6,968,701	6,835,972	6,864,932	6,890,347	41,197
	Compensation for farmers (welfare slaughtering)	3,857,286	3,807,367	3,898,708	3,842,599	3,856,726	3,874,810	21,610
	Net DCC for TSK/authorities	4,448,075	4,381,878	4,503,237	4,428,254	4,447,367	4,472,390	28,601
	Net DCC for farmers	2,416,982	2,376,285	2,469,518	2,398,500	2,417,086	2,431,625	22,410
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**16,454,196**	**15,964,206**	**16,994,425**	**16,255,333**	**16,459,012**	**16,636,835**	**251,691**
	Total net cost of epidemic without price effects	**16,454,196**	**15,964,206**	**16,994,425**	**16,255,333**	**16,459,012**	**16,636,835**	**251,691**

Table A22: Results of 100 simulations of the worst-case scenarios without price effects

Analysis of 100 iterations of the Jade-Weser worst-case scenario

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
1km culling	**Total direct cost (DC)**	**86,867,975**	**84,897,606**	**88,195,881**	**86,592,385**	**86,953,716**	**87,193,817**	**542,933**
	Compensation for farmers	76,189,422	74,392,853	77,415,680	75,940,631	76,280,030	76,469,420	494,881
	Net DC for TSK/authorities	86,867,975	84,897,606	88,195,881	86,592,385	86,953,716	87,193,817	542,933
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**21,490,503**	**21,257,847**	**21,687,100**	**21,436,920**	**21,492,527**	**21,544,963**	**87,538**
	Compensation for farmers (welfare slaughtering)	4,414,196	4,263,913	4,536,000	4,386,327	4,414,096	4,443,322	48,021
	Net DCC for TSK/authorities	5,017,985	4,819,981	5,177,992	4,980,852	5,016,868	5,058,536	63,547
	Net DCC for farmers	16,472,518	16,250,429	16,624,938	16,437,206	16,476,903	16,514,577	62,983
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**108,358,478**	**106,184,526**	**109,837,580**	**108,051,759**	**108,452,870**	**108,676,447**	**601,980**
	Total net cost of epidemic without price effects	**108,358,478**	**106,184,526**	**109,837,580**	**108,051,759**	**108,452,870**	**108,676,447**	**601,980**
3km vaccination	**Total direct cost (DC)**	**23,747,060**	**22,560,189**	**24,719,695**	**23,475,170**	**23,782,156**	**24,058,549**	**439,096**
	Compensation for farmers	12,445,625	11,264,035	13,381,309	12,182,979	12,476,201	12,720,605	420,177
	Net DC for TSK/authorities	23,747,060	22,560,189	24,719,695	23,475,170	23,782,156	24,058,549	439,096
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**14,752,213**	**14,533,604**	**14,999,183**	**14,695,245**	**14,748,668**	**14,804,506**	**97,638**
	Compensation for farmers (welfare slaughtering)	5,919,419	5,775,453	6,079,835	5,877,900	5,922,212	5,956,064	57,504
	Net DCC for TSK/authorities	6,754,079	6,559,420	6,967,386	6,700,793	6,757,169	6,802,835	76,234
	Net DCC for farmers	7,998,134	7,828,216	8,127,541	7,958,865	8,000,001	8,035,431	54,829
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**38,499,273**	**37,093,793**	**39,609,552**	**38,187,395**	**38,550,918**	**38,821,563**	**497,360**
	Total net cost of epidemic without price effects	**38,499,273**	**37,093,793**	**39,609,552**	**38,187,395**	**38,550,918**	**38,821,563**	**497,360**

Grafschaft Bentheim

Table A23: Results of 100 simulations of the best-case scenarios without price effects

