Wageningen University – Department of Social Sciences

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The epidemiological and economic impact of non-vaccination and vaccination to control Classical Swine Fever in North Rhine Westphalia and Lower Saxony

A pilot study

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Abstract

An outbreak of classical swine fever (CSF) in a susceptible population could have a big epidemiological and economic impact. Therefore an effective CSF controlling strategy is required. The use of pre-emptive culling in a 1km radius is an effective method to control a CSF epidemic, however the use of pre-emptive culling is more and more rejected by the general public, so alternative control strategies are investigated. Therefore, the aim of this pilot study is to compare non-vaccination and vaccination based CSF control in North Rhine Westphalia (NRW) and Lower Saxony (LS), with the focus on: the epidemiological impact, the economic impact at sector level and the impact on the net labour income for individual farms located in the various disease control zones.

The epidemiological impact was calculated by using the simulation software InterSpread Plus. Three control strategies were considered: a depopulation strategy, a vaccination strategy with depopulation in a 1km radius for three days and a vaccination strategy without depopulation in a 1km radius. The economic impact at sector level was restricted to calculating the direct costs (disease control costs) and direct consequential costs (costs directly resulting from the control measures applied). The economic impact at individual level was based on a deterministic cost spreadsheet model, where the net labour income of different situations was compared to the net labour income of a normal year.

The three control strategies were all sufficient in controlling the CSF epidemics, with some minimal differences, in the number of infected farms and the duration of the epidemic. The depopulation strategy resulted in the most farms depopulated, and the vaccination without depopulation resulted in the most farms vaccinated and least depopulated. All control strategies resulted in nearly the same economic impact. The vaccination strategy resulted in a lower net labour income for the farmers, especially if a farm was vaccinated in the worst-case the farmer earned €54.000 less than in he would have earned in a normal production year.

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1. Introduction

Classical swine fever (CSF) is a highly contagious pig disease, caused by a pest-virus (Moennig, 2000). An outbreak of CSF in a susceptible population could have a big epidemiological and economic impact. As happened in the Netherlands in 1997/1998, when 429 farms were infected resulting in an economic impact (only the direct- and direct consequential costs) of $2.3 billion (Meuwissen et al., 1999). The last outbreak of CSF in Germany occurred in 2006, but there is always a risk of an CSF outbreak, since several (Eastern) European countries are not CSF free (Postel et al., 2013; OIE, 2014).

In case of a CSF outbreak the EU has a set of mandatory control measures according to Council Directive 2001/89/EC (Anonymous, 2001). Control measures according to this directive are: culling of all pigs on the detected farm, culling of pigs on the contact farms, establishment of protection and surveillance zones (movement restriction zones (MRZs)). Since these mandatory control measures are minimal and not so effective, Germany also uses pre-emptive depopulation of farms in a 1km radius of a detected farm as an extra control measure (Anonymous, 2006; Brosig, 2012; Brosig et al., 2012; Hop et al., 2014).

The use of pre-emptive culling of farms was effective to control CSF in 1997/1998, as well as the foot and mouth disease (FMD) in 2001 and avian influenza (AI) in 2003, with as negative side effect that millions of (mostly) healthy animals were culled and rendered. This side effect is not acceptable from an ethical and economic point of view. Aside if it is ethical or economic acceptable, the general public is more and more protesting against this pre-emptive culling of (healthy) animals.

Therefore emergency vaccination is as a (additional) control measure of particular interest, but the EU has not yet accepted the use of emergency vaccination. There are two types of emergency vaccination, the use of a modified live vaccine and the use of a marker vaccination (Greiser-Wilke and Moennig, 2004). The use of modified live vaccine, results that animals are culled and rendered, because they are not comparable from infected animals (Moennig, 2000; Greiser-Wilke and Moennig, 2004). Animals that are vaccinated with the marker vaccine can be serologically distinguished from infected animals (Greiser-Wilke and Moennig, 2004). The downside of this marker vaccine is that it will take at minimum fourteen days until the animals are immune to the virus (Uttenthal et al., 2001; Beer et al., 2007). A risk of using emergency vaccination is that the value and demand of animals and animal products decreases. This could cause major market effects, especially for net exporting countries (Mangen and Burell, 2003; Boklund et al., 2009). Only depopulated farms are compensated during a CSF epidemic, and not the farms that are vaccinated or located inside a MRZ. Therefore the economic consequence could be different for individual farms located in different disease control zones.

In Germany several studies have been conducted on the epidemiologic impact of a CSF outbreak and possible control strategies: for instance Karsten et al. (2005, 2007) and Thulke et al. (2009) studied the non-vaccination strategies to control CSF. Kaden et al. (2006) and Blome et al. (2014) had their focus on the vaccination strategy. Brosig (2012) compared different strategies (both non-vaccination and vaccination) on the epidemiological impact. The economic impact of the different control strategies had not been studied intensively in Germany. Next to specific studies about Germany also the result of cross-border CSF outbreaks within the Netherlands and Germany have been studied (Arens et al., 2012; Hop et al., 2014). The studies from Hop et al. (2014) also included an economic impact of different control strategies, like the use of pre-emptive culling or emergency vaccination.

The aim of this pilot study is to compare non-vaccination and vaccination based CSF control in North Rhine Westphalia (NRW) and Lower Saxony (LS), with the focus on: 1) the epidemiological impact, 2) the economic impact at sector level and 3) the impact on the net labour income for individual farms located in the various disease control zones. From the research aim the following research questions were derived:

- What is the epidemiological impact of non-vaccinated and vaccinated based CSF control?
- What is the economic impact of non-vaccinated and vaccinated based CSF control at sectorial level?
- What is the impact of non-vaccinated and vaccinated based CSF control at the net farm income for individual farms located in the various control zones?

2. Materials and methods

2.1. Overall approach

InterSpread Plus (ISP), a program to simulate the spread of CSF epidemics was used to compare the epidemiological impact of non-vaccinated and vaccinated CSF control in NRW and LS. To calculate the economic impact at sector level, the epidemiological impact results from the ISP model were analysed with the software program SPSS. Finally the economic impact at individual farm level was modelled in a deterministic spreadsheet cost model, the epidemiological results were also used for this model. In Figure 1, a schematic overview is given of the overall approach, this figure also shows that the output of ISP was used for both the calculation of the economic impact at sector level as for the economic impact at individual farm level.

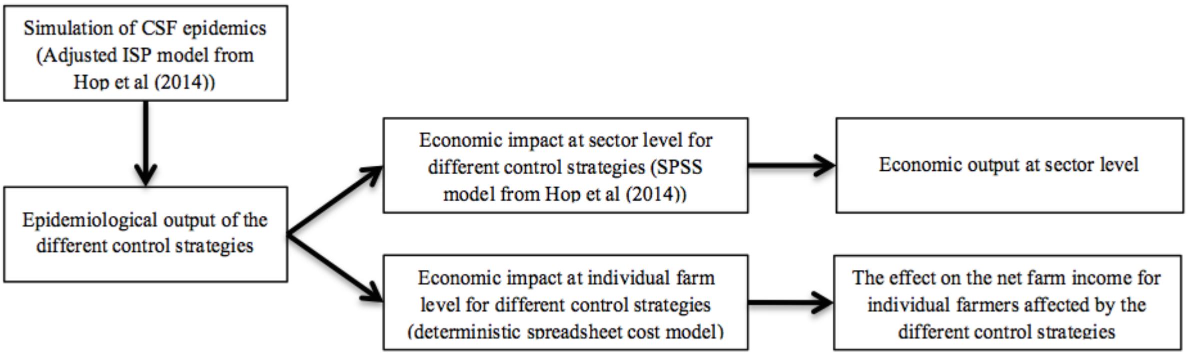

Figure 1: Schematic overview of the overall approach of the methods

2.2. Simulation of CSF epidemics

2.2.1. Simulation model

The InterSpread Plus model described in the paper from Hop et al. (2014) was adjusted and used, to simulate the epidemiological impact of non-vaccinated and vaccinated CSF control in NRW and LS.
ISP is a stochastic, dynamic and spatially explicit software programme to simulate the spread of diseases among populations (Stevenson et al., 2013). Since ISP simulates the spread of diseases it is possible to investigate the impact of different CSF control strategies. Therefore ISP (version 2.001.10; Stern, 2003 and Stevenson et al., 2013) was used to simulate the epidemiological impact for the different CSF control strategies.
ISP has been used the last years by different researchers to simulate the epidemiological impact of CSF, for example in the Netherlands (Hop et al., 2014), Belgium (Ribbens, 2009) and Denmark (Boklund et al., 2009). ISP has been used for other epizootic diseases as well, like FMD (Yoon et al., 2006; Stevenson et al., 2013) and Avian Influenza (Longworth et al., 2012a,b). Longworth et al. (2012a), has discussed the suitability of ISP, including the ability of ISP to model potential spatial jumps in epidemics. These jumps are relevant to determine the economic impact (Hop et al., 2014).
Since ISP is a simulation model an index farm (the first infected farm in an epidemic) has to be selected. Then the spread of CSF between farms occurs via movement (of humans, animals or fomites), local spread (5 km or less) and airborne spread (not applicable for CSF) (Stevenson et al., 2013). The spread mechanisms are stochastic and spatially go through the farm locations. Controls influencing the transmission probabilities of the diverse spread mechanisms are: depopulation, vaccination, movement restrictions and surveillance. (Hop et al., 2014). The time unit used in the model was a single day, and the model run for 500 days. The iteration was set to 500 for each simulated CSF control strategy. The software SPSS (version 22) was used to analyse the ISP output following the approach of Longworth et al. (2012a,b).

2.2.1.1. Population at risk

The population at risk was the commercial pig population in NRW and LS. A farm file containing a unique farm identifier, farm class, the number of animals on the farm and a set of Cartesian coordinates (defining the location of each farm in Euclidean space) was used, to use the population in ISP. The farm file was the same farm file that was used by Hop et al. (2014), only the data from NRW and LS was used and the data about the Netherlands was not used.

2.2.1.2. Index farms

The index farm is the farm where the simulated outbreak starts, and starts to infect other farms. The index farm is a farm in a densely populated livestock area (DPLA) since this is the most likely area where an outbreak starts. Four index farms (two from NRW and two from LS) were randomly selected from all farrowing farms for which the number within a 10-km radius exceeded the 50th and 90th percentiles of pig farm densities in the main pig-producing areas Munster (NRW) and Weserems (LS). Table 1 represents the average farm density of the two main pig-producing areas Munster (NRW) and Weserems (LS). The farm density is almost the same at the 1km radius for both regions.

Table 1: Average pig farm densities (number of farms including recreational farms within radii of 1 and 10 km) for the regions North Rhine Westphalia (NRW) and Lower Saxony (LS) (Hop et al., 2014).

		Farm density (number of farms)[1]		
			Percentiles	
Region	Radius (km)	Mean	50^{th}	90^{th}
NRW	1	5	4	9
	10	220	229	352
LS	1	4	3	7
	10	225	193	479

1: Pig farm densities are calculated for those regions that include at least one pig farm in a 1- or 10-km radius, respectively.

The four selected index farms represented a simulated outbreak inside a highly density populated livestock area (NRW_hd and LS_hd) or an average density populated livestock area (NRW_ad and LS_ad). The selected index farms are presented in Figure 2, this figure shows the location of all pig farms (grey dots) and highlights the four index farms (red dots). In Table 2, characteristics of the four index farms are given with respect to the number of farms within radii of 1, 2, 3 and 10 km of the index farm (Hop et al., 2014). The two average density farms, NRW_ad and LS_ad are more comparable than the two high-density farms, NRW_hd and LS_hd.