Analysis of 100 iterations of the Grafschaft Bentheim best-case scenario

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
1km culling	**Total direct cost (DC)**	**3,959,594**	**3,491,345**	**4,170,566**	**3,843,783**	**4,037,295**	**4,072,818**	**171,659**
	Compensation for farmers	2,967,831	2,555,303	3,175,164	2,857,574	3,017,332	3,085,603	150,715
	Net DC for TSK/authorities	3,959,594	3,491,345	4,170,566	3,843,783	4,037,295	4,072,818	171,659
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**2,761,324**	**2,696,277**	**2,827,513**	**2,741,485**	**2,764,089**	**2,782,305**	**28,725**
	Compensation for farmers (welfare slaughtering)	2,047,428	1,991,036	2,100,866	2,027,988	2,045,951	2,063,914	24,099
	Net DCC for TSK/authorities	2,461,519	2,392,727	2,526,647	2,437,731	2,459,687	2,481,643	29,394
	Net DCC for farmers	299,805	276,821	311,180	294,089	303,106	305,699	8,535
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**6,720,918**	**6,238,864**	**6,984,253**	**6,572,187**	**6,787,661**	**6,852,552**	**175,861**
	Total netto cost of epidemic without price effects	**6,720,918**	**6,238,864**	**6,984,253**	**6,572,187**	**6,787,661**	**6,852,552**	**175,861**
3km vaccination	**Total direct cost (DC)**	**1,904,509**	**1,538,375**	**2,218,122**	**1,867,661**	**1,873,549**	**1,986,255**	**137,198**
	Compensation for farmers	646,593	312,904	941,524	589,546	624,533	719,428	127,437
	Net DC for TSK/authorities	1,904,509	1,538,375	2,218,122	1,867,661	1,873,549	1,986,255	137,198
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**4,375,509**	**4,288,051**	**4,466,708**	**4,352,432**	**4,380,470**	**4,399,250**	**37,907**
	Compensation for farmers (welfare slaughtering)	3,381,152	3,312,422	3,451,032	3,364,464	3,370,134	3,396,560	32,187
	Net DCC for TSK/authorities	4,047,773	3,963,835	4,132,983	4,027,856	4,033,920	4,066,363	39,382
	Net DCC for farmers	327,736	298,803	353,481	322,465	325,893	334,029	11,109
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**6,280,018**	**5,939,450**	**6,598,593**	**6,189,870**	**6,264,073**	**6,352,494**	**137,346**
	Total net cost of epidemic without price effects	**6,280,018**	**5,939,450**	**6,598,593**	**6,189,870**	**6,264,073**	**6,352,494**	**137,346**

Table A24: Results of 100 simulations of the probable/medium scenarios without price effects

Analysis of 100 iterations of the Grafschaft Bentheim probable/medium scenario

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
1km culling	**Total direct cost (DC)**	**22,848,352**	**21,495,565**	**23,988,723**	**22,499,247**	**22,977,868**	**23,208,245**	**522,430**
	Compensation for farmers	18,583,493	17,431,523	19,565,838	18,261,506	18,683,564	18,910,251	455,653
	Net DC for TSK/authorities	22,848,352	21,495,565	23,988,723	22,499,247	22,977,868	23,208,245	522,430
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**8,775,877**	**8,624,725**	**8,933,339**	**8,744,814**	**8,782,312**	**8,801,255**	**51,980**
	Compensation for farmers (welfare slaughtering)	4,583,251	4,473,643	4,739,148	4,555,875	4,578,325	4,606,051	46,931
	Net DCC for TSK/authorities	5,598,965	5,458,047	5,798,737	5,564,240	5,593,503	5,627,773	59,987
	Net DCC for farmers	3,176,912	3,069,961	3,272,175	3,150,415	3,177,338	3,214,646	42,661
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**31,624,229**	**30,290,969**	**32,771,035**	**31,253,341**	**31,728,484**	**32,019,627**	**527,863**
	Total net cost of epidemic without price effects	**31,624,229**	**30,290,969**	**32,771,035**	**31,253,341**	**31,728,484**	**32,019,627**	**527,863**

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
3km vaccination	**Total direct cost (DC)**	6,404,992	5,845,812	7,126,075	6,151,424	6,388,104	6,593,340	275,485
	Compensation for farmers	2,627,924	2,162,533	3,201,259	2,420,534	2,628,673	2,792,685	235,413
	Net DC for TSK/authorities	6,404,992	5,845,812	7,126,075	6,151,424	6,388,104	6,593,340	275,485
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	8,502,180	8,342,439	8,605,493	8,475,413	8,513,274	8,538,026	57,093
	Compensation for farmers (welfare slaughtering)	5,803,033	5,679,770	5,903,743	5,777,162	5,807,625	5,832,069	47,818
	Net DCC for TSK/authorities	7,085,488	6,925,056	7,217,600	7,051,812	7,090,314	7,123,405	62,508
	Net DCC for farmers	1,416,691	1,367,825	1,475,407	1,395,987	1,415,171	1,433,108	24,296
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**14,907,171**	**14,388,146**	**15,557,663**	**14,673,739**	**14,912,986**	**15,085,623**	**263,852**
	Total net cost of epidemic without price effects	**14,907,171**	**14,388,146**	**15,557,663**	**14,673,739**	**14,912,986**	**15,085,623**	**263,852**