Table 2: Summary information on the number of farms located within radii of 1, 2, 3 and 10 km of the index farm, used for simulated classical swine fever (CSF) outbreaks North Rhine Westphalia (NRW) and Lower Saxony (LS) (Hop et al., 2014).

	Number of farms within radii of 1, 3 and 10 km of the index farm			
Index farm[1]	1 km	2 km	3 km	10 km
NRW_hd (Steinfurt region)	14	26	47	372
NRW_ad (Dorbaum region)	4	14	23	240
LS_hd (Steinfeld region)	11	25	53	618
LS_ad (Bissendorf region)	4	14	28	233

1: Hd = High-density index farm; ad = average density index farm.

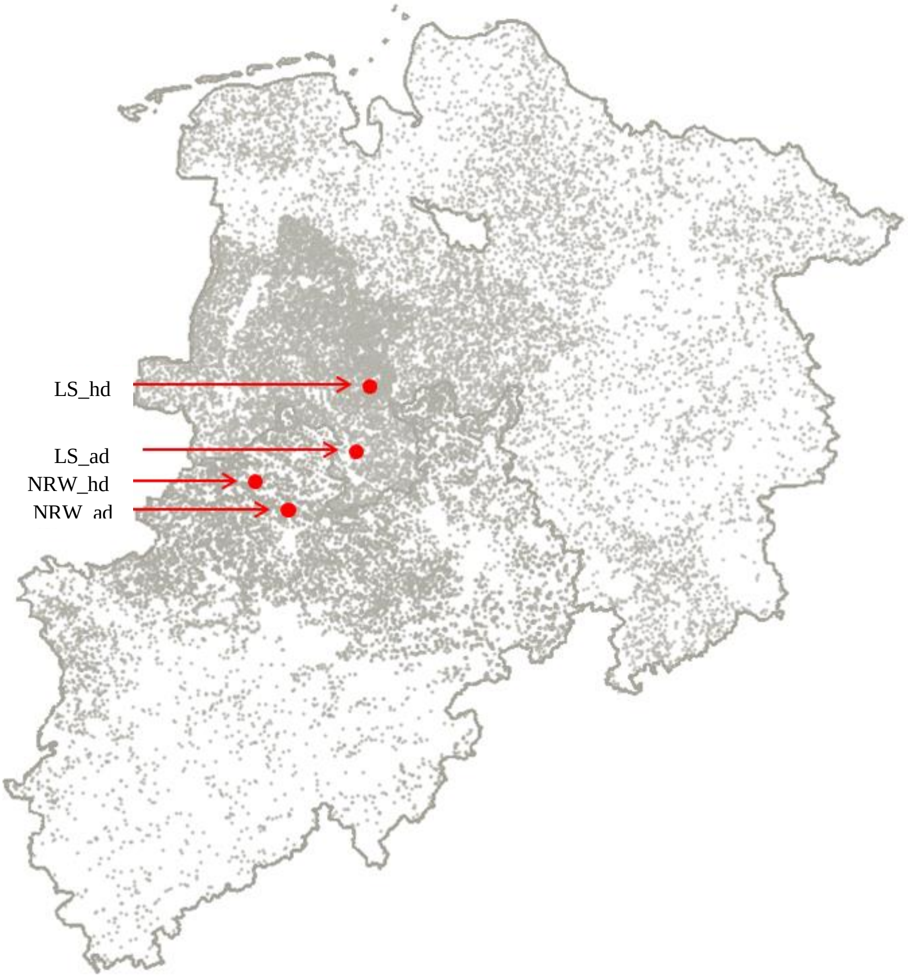

Figure 2: Location of pig farms (grey dots) and index farms (red dots) North Rhine Westphalia (NRW) and Lower Saxony (LS) used in simulations of classical swine fever (CSF) outbreaks.

2.2.1.3. Parameters describing the spread of CSF

Movements and local spread are the main spreading mechanisms in ISP for CSF because there is no scientific evidence that CSF can spread via the long distance airborne spread mechanism (Boklund et al., 2009; Ribbens, 2009). The probability values for the movement and local spread mechanisms are kept the same with values in described by Hop et al. (2014).

2.2.1.4. CSF control strategies

Three different control strategies were modelled in ISP: one non-vaccination and two vaccination strategies. The non-vaccination strategy (Depop) is the current situation and therefore is it used as the baseline situation (Groeneveld, personal communication). The two vaccination strategies, one strategy with depopulation in 1km (Vacc_depop) and one strategy without depop (Vacc_nodepop). A schematic overview of the three control strategies is given in Figure 3. Table 3 provides an overview of the different control measures for each control strategy.

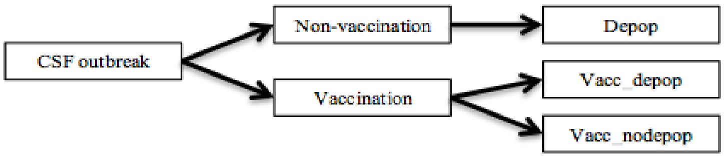

Figure 3: Schematic overview of the different classical swine fever (CSF) control strategies

Table 3: Set of control measures for classical seine fever (CSF) control, strategies are based on depopulation and vaccination for the regions North Rhine Westphalia (NRW) and Lower Saxony (LS).

	Control strategies		
Control measures	**Depop**	**Vacc_depop**	**Vacc_nodepop**
Depopulation of detected farms	x	x	x
Installation of and screening within a 0-3 km protection zone and a 3-10 km surveillance zone around each detected farm	x	x	x
Movement restrictions on live pigs and manure, professionals and vehicles in these zones	x	x	x
Tracing and depopulation of contacts	x	x	x
72-h movement standstill: restriction on all movements throughout the entire NRW and LS regions after the first detection	x	x	x
Implementation of regionalisation with movement restrictions[1]	x	x	x
Pre-emptive depopulation within a 1km radius of detected farms[2]	x	x	-
Vaccination-to-live (protective vaccination) using an E2 sub-unit vaccine (marker vaccine) in a 2km radius of detected farms[3]	-	x	x

1: NRW and LS were divided into five and four regions. During the first seven days following detection, movements between regions were prohibited. After seven days, regions without protection or surveillance zones were allowed to move within the same country.

2: In case of Vacc_depop, pre-emptive depopulation within a 1km radius of detected farms was only modelled for days 1-3 following first detection.

3: In case of Vacc_depop, vaccination was modelled to begin on day four following first detection.

Depopulation strategy (Depop)

This strategy was based on the mandatory control measures described in the EU directive 2001/89/EC (Anonymous, 2001), with additional measures. These mandatory control measures were: depopulation of detected farms, installation of a 3km protection zone and a 10km surveillance zone around each detected farm, movement restrictions on live pigs and manure, professionals and vehicles in these zones, and tracing and depopulation of contacts. The additional control measures were: a 72 hour movement standstill for the entire NRW and LS region after first detection, implementation of regionalisation with movement restrictions, pre-emptive depopulation within a 1km radius of detected farms.

The depopulation capacity was set to five farms during the first seven days and ten farms from day eight onwards. The depopulation was modelled to start the day after the first detection. The duration of the protection (3km movement restriction zone (MRZ)) and surveillance (10km MRZ) zones were assumed to be 37 and 28 days after the last detection. All farms inside the MRZ were screened and in the 3km zone the farms were clinically inspected. The end screen included a clinical inspection (3km and 10km MRZ) and blood sampling (3km MRZ), if there was a negative result the MRZ were lifted, if there was a positive result the duration was increased with a new period of 37 and 28 days (Hop et al., 2014).

Vaccination with depopulation (Vacc_depop)

This strategy was based on the depopulation strategy, with an additional control measure namely: the use of an E2 sub-unit vaccine (marker vaccine) in a 2km radius of detected farms. The pre-emptive depopulation within a 1km radius of a detected farm was only modelled for the first three days following first detection, the depopulation capacity was set to five farms a day. The use of the marker vaccine was modelled to begin on day four following first detection, the vaccination capacity was set to 100 farms a day. The time in which marker vaccination resulted in herd immunity was assumed to be eight to fourteen days (Boklund et al., 2009; Hop et al., 2014).

Vaccination without depopulation (Vacc_nodepop)

This strategy was based on the vaccination with depopulation, but without the pre-emptive depopulation within a 1km radius control measure. The use of the marker vaccine was modelled to begin on day one following first detection, the vaccination capacity was set to 100 farms a day. The time in which marker vaccination resulted in herd immunity was assumed to be eight to fourteen days (Boklund et al., 2009; Hop et al., 2014).

2.2.2. Sensitivity analysis

To analyse epidemiological output sensitivity to changes in the control strategies, the three veterinary control strategies were run with different control parameters. All other parameter values were kept constant, so each time only a single control parameter changed. Table 4 shows how the control variants differ from the three main veterinary control strategies. In short, the vaccination strategy (*Vacc_depop*) was modelled with a variant on the day at which pre-emptive depopulation of farms around a detected farm ends and vaccination starts (day two instead of day four). Additionally, both the vaccination and depopulation strategies were modelled with unrestricted depopulation capacity to analyse whether current capacities are limiting the control of CSF.

A control strategy based on the minimum EU requirements was considered unrealistic, because a previous study by Hop et al. (2014) had shown that a EU minimum strategy (EU_min) resulted in an increase of 30-50% for both duration of the epidemic as for the total costs. Therefore a EU_min strategy was not modelled as one of the main control strategies. However, to show the effect of the current contingency plans' measures, the EU_min strategy was modelled as a variant on the depopulation strategy (see Table 4 for a description of the changes in control parameter values).

As described in the results, index farm NRW_hd resulted in the largest outbreaks and therefore, was assumed to be most sensitive to changes in disease control parameters. For that reason, NRW_hd was chosen for additional analyses. Furthermore, variants in control strategies for index farm NRW_ad were included as well.

Table 4: Changes in the classical swine fever (CSF) control parameters as modelled in the sensitivity analyses.

Strategy	Abbreviation of changed control parameter	Description of control parameter value	Original control parameter value
Vacc_ depop	Depop_1km_1day	Only on day one following first detection: pre-emptive depopulation within a 1km radius of detected farms. Vaccination starts on day two.	On days one to three following first detection: pre-emptive depopulation within a 1km radius of detected farms. Vaccination starts on day four.
	Depop_1000	Depopulation capacity: 1,000 farms per day (unlimited capacity)	Depopulation capacity: five farms per day for the first week and ten farms per day thereafter.
Depop	EU_min[1]	No 72-h movement standstill, no pre-emptive depopulation within a 1km radius of detected farms, and no implementation of regionalisation with movement restrictions.	Includes a 72-h movement standstill; pre-emptive depopulation within a 1km radius of detected farms, and implementation of regionalisation with movement restrictions.
	Depop_1000	Depopulation capacity: 1,000 farms per day (unlimited capacity)	Depopulation capacity: five farms per day for the first week and ten farms per day thereafter.

1: For control strategy variant EU_min, more than 1 control parameter value changed.

2.3. Economic impact at sector level

The total economic impact consists of the direct costs (DC), direct and indirect consequential costs (DCC and ICC) and aftermath costs (AC). Only the DC and DCC were covered in this study. The economic impact was only calculated for farmers and the government that organises the CSF control, and not for the related industries (e.g. slaughterhouses).

2.3.1. Direct costs

The DC are the costs made to control the CSF outbreak, including on-farm costs such as culling of infected animals, pre-emptive culling (including compensation), vaccination and surveillance but also the organisational costs (Longworth et al., 2012a).

The DC was calculated based according to the method described in Hop et al. (2014). In Table 5 the per-unit DC parameters used in the calculations of the DC are given. Organisation costs include costs such as running the crisis centre, hiring personal and tracing (Hop et al., 2014). The organisational costs were estimated at € 150,000 per day based on the CSF outbreak in the Netherlands in1997-1998 and Avian Influenza outbreak in the Netherlands in 2003 (Hop et al., 2014). Costs for clinical examination and serological screening include costs for preparation, materials needed and labour costs for a vet with helpers. Depopulation costs include organisation costs. Vaccination costs include vaccines and labour costs for a vet and four helpers. The costs for the destruction of feed was based on the average present amount of feed on the farm for sow farmers 14 days and for slaughter pigs seven days (Hop et al., 2014). For a more detailed description of the direct costs calculation see Hop et al. (2014).

Table 5: Per-unit cost parameters used in the calculation of direct costs associated with classical swine fever (CSF) outbreaks in North Rhine Westphalia (NRW) and Lower Saxony (LS) (Hop et al., 2014).

Cost categories	Abbreviation of cost category	Unit	Value (€)
Organisation	cOrg	€ / day (duration)	150,000.00
Clinical examination and serological screening	cScreen	€ / farm in MRZ[1]	408.45
Depopulation of sows	cDepop	€ / depopulated sow	440.03
Depopulation of slaughter pigs	cDepop	€ / depopulated slaughter pig	83.95
Vaccination of sows	cVacc	€ / vaccinated sow	1.36
Vaccination of gilts or slaughter pigs	cVacc	€ / vaccinated gilt or slaughter pig	1.36
Vaccination of piglets	cVacc	€ / vaccinated piglet	1.39
Destruction of sow feed	cFeed	€ / depopulated sow	20.00
Destruction of slaughter pig feed	cFeed	€ / depopulated slaughter pig	3.20

1: MRZ = movement restriction zone.

2.3.2. Direct consequential costs

The DCC are costs that originate from the disease control and refer to farms inside the MRZ that are not directly affected by the CSF outbreak. The DCC include cost such as controlled slaughter due to welfare problems, empty stables and movement restrictions (Longworth et al., 2012a; Hop et al., 2014). The DCC calculation was based on the approach described in Hop et al. (2014). In Table 6 the per-unit DCC cost parameters used in the calculations of the DCC are given. Farmers should have enough space to keep animals for six additional weeks, so if an outbreaks takes longer than six weeks farmers have welfare costs. The costs for idle farms were based on the fixed costs including profit margin per sow or slaughter pig and labour costs were assumed to be fixed (Hop et al., 2014). For a more detailed description of the direct consequential costs calculation see Hop et al. (2014).

Table 6: Per-unit cost parameters used in the calculation of direct consequential costs associated with classical swine fever (CSF) outbreaks in North Rhine Westphalia (NRW) and Lower Saxony (LS) (Hop et al., 2014).

Cost categories	Abbreviation of cost category	Unit	Value (€)
Controlled slaughter of slaughter pigs due to welfare problems	cWelf	€ / slaughter pig in MRZ[1] for > 6 weeks	10.16
Exemptions in movement restrictions to allow for movement of vaccinated piglets due to welfare problems	cWelf	€ / piglet in MRZ for > 6 weeks	9.62
Empty stables sows incl. piglets (idle production factors)	cIdle	€ / depopulated sow / day	0.99
Empty stables slaughter pigs (idle production factors)	cIdle	€ / depopulated slaughter pig / day	0.18
Movement restrictions piglets	cMovRes	€ / piglet in MRZ	0.78
Movement restrictions slaughter pigs	cMovRes	€ / slaughter pig in MRZ	1.65

1: MRZ = movement restriction zone.

2.4. Economic impact at individual farm level

In case of a CSF outbreak, there are different situations for an individual farm. These situations were related to different economic factors that result in an economic impact. An overview of the important economic factors is given in Table 7. This table shows for the two control strategies (Depop and Vacc_depop) the factors that cause the different situations namely: the location of the farm in various control zones (depopulation, vaccination, MRZ or region), day of detection in the production cycle (begin (day 1), half-way (day 58) or end (day 116)) and the duration of the outbreak based on the percentile (50^{th} or 95^{th}) and the index farm (NRW_hd or NRW_ad)). Combining these factors in the following formula: Location * Day of detection * Duration resulted in: a total of 220 (80 depopulation (4*5*4) and 140 vaccination (7*5*4)) CSF-related situations, Therefore the aim of this chapter is to compare the net labour income of a normal situation (baseline) with the 220 different situations in NRW. The focus was only on NRW since the results of an outbreak in LS are comparable with an outbreak in NRW.

Table 7: The economic factors causing the different situations an individual farm could be in during a classical swine fever (CSF) outbreak in the region North Rhine Westphalia (NRW).

	Control strategy	
Factors	**Depop**	**Vacc_depop**
Location of the individual farm		
Depopulation[1]	x	x
3-km MRZ[2]	x	x
10-km MRZ[3]	x	x
Region[4]	x	x
Vaccination_no-sell[5]	-	x
Vaccination_sell[6]	-	x
Vaccination_buy[7]	-	x
Day of CSF detection during production cycle and feeding style[8]		
Day 1 of production cycle (feeding: ad libitum)	x	x
Day 58a of production cycle (feeding: ad libitum)	x	x
Day 58b of production cycle (feeding: ad libitum till day 58 & restricted from day 58)	x	x
Day 58c of production cycle (feeding: ad libitum till day 116 & restricted from day 116)	x	x
Day 116 of production (feeding restricted)	x	x
Duration of the CSF outbreak[9]		
NRW_ad + 50th percentile	x	x
NRW_ad + 95th percentile	x	x
NRW_hd + 50th percentile	x	x
NRW_hd + 95th percentile	x	x

1: Farm is depopulated at day of detection
2: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
3: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
4: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
5: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
6: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, vaccinated piglets were bought for the next production cycle. These piglets were kept till slaughter weight and sold for the vaccinated slaughter pig price.
8: Feeding Ad libitum (unlimited feed) or restricted feeding (feeding at maintenance level).
9: Based on the index farm (abbreviations explained in Table 2) and the percentiles 50th

The different situations for an individual farm were modelled in a deterministic spreadsheet cost model. The calculations made were based on a profit and loss statement, as stated in the KWIN (2013). Since this thesis is a pilot study and time was limiting some assumptions were made. The first assumption made was that aftermath costs were not included, this means that the day after the eradication of the CSF epidemic, a normal day occurs (no surpluses or shortages of pigs and no price fluctuations). The second assumption made was that the variable costs were zero if a farm was idle. The third assumption made was that the labour costs were fixed costs. The fourth and final assumption made was that the farmer could always sell his pigs, even if they were vaccinated or too fat (at a reduced price).

In Table 8 an overview is given of the formulas used to calculate the net labour income for the different scenarios. First the revenues and costs were calculated, which resulted in the net labour income per delivered slaughter pig. Then the net labour income per delivered slaughter pig was multiplied with 500, since the average farm size was 500 slaughter pigs.

Table 8: The profit and loss statement with associated formulas

Profit and loss statement categories	Formulas
Average revenues per delivered slaughter pig	
Revenues[1]	Meat price or compensation per kg * average slaughter weight
Average costs per delivered slaughter pig	
Purchase of piglets	Piglet purchase price
Feeding costs	Feed price * average growth slaughter pig * feed conversion ratio
Animal dropout costs	(Dropout rate * Value average present slaughter pig) / (100% - dropout rate)
Additional process costs	
Costs for healthcare	Cost of healthcare per day * age in days when slaughtered
Costs for special healthcare	Cost of special healthcare per day * age in days when slaughtered
Costs for water	Cost of water per day * age in days when slaughtered
Costs for heating	Cost of heating per day * age in days when slaughtered
Costs for electricity	Cost of electricity per day * age in days when slaughtered
Miscellaneous costs (incl. litter)	Miscellaneous costs per day * age in days when slaughtered
Interest animals and capital in feed	((Value average present slaughter pig + capital in feed) * Interest rate) / 365 * age in days when slaughtered
Interest capital in land and cash	Capital in land and cash * Interest rate / 365 * length of CSF epidemic in days
Housing costs	Building cost per slaughter pig place / 365 * length of CSF epidemic in days
Manure costs	Manure costs * average slaughter weight
Labour costs	Wages per year/ 365 * length of CSF epidemic in days
Net labour income per delivered slaughter pig	
Net labour income	Average revenues – average costs + labour costs per delivered slaughter pig
Total annual net labour income	
Annual net labour income	(Net labour income per delivered slaughter pig (during epidemic) * 500 pigs) + (Net labour income per year (baseline) / 365 * (365 - duration of the epidemic in days))

1: Meat price is used for all situations except for the when the farm is depopulated then the compensation is paid

In Table 9 the input parameters used for the profit and loss statement calculation are given. Table 10 show the meat prices and compensation prices for different slaughter weights. The meat price for vaccinated pig meat was hard to estimate, therefore the study from Bergevoet et al. (2007) was used to estimate the vaccinated meat prices.

Table 9: Input parameters used in the calculation of the economic impact on individual farms

Input parameters	Unit	Value
Piglet purchase price[a]	€ / Piglet	55.00
Growth (ad libitum feeding)[a]	Kg/day	0.77
Growth (restricted feeding)[c]	Kg/day	0.50
Feed price[a,b]	€ / Kg feed	0.29
Feed conversion ratio[a]		2.82
Dropout rate[b]	%	2.40
Value average present slaughter pig (VaSp)[a,b]	€ / Slaughter pig	112.40
Costs for healthcare[a,b]	€ / Slaughter pig	1.00
Costs for special healthcare[a,b]	€ / Slaughter pig	0.10
Costs for water[b]	€ / Slaughter pig	0.90
Costs for heating[b]	€ / Slaughter pig	0.70
Costs for electricity[b]	€ / Slaughter pig	1.15
Miscellaneous costs (incl. litter)[b]	€ / Slaughter pig	0.50
Interest rate[b]	%	6.00
Capital in land and cash[a,b]	€ / Slaughter pig	5.00
Capital in feed[a,b]	€ / Slaughter pig	3.24
Building costs[a]	€ / Slaughter pig	46.43
Manure costs[a]	€ / Kg of slaughter weight	0.02
Wage farmer per year[b]	€ / Slaughter pig	14.34

a: Source: (Hoste, 2013)
b: Source: (KWIN, 2013)
c: Source: (Niemi, 2008)

Table 10: The meat prices and compensation prices per kg meat for different slaughter weights and situations

Location of the farm	Slaughter weight (kg)	Meat price (€/kg)	Compensation (€/kg)
Baseline	96	1.60[a]	
Depopulation[1]			
Depopulated on day 1 of production cycle	22		2.82[b]
Depopulated on day 58 of production cycle	60		1.90[b]
Depopulated on day 116 of production cycle	96		1.83[b]
Movement restriction zone			
MRZ price 1[1]	96 – 100	1.50[a]	
MRZ price 2[2]	100 – 115	1.40[c]	
MRZ price 3[2]	>115	1.30[c]	
Region[1]	96	1.50[a]	
Vaccination			
Normal animal	96	1.10[c]	
Heavier animal	> 96	1.00[c]	

a: Source: (AMI, 2014)

b: Source: (TSK, personal communication)

c: Based on sow slaughter prices, Source: (AMI, 2014)

d: Source: (Bergevoet et al., 2007)

1: Animal has the same weight as in the baseline situation but there is a surplus of slaughter pigs since farmers cannot leave the region to sell their pigs

2: Animals are heavier, because they are kept longer on the farm due to movement restrictions, resulting in a lower quality and price of meat.