Table A25: Results of 100 simulations of the worst-case scenarios without price effects

Analysis of 100 iterations of the Grafschaft Bentheim worst-case scenario

	Cost category	Mean	Min	Max	25% quantil	50% quantil	75% quantil	Standard deviation
1km culling	**Total direct cost (DC)**	**84,209,978**	**81,588,983**	**87,578,247**	**83,655,255**	**84,131,540**	**84,870,139**	**1,027,753**
	Compensation for farmers	71,965,333	69,663,065	74,822,826	71,465,439	71,903,967	72,568,180	902,731
	Net DC for TSK/authorities	84,209,978	81,588,983	87,578,247	83,655,255	84,131,540	84,870,139	1,027,753
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**17,970,760**	**17,769,913**	**18,141,064**	**17,927,820**	**17,972,967**	**18,027,361**	**74,048**
	Compensation for farmers (welfare slaughtering)	4,390,524	4,041,507	4,625,504	4,351,796	4,402,364	4,437,082	83,446
	Net DCC for TSK/authorities	5,436,728	4,995,945	5,730,891	5,389,327	5,451,628	5,492,355	104,309
	Net DCC for farmers	12,534,031	12,282,955	12,843,743	12,481,019	12,533,467	12,603,188	97,332
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**102,180,738**	**99,492,965**	**105,417,935**	**101,574,693**	**102,126,081**	**102,917,522**	**1,043,545**
	Total net cost of epidemic without price effects	**102,180,738**	**99,492,965**	**105,417,935**	**101,574,693**	**102,126,081**	**102,917,522**	**1,043,545**
3km vaccination	**Total direct cost (DC)**	**18,204,755**	**17,165,470**	**19,230,073**	**17,964,038**	**18,191,080**	**18,473,262**	**421,433**
	Compensation for farmers	10,079,930	9,127,639	10,955,648	9,859,047	10,063,959	10,305,808	359,086
	Net DC for TSK/authorities	18,204,755	17,165,470	19,230,073	17,964,038	18,191,080	18,473,262	421,433
	Net DC for farmers	-	-	-	-	-	-	-
	Total direct consequential cost (DCC)	**15,540,489**	**15,168,151**	**15,957,757**	**15,448,953**	**15,535,583**	**15,623,771**	**130,828**
	Compensation for farmers (welfare slaughtering)	8,536,276	8,270,137	8,819,723	8,457,563	8,540,650	8,611,221	106,591
	Net DCC for TSK/authorities	10,505,261	10,144,105	10,876,319	10,403,097	10,511,853	10,602,697	138,527
	Net DCC for farmers	5,035,228	4,917,817	5,141,654	5,006,617	5,033,913	5,070,257	46,724
	+ Net DCC for farmers due to price effects in MRZs	-	-	-	-	-	-	-
	Total gross cost of epidemic without price effects	**33,745,244**	**32,730,619**	**34,704,636**	**33,523,294**	**33,736,209**	**33,995,331**	**394,613**
	Total net cost of epidemic without price effects	**33,745,244**	**32,730,619**	**34,704,636**	**33,523,294**	**33,736,209**	**33,995,331**	**394,613**

APPENDIX IV: FILES OF THE REPORT AND THE EXCEL MODEL

Data disc:

- Microsoft Excel file with the static epidemiological and economic model (explanation included)
- PDF files of the thesis report (a print version with tables in portrait format and a display version with tables in landscape format)
- Online References as PDF

PERSONAL DECLARATION

I hereby affirm that I have prepared the present paper self-dependently, and without the use of any other tools, than the ones indicated. All parts of the text, having been taken over verbatim or analogously from published or not published scripts, are indicated as such. The thesis has not yet been submitted in the same or similar form, or in extracts within the context of another examination.

Bawinkel (Germany), 29th January 2015

Student's signature