3. Results

3.1. Simulation of CSF epidemic results

The epidemiological results for the three control strategies for simulated outbreaks indexed in NRW and LS are presented in Table 11. This table shows the number of farms infected, depopulated, vaccinated and located inside a MRZ, as well the duration of the CSF outbreak for the 50th and 95th percentile. The duration is excluding the high-risk period (HRP), this is the time it takes from infection to detection. Also the number of animals depopulated, vaccinated or located inside a MRZ was calculated see **(Appendix A)**.

Table 11: Epidemiological results for the three control strategies for simulated classical swine fever (CSF) outbreaks indexed in North Rhine Westphalia (NRW) and Lower Saxony (LS).

Index farm[3]	Control strategy[4]	No. of farms infected		No. of farms depopulated		No. of farms vaccinated		No. of farms in MRZ[1]		Duration in days (excl. HRP[2])	
		50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
NRW_hd	Depop	18	49	42	102	0	0	1,090	2,383	79	180
	Vacc_depop	18	51	27	62	74	195	1,091	2,203	99	174
	Vacc_nodepop	18	45	22	54	85	181	946	1,910	90	162
LS_hd	Depop	12	28	28	69	0	0	1,190	2,410	67	141
	Vacc_depop	12	27	19	39	62	180	1,194	2,329	81	151
	Vacc_nodepop	12	28	14	31	81	196	1,179	2,271	81	135
NRW_ad	Depop	5	25	13	51	0	0	521	1,532	64	139
	Vacc_depop	5	25	9	34	27	115	518	1,479	74	151
	Vacc_nodepop	5	25	6	30	32	106	513	1,460	75	153
LS_ad	Depop	5	17	11	38	0	0	406	1,425	64	144
	Vacc_depop	5	17	8	23	24	101	406	1,412	72	138
	Vacc_nodepop	5	17	6	20	27	104	405	1,427	73	140

1: MRZ = movement restriction zone.

2: HRP = high-risk period.

3: Hd = high-density index farm; ad = average density index farm.

4: The set of control measures for control strategies based on depopulation and vaccination is presented in Table 3.

When looking at the different control strategies, there was a minimal difference between the numbers of farms infected. Index farm NRW_hd resulted in the most farms infected, namely 18 and 49 infected farms at the 50th and 95th percentiles, respectively. When looking at index farm LS_hd there were 33% (12 farms) and 40% (28 farms) less infected farms at the 50th and 95th percentiles than NRW_hd. Comparing index farm NRW_av with NRW_hd resulting in 72% (5 farms) and 49% (17 farms) less infected farms at the 50th and 95th percentiles. Comparing index farm LS_av with LS_hd resulting in 58% (5 farms) and 32% (17 farms) less infected farms at the 50th and 95th percentiles.

When looking at the number of farms depopulated, there was a difference between the different control strategies. Control strategy Depop resulted at all index farms in the most farms depopulated. This is mainly due to the fact that Depop uses pre-emptive depopulation of farms in a 1km radius around detected farms. Control strategy Vacc_nodepop resulted at all index farms in the least farms infected. Index farm NRW_hd resulted again with the most farms affected, i.e., 42 and 102 depopulated farms at the 50th and 95th percentiles, respectively. Comparing index farm LS_hd with NRW_hd, all control strategies resulted in less farms depopulated for both the 50th and the 95th percentiles. Comparing index farm NRW_av with NRW_hd resulted almost in three and two times of less farms depopulated at the 50th and 95th percentiles, respectively. Comparing index farm LS_av with LS_hd resulted in almost 40% and 60% less farms depopulated at the 50th and 95th percentiles, respectively.

Control strategy Vacc_depop resulted at all four index farms at the 50th percentile in less farms vaccinated. For the 95th percentile Vacc_depop resulted at index farms NRW_hd and NRW_ad in more farms and for index farms LS_hd and LS_ad in less farms vaccinated than Vacc_nodepop. Index farm NRW_hd had the most farms vaccinated for control strategy Vacc_depop (50th and 95th) and Vacc_nodepop (50th). Index farm LS_hd had the most farms vaccinated for control strategy Vacc_nodepop (95th). Index farm LS_ad resulted for both control strategies in the lowest amount of animals vaccinated.

There was little difference between numbers of farms located inside a movement restriction zone, between the different control strategies, for most index farms. The most farms located inside a MRZ were at index farm LS_hd (2,410 farms; 95th percentile). The difference between the control strategies for index farm NRW_hd is larger than the differences between the control strategies for other index farms. Comparing index farm NRW_hd with LS_hd resulted for all control strategies in fewer farms inside a MRZ for NRW_hd. Comparing index farm NRW_av with LS_av resulted for all control strategies in more farms inside a MRZ for NRW_av.

When looking at the duration of the epidemic there is a difference between the 50th and 95th percentile for each index farm. The Depop strategy has the lowest duration of the simulated outbreak for all index farms at the 50th percentile, but at the 95th percentile it has the longest duration at index farms NRW_hd and LS_av. Index farm NRW_hd had the longest duration of the epidemic, namely 99 and 180 days at the 50th as the 95th percentiles, respectively.

3.2. Economic impact at sector level results

The direct and direct consequential costs for the three control strategies are presented in Table 12 and Table 13. These tables show the total DC/DCC in million euros as well as the cost of the DC/DCC categories.

Table 12: Direct costs (million €) for three control strategies for simulated classical swine fever (CSF) outbreaks indexed in North Rhine Westphalia (NRW) and Lower Saxony (LS).

Index farm	Control strategy	Direct cost (DC) categories[1] cOrg 50th	cOrg 95th	cScreen 50th	cScreen 95th	cDepop 50th	cDepop 95th	cVacc 50th	cVacc 95th	cFeed 50th	cFeed 95th	Total DC 50th	Total DC 95th
NRW_hd	Depop	11.9	27.0	0.4	1.0	1.5	4.8	0	0	0.1	0.2	**13.9**	**33.0**
	Vacc_depop	14.9	26.1	0.4	0.9	0.8	2.5	0.1	0.2	0.0	0.1	**16.2**	**29.8**
	Vacc_nodepop	13.5	24.3	0.4	0.8	0.7	2.4	0.1	0.1	0.0	0.1	**14.7**	**27.7**
LS_hd	Depop	10.1	21.2	0.5	1.0	1.8	4.4	0	0	0.1	0.2	**12.5**	**26.8**
	Vacc_depop	12.2	22.7	0.5	1.0	1.2	2.3	0.1	0.2	0.0	0.1	**14.0**	**26.3**
	Vacc_nodepop	12.2	20.3	0.5	0.9	0.9	2.0	0.1	0.2	0.0	0.1	**13.7**	**23.5**
NRW_ad	Depop	9.6	20.9	0.2	0.6	0.5	2.8	0	0	0.0	0.1	**10.3**	**24.4**
	Vacc_depop	11.1	22.7	0.2	0.6	0.3	1.6	0.0	0.1	0.0	0.1	**11.6**	**25.1**
	Vacc_nodepop	11.3	23.0	0.2	0.6	0.3	1.4	0.0	0.1	0.0	0.1	**11.8**	**25.2**
LS_ad	Depop	9.6	21.6	0.2	0.6	0.6	2.2	0	0	0.0	0.1	**10.4**	**24.5**
	Vacc_depop	10.8	20.7	0.2	0.6	0.4	1.3	0.0	0.1	0.0	0.1	**11.4**	**22.8**
	Vacc_nodepop	11.0	21.0	0.2	0.6	0.3	1.1	0.0	0.1	0.0	0.0	**11.5**	**22.8**

1: Abbreviations of DC categories are explained in Table 5.

2: Hd = high-density index farm; ad = average density index farm.

3: The set of control measures for control strategies based on depopulation and vaccination is presented in Table 3.

Table 13: Direct consequential costs (million €) for three control strategies for simulated classical swine fever (CSF) outbreaks indexed in North Rhine Westphalia (NRW) and Lower Saxony (LS).

		Direct consequential cost (DCC) categories[1]									
	Control	cIdle		cMovRes		cWelf		Total DCC		Total DC and DCC	
Index farm[2]	strategy[3]	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
NRW_hd	Depop	0.1	0.4	0.9	2.0	1.6	5.2	**2.6**	**7.6**	**16.5**	**40.6**
	Vacc_depop	0.1	0.3	0.9	1.8	3.5	10.1	**4.5**	**12.2**	**20.7**	**42.0**
	Vacc_nodepop	0.1	0.3	0.8	1.7	4.7	10.7	**5.6**	**12.7**	**20.3**	**40.4**
LS_hd	Depop	0.2	0.4	1.3	2.4	1.1	6.2	**2.6**	**9.0**	**15.1**	**35.8**
	Vacc_depop	0.1	0.3	1.3	2.4	3.1	12.1	**4.5**	**14.8**	**18.5**	**41.1**
	Vacc_nodepop	0.1	0.2	1.3	2.3	7.1	13.6	**8.5**	**16.1**	**22.2**	**39.6**
NRW_ad	Depop	0.0	0.2	0.4	1.3	0.0	2.4	**0.4**	**3.9**	**10.7**	**28.3**
	Vacc_depop	0.0	0.1	0.4	1.3	0.4	5.8	**0.8**	**7.2**	**12.4**	**32.3**
	Vacc_nodepop	0.0	0.1	0.4	1.2	0.9	6.3	**1.3**	**7.6**	**13.1**	**32.8**
LS_ad	Depop	0.0	0.2	0.3	1.3	0.0	2.0	**0.3**	**3.5**	**10.7**	**28.0**
	Vacc_depop	0.0	0.1	0.3	1.3	0.2	6.2	**0.5**	**7.6**	**11.9**	**30.4**
	Vacc_nodepop	0.0	0.1	0.3	1.3	0.7	6.2	**1.0**	**7.6**	**12.5**	**30.4**

1: Abbreviations of DCC categories are explained in Table 5.

2: Hd = high-density index farm; ad = average density index farm.

3: The set of control measures for control strategies based on depopulation and vaccination is presented in Table 3.

The depopulation strategy had the lowest DC at the 50th percentile, but the vaccination strategies followed closely. The organisational costs (based on the duration of the simulated epidemic) were the largest DC category (between 81% and 96% of the total DC), followed by the depopulation costs (between 3% and 16% of the total DC), which increased substantially if the outbreak increased. The highest DC were calculated at index farm NRW_hd, here the DC ranged from €13.9 million for depopulation to €16.2 million for Vacc_depop.

The depopulation had the lowest DCC at the 50th and 90th percentile. The costs of welfare measures were the largest DCC category, these costs relate to the amount of farms in the MRZs. Because LS_hd had the most farms in the MRZ, it also had the highest welfare costs (€ 13.6 million) and therefore also the highest total DCC (€16.1 million).

The total costs (DC+DCC) were at almost all the index farms for both the 50th and 90th percentile the lowest for the Depop strategy, except at index farm NRW_hd there the total costs were similar for Depop and Vacc_nodepop at the 95th percentile. NRW_hd and LS_hd had almost the same amount of total costs. As well as NRW_ad and LS_ad had almost the same total costs.

3.3. Sensitivity analysis results

Table 14 presents the results of epidemiological output sensitivity to changes in the control strategy parameters and Table 15 presents the associated DC and DCC. Results in these tables are presented for index farms NRW_hd and NRW_ad as absolute changes from the baseline strategies.

Table 14: Epidemiological output sensitivity to changes in the control strategy parameters for simulated classical swine fever (CSF) outbreaks indexed at farms NRW_hd and NRW_ad (results presented as an absolute change from the baseline strategies).

Index farm	Control strategy	Changed parameter[1]	No. of farms infected		No. of farms depopulated		No. of farms vaccinated		No. of farms in MRZ[2]		Duration in days (excl. HRP[3])	
			50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
NRW_hd	Depop		**18**	**49**	**42**	**102**	**-**[4]	**-**	**1,090**	**2,383**	**79**	**180**
		Depop_1000	0	+6	0	+9	-	-	-23	+62	+2	+1
		EU_min	+5	+10	-15	-35	-	-	+47	+79	+41	+37
NRW_hd	Vacc_depop		**18**	**51**	**27**	**62**	**74**	**195**	**1,091**	**2,203**	**99**	**174**
		Depop_1000	0	-4	0	-1	0	-8	-20	-52	0	+3
		Depop1km_1 day	0	0	-1	0	+3	-1	-24	-67	+1	+2
NRW_ad	Depop		**5**	**25**	**13**	**51**	**-**	**-**	**521**	**1,532**	**64**	**139**
		Depop_1000	0	+1	0	+2	-	-	0	-15	0	-2
		EU_min	+1	+4	-6	-17	-	-	+13	+55	+14	+35
NRW_ad	Vacc_depop		**5**	**25**	**9**	**34**	**27**	**115**	**518**	**1,479**	**74**	**151**
		Depop_1000	0	+1	0	0	0	-2	0	-8	0	0
		Depop1km_1 day	0	+1	-1	-3	+1	-10	0	-64	0	-7

1: Abbreviations of changed parameters are explained in Table 4.

2: MRZ = movement restriction zone.

3: HRP = high-risk period.

4: Not applicable.

Table 15: Economic (DC and DCC (€ million)) output sensitivity to changes in the control strategy parameters for simulated classical swine fever (CSF) outbreaks indexed at farms NRW_hd and NRW_ad (results presented as an absolute change from the baseline strategies).

Index farm	Control strategy	Changed parameter[1]	DC		DCC		Total DC and DCC	
			50th	95th	50th	95th	50th	95th
NRW_hd	Depop		**13.9**	**33.0**	**2.6**	**7.6**	**16.5**	**40.6**
		Depop_1000	+0.3	+0.6	0	+0.7	+0.3	+1.3
		EU_min	+5.4	+3.5	+4.1	+7.8	+9.5	+11.3
NRW_hd	Vacc_depop		**16.2**	**29.8**	**4.5**	**12.2**	**20.7**	**42.0**
		Depop_1000	0	+0.6	+0.1	+0.3	+0.1	+0.9
		Depop1km_1day	+0.1	+0.2	+0.3	+0.7	+0.4	+0.9
NRW_ad	Depop		**10.3**	**24.4**	**0.4**	**3.9**	**10.7**	**28.3**
		Depop_1000	+0.1	-0.3	+0.1	0	+0.2	-0.3
		EU_min	+1.9	+4.2	+0.9	+5.1	+2.8	+9.3
NRW_ad	Vacc_depop		**11.6**	**25.1**	**0.8**	**7.2**	**12.4**	**32.3**
		Depop_1000	+0.1	-0.1	+0.1	0	+0.2	-0.1
		Depop1km_1day	0	-1.3	+0.3	-0.3	+0.3	-1.6

1: Abbreviations of changed parameters are explained in Table 4.

Changing the depopulation capacity (Depop_1000) so that there is no restriction on depopulation capacity, resulted in almost no differences in number of farms infected, depopulated, inside a MRZ or the length of the CSF outbreak for NRW_ad. For NRW_hd it had a little impact on these parameters.

The control strategy based on the EU requirements (EU_min) compared with index farm NRW_hd, resulted in an increased amount of farms infected (28% and 20%) located inside a MRZ (4% and 3%) and a longer duration of the epidemic (52% and 21%), but resulted in less farms depopulated (36% and 34%). The difference between EU_min and NRW_ad was less then between EU_min and NRW_hd.

A Vacc_depop starting at day 2 instead of day 4 (Depop1km_1day) had hardly an effect on the epidemiological output, and a 2% increase on the total DC and DCC.

The total costs were for almost all the alternative control strategies higher except for Depop1km_1day (NRW_ad; 95th). The EU_min resulted in an increase of 25-30% total costs for both NRW_hd as NRW_ad for the 95th percentile.

3.4. Economic impact at individual farm level results

Table 16 and **Appendix B** present the comparison of the net labour income of a farm at different locations during a CSF outbreak with a baseline scenario. This table shows next to the difference with the baseline also how the annual net labour income is composed. The revenues at the depopulation rows are compensation paid to the farmers.

The baseline situation, the costs per slaughter pig (€139.08) are lower than the revenues per slaughter pig (€153.62) so there is a positive net result per slaughter pig (€14.54). Since the farmer is the only worker at the farm he also receives the paid labour costs (€4.64), adding those two numbers (€14.54 + €4.64) makes the net labour income per slaughter pig €19.18. The farmers has 500 slaughter pigs and has approximately 3.09 production rounds per year, multiplying these numbers with the net labour income per slaughter pig results in the annual net labour income (€29,657.11).

The costs, revenues, net result per slaughter pig, net labour income and annual net labour income for the different index farms and location are all calculated at the same way.

Zero at the column difference in annual net labour income compared with baseline farm, means that CSF epidemic has been eradicated before the pigs are slaughtered, so value of the meat is the same as the normal price. In the case of index farm NRW_hd with control strategy Depop, a farm that has been depopulated received that production year €10,047.30 (50th) and €24,797 (95th) less than the baseline situation.

The last column (Difference in annual net labour income compared with baseline farm) of Table 16 and **Appendix B** are graphically displayed Figure 5 and Figure 4. These figures show different CSF outbreak moments in the production cycle day 1 (begin), day 58a (halfway, feeding ad libitum), day 58b (halfway, feeding restricted from day 58), day 58c (halfway, feeding restricted from day 116) and day 116 (slaughter weight). The higher a bar of figures 4a-d and 4a-d is the larger the difference is with the baseline scenario, so the less money a farmer earns.

Table 16: The net farm income for an individual fattening farm compared with the baseline scenario in case of a classical swine fever (CSF) outbreak on day 1 of the fattening production cycle.

Index farm[1] and control strategy	Location in zone	Duration of outbreak (days)[9]		Costs per slaughter pig		Revenues or compensation per slaughter pig		Net result per slaughter pig		Net labour income per slaughter pig		Annual net labour income (500 pigs)		Difference in annual net labour income (compared with baseline farm)	
		50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
	Baseline	-	-	139.08		153.62		14.54		19.18		29,657.11			
NRW_hd / Depop	Depopulation[2]	79	180	70.83	87.94	60.79	60.79	-10.04	-27.15	-6.86	-19.85	19,609.81	4,859.36	-10,047.30	-24,797.75
	3 km MRZ[3]	79	180	139.08	165.70	153.62	157.94	14.54	-7.77	19.18	-0.57	29,657.11	14,550.92	0	-15,106.19
	10 km MRZ[4]	79	180	139.08	164.18	153.62	157.94	14.54	-6.24	19.18	0.60	29,657.11	15,865.36	0	-13,791.76
	Region[5]	79	180	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
NRW_hd / Vacc_depop	Depopulation	99	174	74.38	87.08	60.79	60.79	-13.59	-26.29	-9.62	-19.34	16,608.58	5,654.96	-13,048.54	-24,002.15
	3 km MRZ	99	174	139.08	164.69	153.62	157.94	14.54	-6.75	19.18	0.21	29,657.11	15,427.21	0	-14,229.90
	10 km MRZ	99	174	139.08	163.16	153.62	157.94	14.54	-5.23	19.18	1.37	29,657.11	16,741.65	0	-12,915.47
	Region	99	174	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
	Vaccination_ns[6]	99	174	139.08	164.69	105.61	112.81	-33.46	-51.87	-28.83	-44.92	9,071.32	-7,135.22	-20,585.80	-36,792.33
	Vaccination_s[7]	99	174	139.08	148.97	105.61	105.61	-33.46	-43.35	-28.83	-36.40	9,071.32	-2,875.14	-20,585.80	-32,532.25
	Vaccination_b[8]	99	174	139.08	120.81	105.61	105.61	-33.46	-15.20	-28.83	-10.56	9,071.32	-79.14	-20,585.80	-29,736.25
NRW_ad / Depop	Depopulation	64	139	68.29	81.00	60.79	60.79	-7.50	-20.21	-4.92	-14.64	21,800.36	10,847.24	-7,856.75	-18,809.87
	3 km MRZ	64	139	139.08	151.78	153.62	147.52	14.54	-4.26	19.18	1.31	29,657.11	18,822.19	0	-10,834.92
	10 km MRZ	64	139	139.08	146.89	153.62	142.48	14.54	-4.40	19.18	0.80	29,657.11	19,299.87	0	-10,357.24
	Region	64	139	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
NRW_ad / Vacc_depop	Depopulation	74	151	70.15	83.19	60.79	60.79	-9.36	-22.40	-6.38	-16.36	20,259.78	9,014.07	-9,397.33	-20,643.04
	3 km MRZ	74	151	139.08	158.31	153.62	154.24	14.54	-4.07	19.18	1.97	29,657.11	18,179.11	0	-11,478.00
	10 km MRZ	74	151	139.08	153.41	153.62	149.20	14.54	-4.21	19.18	1.48	29,657.11	18,662.08	0	-10,995.03
	Region	74	151	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
	Vaccination_ns	74	151	139.08	158.31	105.61	110.17	-33.46	-48.14	-28.83	-42.09	14,217.77	-3,855.32	-15,439.35	-33,512.44
	Vaccination_s	74	151	139.08	145.07	105.61	105.61	-33.46	-39.46	-28.83	-33.42	14,217.77	483.97	-15,439.35	-29,173.15
	Vaccination_b	74	151	139.08	120.81	105.61	105.61	-33.46	-15.20	-28.83	-10.56	14,217.77	-79.14	-15,439.35	-29,736.25

1: Hd high-density index farm; ad = average density index farm.
2: Farm is depopulated at day of detection
3: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
4: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
5: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
6: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle.
8: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight; vaccinated piglets were bought for the next production cycle.
9: Data from epidemiological results (Table 11).

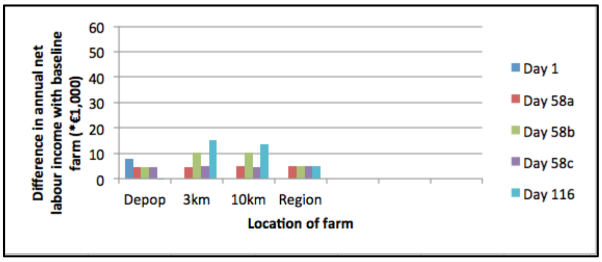

Figure 4a. Index farm NRW_ad, control strategy Depop; 50th

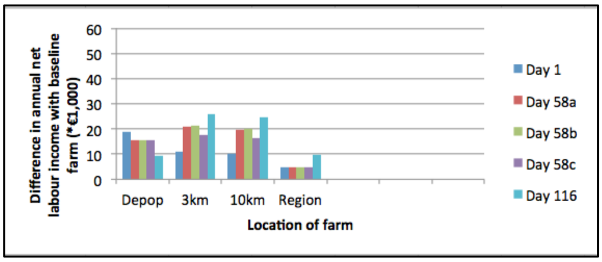

Figure 4b. Index farm NRW_ad, control strategy Depop; 95th

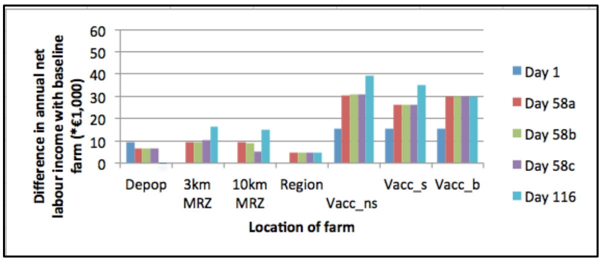

Figure 4c. Index farm NRW_ad, control strategy Vacc_depop; 50th

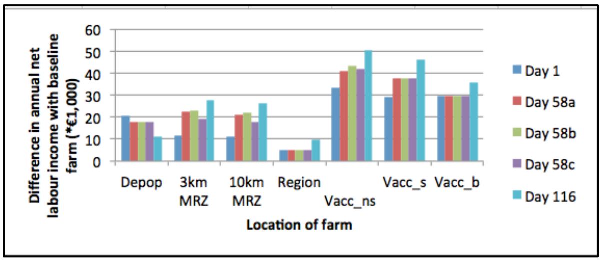

Figure 4d. Index farm NRW_ad, control strategy Vacc_depop; 95th

Figure 5: Comparing the difference between the annual net farm income with the baseline situation for multiple Classical swine fever (CSF) detection days during the production cycle for the different locations during a simulated CSF outbreak at index farm NRW_ad with control strategies Depop and Vacc_depop. Abbreviations are explained in Table 7.

Figure 4a and 4c show a depopulated farm at day 116, results in a higher annual net labour income than the baseline scenario. Also in figure 4a and 4c the farms that are inside the 3km-1km or region at day 1 have the same annual net labour income as the baseline scenario, all the other farms in figure 4 have a lower annual net labour income than the baseline scenario. Vaccination, results always in a lower annual net labour income than if a farm is located in another location. Using restricted feeding (day 58b and 58c) has little effect compared with normal feeding (58a).

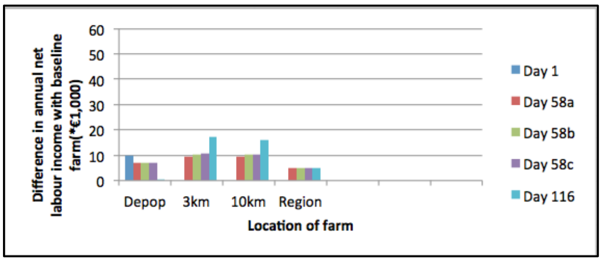

Figure 5a. Index farm NRW_hd, control strategy Depop; 50th

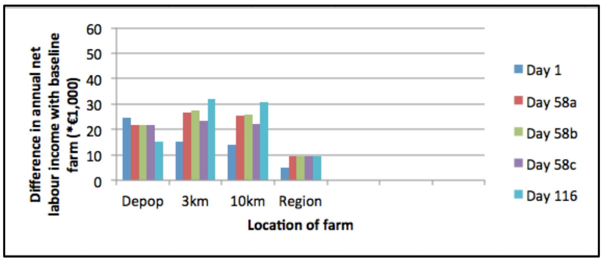

Figure 5b. Index farm NRW_hd, control strategy Depop; 95th

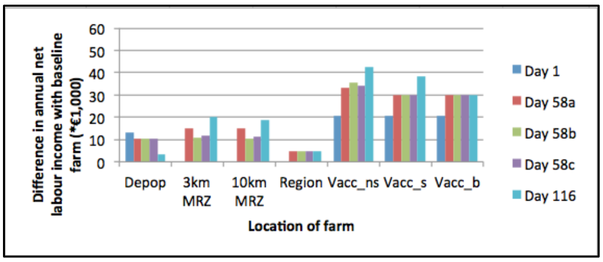

Figure 5c. Index farm NRW_hd, control strategy Vacc_depop; 50th

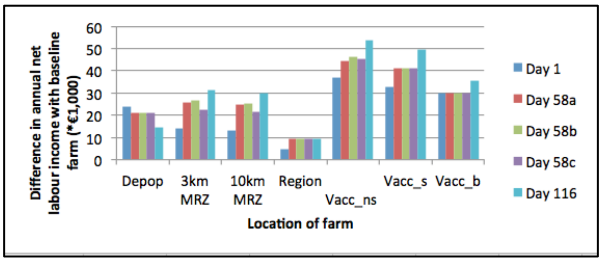

Figure 5d. Index farm NRW_hd, control strategy Vacc_depop; 95th

Figure 4: Comparing the difference between the annual net farm income with the baseline situation for multiple classical swine fever (CSF) detection days during the production cycle for the different locations during a simulated CSF outbreak at index farm NRW_hd with control strategies Depop and Vacc_depop. Abbreviations are explained in Table 7.

When an index farm is selected in a high-density area like NRW_hd, the annual net labour income is always worse than the baseline situation. Expect in six cases where it is the same, because the outbreak has been eradicated before the end of the production cycle (Figure 5a and c, Day1, locations 3km, 10km and region). The largest difference with the baseline scenario is presented in figure 5d, if the farm is vaccinated on day 116 and the farmer keeps his animals on the farm he looses around €54,000 that year.

4. Discussion

The aim of this pilot study was to compare non-vaccination and vaccination based CSF control in North Rhine Westphalia (NRW) and Lower Saxony (LS), with the focus on: 1) the epidemiological impact, 2) the economic impact at sector level and 3) the impact on the net farm income for individual farms located in the various disease control zones.

4.1. Epidemiological impact

For NRW there was a clear distinction in the epidemiological results between the high-density index farm (NRW_hd) and average density index farm (NRW_ad). For LS this was also the case except for the difference in duration of the outbreak, here the high density index farm (LS_hd) was slightly higher or even lower than the average density index farms (LS_ad and NRW_ad). This could be caused by the reason that there is a higher fattening/farrowing farm ration in LS than NRW, resulting in more "death ends" for the CSF epidemic, since fattening farms only transport to the slaughter houses and not to other pig farms. These differences in the NRW region are in compliance with findings of Mangen et al. (2002), Brosig (2012) and Hop et al. (2014). The most notable difference with studies conducted in the past (by e.g. Mangen et al., 2002; Karsten et al., 2007) is that both the duration and the size of an simulated epidemic are smaller. This difference could be explained that the pig farm density is lower nowadays than 10 years ago, resulting in a lower local spread chance (Hop et al., 2014).

The control strategy Depop resulted in the highest number of farms depopulated, but if there is no market for the vaccinated animals, the two vaccination strategies will result in the most animals culled. There is a minimal difference in the number of animals infected or located inside a MRZ for the three control strategies. The major difference between the control strategies is the duration of the epidemic. At the 50th percentile the Depop strategy resulted in the shortest epidemic duration, but at the 95th percentile it resulted 50% of the cases in the longest duration. This was not completely in line with what I expected, I expected that both the 50th as the 95th percentile the Depop strategy would result in the shortest duration followed by Vacc_depop and as last Vacc_nodepop. The Vacc_nodepop strategy resulted in all situations in a shorter or the same duration than the Vacc_depop strategy. A reason for this could be that in the case of Vacc_depop, vaccination and, consequently, the time in which herds reach immunity starts three days later compared with strategy Vacc_nodepop. Despite strategy Vacc_depop includes pre-emptive depopulation in a 1km radius around detected farms during the first three days, the local spread in the 1-2km zones can continue during the first three days of an outbreak (this mainly happens in worst-case outbreaks). Therefore, strategy Vacc_depop results in longer epidemics for high-density index farms during worst-case outbreaks (the 95th percentiles). The results of the epidemiological impact are similar to the studies of (Backer et al., 2009; Hop et al., 2014).

The sensitivity analysis showed that all three control strategies resulted in less farms infected, located inside a MRZ and a shorter duration. Hop et al. (2014) also found that a control strategy based only on the EU mandatory control measures is not sufficient enough to control a CSF epidemic.

The duration of both the vaccination strategies could be underestimated because the time in which marker vaccination resulted in herd immunity was assumed to be 8 to 14 days (Boklund et al., 2009; Hop et al., 2014), but other studies showed that minimal 14 days are required to gain herd immunity (Uttenthal et al., 2001; Beer et al., 2007). The farm files used for the simulation were based on data from 2007 (NRW) and 2010 (LS), probably there are less farms now, so the density is lower and therefore the local spread chance has been reduced, resulting in a slightly overestimated of the duration.

4.2. Economic impact at sector level

For both NRW and LS there was a clear distinction in the economic results between the high-density index farms (NRW_hd and LS_hd) and average density index farm (NRW_ad and LS_hd). The depop strategy resulted at all the index farms at the lowest total costs. The Vacc_depop resulted in lower total costs at the average density index farms and the Vacc_nodepop resulted in lower total costs at the high-density index farms.

The direct costs are composed mostly out of the organisational costs (cOrg), between 81% and 96%. These organisational costs are set to a fixed amount per day, namely €150,000. If these costs are over- or underestimated, the total costs will chance completely. The other cost categories are linked to the amount of farms/animals affected by the CSF epidemic.

4.3. Economic impact at individual farm level

Both the control strategies Depop and Vacc_depop, result in almost the same difference with the baseline scenario for the farms located in the depopulation, 3km, 10km or region zones. This means that for these farmers it does not make a big difference if a Depop or a Vacc_depop strategy is used. Farms that were vaccinated have a difference with the baseline scenario that is two times as high as farms located inside the 3km MRZ (second worse result, when compared with the baseline). This means that for these farmers (that were depopulated or located inside the 3km MRZ, at strategy Depop) the Vacc_depop strategy is not preferred. This problem could be solved if farmers received a higher meat price for vaccinated meat.

Due to the assumptions made there are some critical points. First of all, calculations were based on the Dutch system (KWIN), but the Dutch key figures were mostly replaced for German key figures, wages of the farmer was for example based on the Dutch farmer wages. But the farmer’s wage is a fixed cost so it will not have an influence on the difference with the baseline scenario. Secondly the vaccination price was estimated based on a study from Bergevoet et al. (2007), this price could have changed in the last 7 years. Since aftermath costs are not included in this study, the differences with the baseline situation are probably an underestimation of the real difference.

5. Conclusion

From this pilot study the following conclusions can be drawn:

- From an veterinary point of view, all three the control strategies (Depop, Vacc_depop and Vacc_nodepop) are effective in controlling a CSF epidemic in NRW and LS, but if there is no market for the vaccinated animals, the Depop strategy outweighs the two vaccination control strategies on animals depopulated;
- From an economic point of view, the two vaccination control strategies (Vacc_depop and Vacc_nodepop) have almost the same costs (DC/DCC) for controlling a CSF epidemic, and the control strategy Depop results in slightly less costs (DC/DCC) for controlling a CSF epidemic. Control strategy Depop out performed both vaccination based control strategies on the effect on individual farmers;
- Further research need to be done on a market and meat prices for vaccinated meat and the effect of aftermath costs for individual farmers.

6. References

AMI, 2014. Pig meat prices. URL http://www.ami-informiert.de (accessed 4.25.14).

Anonymous, 2001. European Union: Council Directive 2001/89/EC on Community measures for the control of classical swine fever. Official Journal L 316, pp. 5-35.

Anonymous, 2006. Commission Decision of 15 May 2006 concerning certain protection measures relating to classical swine fever in Germany and repealing Decision 2006/274/EC.

Arens, L., Thulke, H.-H., Eisinger, D., Theuvsen, L., 2012. Administrative cooperation and disease control in cross-border pork production. Food Policy 37, 473–482. doi:10.1016/j.foodpol.2012.04.007

Backer, J.A., Hagenaars, T.J., van Roermund, H.J.W., de Jong, M.C.M., 2009. Modelling the effectiveness and risks of vaccination strategies to control classical swine fever epidemics. J. R. Soc. Interface 6, 849–61. doi:10.1098/rsif.2008.0408

Beer, M., Reimann, I., Hoffmann, B., Depner, K., 2007. Novel marker vaccines against classical swine fever. Vaccine 25, 5665–70. doi:10.1016/j.vaccine.2006.12.036

Bergevoet, R., van der Kroon, S., Baltussen, W., Hoste, R., Backus, G., Backer, J., Hagenaars, T., Engel, B., de Jong, M., van Roermund, H., 2007. Vaccinatie bij varkenspest : epidemiologische en sociaaleconomische effecten. LEI Rep. 5.07.06, ASG Rep. ASG07- IOO442.

Boklund, A., Toft, N., Alban, L., Uttenthal, Å., 2009. Comparing the epidemiological and economic effects of control strategies against classical swine fever in Denmark. Prev. Vet. Med. 90, 180–193.

Brosig, J., 2012. Alternative Classical Swine Fever Control Strategies: A Simulation Study. Christian-Albrechts-Universität zu Kiel.

Brosig, J., Traulsen, I., Krieter, J., 2012. Control of Classical Swine Fever Epidemics Under Varying Conditions - With Special Focus on Emergency Vaccination and Rapid PCR Testing. Transbound. Emerg. Dis. 2006. doi:10.1111/tbed.12028

Elbers, A.R.., Stegeman, A., Moser, H., Ekker, H.M., Smak, J.A., Pluimers, F.H., 1999. The classical swine fever epidemic 1997–1998 in the Netherlands: descriptive epidemiology. Prev. Vet. Med. 42, 157–184. doi:10.1016/S0167-5877(99)00074-4

Greiser-Wilke, I., Moennig, V., 2004. Vaccination against classical swine fever virus: limitations and new strategies. Anim. Heal. Res. Rev. 5, 223–226. doi:10.1079/AHR200472

Hop, G.E., Mourits, M.C.M., Oude Lansink, A.G.J.M., Saatkamp, H.W., 2014. Simulation of Cross- border Impacts Resulting from Classical Swine Fever Epidemics within the Netherlands and Germany. Transbound. Emerg. Dis. 1–35.

Hoste, R., 2013. Productiekosten van varkens, LEI-rapport 2013-030. Den Haag.

Karsten, S., Rave, G., Teuffert, J., Krieter, J., 2007. Evaluation of Measures for the Control of Classical Swine Fever Using a Simulation Model. Arch. fur Tierzucht 50, 92–104.

KWIN, 2013. Kwantitatieve Informatie Veehouderij 2012–2013 (in Dutch). Handboek 13 by Livestock Research., 13th ed. Wageningen UR, Lelystad.

Longworth, N., Mourits, M.C.M., Saatkamp, H.W., 2012a. Economic Analysis of HPAI Control in the Netherlands I: Epidemiological Modelling to Support Economic Analysis. Transbound. Emerg. Dis. doi:10.1111/tbed.12021

Longworth, N., Mourits, M.C.M., Saatkamp, H.W., 2012b. Economic analysis of HPAI control in The Netherlands II: Comparison of control strategies. Transbound. Emerg. Dis. doi:10.1111/tbed.12034

Mangen, M.-J.., Nielen, M., Burrell, A.., 2002. Simulated effect of pig-population density on epidemic size and choice of control strategy for classical swine fever epidemics in The Netherlands. Prev. Vet. Med. 56, 141–163. doi:10.1016/S0167-5877(02)00155-1

Mangen, M.-J.J., Burell, A.M., 2003. Who gains, who loses? Welfare effects of classical swine fever epidemics in the Netherlands. Eur. Rev. Agric. Econ. 30, 125–154. doi:10.1093/erae/30.2.125

Meuwissen, M.P.., Horst, S.H., Huirne, R.B.., Dijkhuizen, A.A., 1999. A model to estimate the financial consequences of classical swine fever outbreaks: principles and outcomes. Prev. Vet. Med. 42, 249–270.

Moennig, V., 2000. Introduction to classical swine fever: virus, disease and control policy. Vet. Microbiol. 73, 93–102.

Niemi, J., 2008. A dynamic programming model for optimising feeding and slaughter decisions regarding fattening pigs. Agric. food Sci. 121.

OIE, 2014. WAHID home page. In: WAHID Disease Information. Disease distribution maps. URL http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/Diseasedistributionmap

Postel, A., Moennig, V., Becher, P., 2013. Classical swine fever in Europe - the current Situation. Berl. Munch. Tierarztl. Wochenschr. 126, 468–475. doi:10.2376/0005-9366-126-468

Ribbens, S., 2009. Evaluating Infection Spread in Belgian Pig Herds Using Classical Swine Fever as a Model. PhD Thesis. Gent.

Stevenson, M.A., Sanson, R.L., Stern, M.W., O'Leary, B.D., Sujau, M., Moles-Benfell, N., Morris, R.S., 2013. InterSpread Plus: a spatial and stochastic simulation model of disease in animal populations. Prev. Vet. Med. 109, 10–24.

Uttenthal, a, Le Potier, M.-F.F., Romero, L., De Mia, G.M., Floegel-Niesmann, G., Uttenthal, Å., 2001. Classical swine fever (CSF) marker vaccine. Trial I. Challenge studies in weaner pigs. Vet. Microbiol. 83, 85–106. doi:10.1016/S0378-1135(01)00409-6

Yoon, H., Wee, S.-H., Stevenson, M.A., O'Leary, B.D., Morris, R.S., Hwang, I.-J., Park, C.-K., Stern, M.W., 2006. Simulation analyses to evaluate alternative control strategies for the 2002 foot-and-mouth disease outbreak in the Republic of Korea. Prev. Vet. Med. 74, 212–25. doi:10.1016/j.prevetmed.2005.12.002

7. Appendices

7.1. Appendix A

Table A1: Number of pigs depopulated, vaccinated and located inside an MRZ for three control strategies for simulated CSF outbreaks indexed in NRW and LS.

		No. of pigs depopulated		No. of pigs vaccinated		No. of pigs in MRZ[1]	
Index farm[2]	**Strategy[3]**	**50th**	**95th**	**50th**	**95th**	**50th**	**95th**
NRW_hd	Depop	19,685	64,444	0	0	860,209	1,921,920
	Vacc_depop	10,748	34,305	48,851	136,149	874,242	1,771,578
	Vacc_nodepop	8,419	30,772	49,681	118,210	781,457	1,647,005
NRW_ad	Depop	6,935	35,156	0	0	406,834	1,198,743
	Vacc_depop	4,017	20,367	20,015	77,177	403,131	1,197,624
	Vacc_nodepop	2,998	18,626	22,134	75,015	405,055	1,178,555
LS_hd	Depop	21,128	54,935	0	0	888,762	1,878,005
	Vacc_depop	13,947	30,716	45,507	135,577	916,756	1,839,569
	Vacc_nodepop	10,790	26,178	59,055	142,836	907,504	1,780,745
LS_ad	Depop	7,160	27,200	0	0	262,556	1,084,120
	Vacc_depop	5,027	16,241	13,577	70,140	267,695	1,076,101
	Vacc_nodepop	4,290	14,911	15,701	73,276	266,129	1,088,906

1: MRZ = movement restriction zone.

2: Hd= High-density index farm; ad = average density index farm.

3: The set of control measures for control strategies based on depopulation and vaccination is presented in Table 3.

7.2. Appendix B

Table B1 The net farm income for an individual fattening farm compared with the baseline scenario in case of a CSF outbreak on day 1 of the fattening production cycle

Index farm[1] and control strategy	Location in zone	Duration of outbreak (days)		Costs per fattened animal		Revenues or compensation per fattened animal		Net result per fattened animal		Net labour income per slaughter pig		Annual net labour income (500 pigs)		Difference in annual net labour income (compared with baseline farm)	
		50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
	Baseline	-	-	139.08		153.62		14.54		19.18		29,657.11			
NRW_hd / Depop	Depopulation[2]	79	180	70.83	87.94	60.79	60.79	-10.04	-27.15	-6.86	-19.85	19,609.81	4,859.36	-10,047.30	-24,797.75
	3 km MRZ[3]	79	180	139.08	165.70	153.62	157.94	14.54	-7.77	19.18	-0.57	29,657.11	14,550.92	0	-15,106.19
	10 km MRZ[4]	79	180	139.08	164.18	153.62	157.94	14.54	-6.24	19.18	0.60	29,657.11	15,865.36	0	-13,791.76
	Region[5]	79	180	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
NRW_hd / Vacc_depop	Depopulation	99	174	74.38	87.08	60.79	60.79	-13.59	-26.29	-9.62	-19.34	16,608.58	5,654.96	-13,048.54	-24,002.15
	3 km MRZ	99	174	139.08	164.69	153.62	157.94	14.54	-6.75	19.18	0.21	29,657.11	15,427.21	0	-14,229.90
	10 km MRZ	99	174	139.08	163.16	153.62	157.94	14.54	-5.23	19.18	1.37	29,657.11	16,741.65	0	-12,915.47
	Region	99	174	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
	Vaccination_ns[6]	99	174	139.08	164.69	105.61	112.81	-33.46	-51.87	-28.83	-44.92	9,071.32	-7,135.22	-20,585.80	-36,792.33
	Vaccination_s[7]	99	174	139.08	148.97	105.61	105.61	-33.46	-43.35	-28.83	-36.40	9,071.32	-2,875.14	-20,585.80	-32,532.25
	Vaccination_b[8]	99	174	139.08	120.81	105.61	105.61	-33.46	-15.20	-28.83	-10.56	9,071.32	-79.14	-20,585.80	-29,736.25
NRW_ad / Depop	Depopulation	64	139	68.29	81.00	60.79	60.79	-7.50	-20.21	-4.92	-14.64	21,800.36	10,847.24	-7,856.75	-18,809.87
	3 km MRZ	64	139	139.08	151.78	153.62	147.52	14.54	-4.26	19.18	1.31	29,657.11	18,822.19	0	-10,834.92
	10 km MRZ	64	139	139.08	146.89	153.62	142.48	14.54	-4.40	19.18	0.80	29,657.11	19,299.87	0	-10,357.24
	Region	64	139	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
NRW_ad / Vacc_depop	Depopulation	74	151	70.15	83.19	60.79	60.79	-9.36	-22.40	-6.38	-16.36	20,259.78	9,014.07	-9,397.33	-20,643.04
	3 km MRZ	74	151	139.08	158.31	153.62	154.24	14.54	-4.07	19.18	1.97	29,657.11	18,179.11	0	-11,478.00
	10 km MRZ	74	151	139.08	153.41	153.62	149.20	14.54	-4.21	19.18	1.48	29,657.11	18,662.08	0	-10,995.03
	Region	74	151	139.08	139.08	153.62	144.02	14.54	4.94	19.18	9.58	29,657.11	24,856.51	0	-4,800.61
	Vaccination_ns	74	151	139.08	158.31	105.61	110.17	-33.46	-48.14	-28.83	-42.09	14,217.77	-3,855.32	-15,439.35	-33,512.44
	Vaccination_s	74	151	139.08	145.07	105.61	105.61	-33.46	-39.46	-28.83	-33.42	14,217.77	483.97	-15,439.35	-29,173.15
	Vaccination_b	74	151	139.08	120.81	105.61	105.61	-33.46	-15.20	-28.83	-10.56	14,217.77	-79.14	-15,439.35	-29,736.25

1: Hd high-density index farm; ad = average density index farm.
2: Farm is depopulated at day of detection
3: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
4: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
5: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
6: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle
8: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight; vaccinated piglets were bought for the next production cycle.

Table B2: The net farm income for an individual fattening farm compared with the baseline scenario in case of a CSF outbreak on day 58 of the fattening production cycle with ad libitum feeding

Index farm[1] and control strategy	Location in zone	Duration of outbreak (days)		Costs per fattened animal		Revenues or compensation per fattened animal		Net result per fattened animal		Net labour income per slaughter pig		Annual net labour income (500 pigs)		Difference in annual net labour income (compared with baseline farm)	
		50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
	Baseline	-	-	139.08		153.62		14.54		19.18		29,657.11			
NRW_hd / Depop	Depopulation[2]	79	180	110.56	127.66	113.83	113.83	3.27	-13.83	8.73	-4.36	22,752.90	8,002.03	-6,904.22	-21,655.08
	3 km MRZ[3]	79	180	153.87	182.67	152.32	158.54	-1.56	-24.13	3.90	-14.65	20,335.97	2,852.69	-9,321.15	-26,804.43
	10 km MRZ[4]	79	180	147.43	181.14	144.53	158.54	-2.90	-22.60	2.20	-13.49	20,218.18	4,167.12	-9,438.93	-25,489.99
	Region[5]	79	180	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
NRW_hd / Vacc_depop	Depopulation	99	174	114.52	127.22	113.83	113.83	-0.69	-13.39	5.57	-4.15	19,544.74	8,591.13	-10,112.37	-21,065.99
	3 km MRZ	99	174	168.23	181.65	157.49	158.54	-10.74	-23.11	-4.49	-13.88	14,518.33	3,728.97	-15,138.78	-25,928.14
	10 km MRZ	99	174	161.76	180.13	150.27	158.54	-11.50	-21.59	-5.60	-12.71	14,692.09	5,043.41	-14,965.02	-24,613.70
	Region	99	174	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
	Vaccination_ns[6]	99	174	168.23	181.65	121.15	121.95	-47.08	-59.70	-40.83	-50.46	-3,653.94	-14,563.73	-33,311.05	-44,220.84
	Vaccination_s[7]	99	174	145.97	158.67	105.61	105.61	-40.36	-53.06	-34.10	-43.82	-290.09	-11,243.70	-29,947.20	-40,900.81
	Vaccination_b[8]	99	174	120.81	120.81	105.61	105.61	-15.19	-15.19	-10.56	-10.56	-79.14	-79.14	-29,736.25	-29,736.25
NRW_ad / Depop	Depopulation	64	139	108.02	120.72	113.83	113.83	5.81	-6.89	10.68	0.96	24,943.62	13,990.01	-4,713.49	-15,667.11
	3 km MRZ	64	139	143.15	175.72	149.30	158.54	6.15	-17.19	11.02	-9.34	25,112.88	8,840.66	-4,544.23	-20,816.45
	10 km MRZ	64	139	139.08	174.20	144.02	158.54	4.94	-15.66	9.58	-8.17	24,856.51	10,155.09	-4,800.61	-19,502.02
	Region	64	139	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	24,856.51	-4,800.61	-4,800.61
NRW_ad / Vacc_depop	Depopulation	74	151	110.28	123.32	113.83	113.83	3.55	-9.49	8.81	-1.17	23,195.95	11,950.24	-6,461.17	-17,706.88
	3 km MRZ	74	151	150.29	177.75	147.99	158.54	-2.30	-19.22	2.96	-10.90	20,271.29	7,088.08	-9,385.82	-22,569.03
	10 km MRZ	74	151	143.86	176.23	140.21	158.54	-3.65	-17.69	1.25	-9.73	20,150.10	8,402.52	-9,507.01	-21,254.60
	Region	74	151	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	24,856.51	-4,800.61	-4,800.61
	Vaccination_ns	74	151	150.29	177.75	105.71	121.95	-44.59	-55.80	-39.33	-47.48	-870.41	-11,204.62	-30,527.52	-40,861.73
	Vaccination_s	74	151	141.74	154.78	105.61	105.61	-36.12	-49.16	-30.86	-40.84	3,361.12	-7,884.59	-26,296.00	-37,541.71
	Vaccination_b	74	151	120.81	120.81	105.61	105.61	-15.19	-15.19	-10.56	-10.56	-79.14	-79.14	-29,736.25	-29,736.25

1: Hd high-density index farm; ad = average density index farm.
2: Farm is depopulated at day of detection
3: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
4: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
5: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
6: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle
8: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, vaccinated piglets were bought for the next production cycle.

Table B3: The net farm income for an individual fattening farm compared with the baseline scenario in case of a CSF outbreak on day 58 of the fattening production cycle with restricted feeding from day 58

Index farm[1] and control strategy	Location in zone	Duration of outbreak (days)		Costs per fattened animal		Revenues or compensation per fattened animal		Net result per fattened animal		Net labour income per slaughter pig		Annual net labour income (500 pigs)		Difference in annual net labour income (compared with baseline farm)	
		50^{th}	95^{th}	50^{th}	95^{th}	50^{th}	95^{th}	50^{th}	95^{th}	50^{th}	95^{th}	50^{th}	95^{th}	50^{th}	95^{th}
	Baseline	-	-	139.08		153.62		14.54		19.18		29,657.11			
NRW_hd / Depop	Depopulation[2]	79	180	110.56	127.66	113.83	113.83	3.27	-13.83	8.73	-4.36	22,752.90	8,002.03	-6,904.22	-21,655.08
	3 km MRZ[3]	79	180	146.23	165.33	144.01	140.18	-2.22	-25.15	3.67	-15.68	19,328.35	2,340.27	-10,328.77	-27,316.84
	10 km MRZ[4]	79	180	146.23	163.81	144.01	140.18	-2.22	-23.63	3.67	-14.51	19,328.35	3,654.70	-10,328.77	-26,002.41
	Region[5]	79	180	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
NRW_hd / Vacc_depop	Depopulation	99	174	114.52	127.22	113.83	113.83	-0.69	-13.39	5.57	-4.15	19,544.74	8,591.13	-10,112.37	-21,065.99
	3 km MRZ	99	174	151.13	164.31	149.41	140.18	-1.72	-24.14	4.54	-14.90	19,030.03	3,216.56	-10,627.08	-26,440.56
	10 km MRZ	99	174	146.23	162.79	144.01	140.18	-2.22	-22.61	3.67	-13.73	19,328.35	4,530.99	-10,328.77	-25,126.12
	Region	99	174	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
	Vaccination_ns[6]	99	174	151.13	164.31	99.61	100.13	-51.52	-64.19	-45.27	-54.95	-5,871.49	-16,808.66	-35,528.60	-46,465.77
	Vaccination_s[7]	99	174	145.97	158.67	105.61	105.61	-40.36	-53.06	-34.10	-43.82	-290.09	-11,243.70	-29,947.20	-40,900.81
	Vaccination_b[8]	99	174	120.81	120.81	105.61	105.61	-15.19	-15.19	-10.56	-10.56	-79.14	-79.14	-29,736.25	-29,736.25
NRW_ad / Depop	Depopulation	64	139	108.02	120.72	113.83	113.83	5.81	-6.89	10.68	0.96	24,943.62	13,990.01	-4,713.49	-15,667.11
	3 km MRZ	64	139	146.23	158.86	144.01	140.18	-2.22	-18.21	3.67	-10.37	19,328.35	8,328.24	-10,328.77	-21,328.87
	10 km MRZ	64	139	146.23	156.86	144.01	140.18	-2.22	-16.69	3.67	-9.20	19,328.35	9,462.68	-10,328.77	-20,014.44
	Region	64	139	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	24,856.51	-4,800.61	-4,800.61
NRW_ad / Vacc_depop	Depopulation	74	151	110.28	123.32	113.83	113.83	3.55	-9.49	8.81	-1.17	23,195.95	11,950.24	-6,461.17	-17,706.88
	3 km MRZ	74	151	144.16	160.42	144.01	140.18	-0.15	-20.24	5.75	-11.92	20,365.08	6,575.67	-9,292.03	-23,081.45
	10 km MRZ	74	151	142.99	158.89	144.01	140.18	1.02	-18.72	6.91	-10.75	20,948.24	7,890.10	-8,708.87	-21,767.01
	Region	74	151	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	24,856.51	-4,800.61	-4,800.61
	Vaccination_ns	74	151	144.16	160.42	96.01	100.13	-48.15	-60.29	-42.26	-51.97	-1,356.87	-13,449.55	-31,013.98	-43,106.66
	Vaccination_s	74	151	141.74	154.78	105.61	105.61	-36.12	-49.16	-30.86	-40.84	3,361.12	-7,884.59	-26,296.00	-37,541.71
	Vaccination_b	74	151	120.81	120.81	105.61	105.61	-15.19	-15.19	-10.56	-10.56	-79.14	-79.14	-29,736.25	-29,736.25

1: Hd high-density index farm; ad = average density index farm.
2: Farm is depopulated at day of detection
3: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
4: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
5: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
6: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle
8: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, vaccinated piglets were bought for the next production cycle.

Table B4: The net farm income for an individual fattening farm compared with the baseline scenario in case of a CSF outbreak on day 58 of the fattening production cycle with restricted feeding from day 116

Index farm[1] and control strategy	Location in zone	Duration of outbreak (days)		Costs per fattened animal		Revenues or compensation per fattened animal		Net result per fattened animal		Net labour income per slaughter pig		Annual net labour income (500 pigs)		Difference in annual net labour income (compared with baseline farm)	
		50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
	Baseline	-	-	139.08		153.62		14.54		19.18		29,657.11			
NRW_hd / Depop	Depopulation[2]	79	180	110.56	127.66	113.83	113.83	3.27	-13.83	8.73	-4.36	22,752.90	8,002.03	-6,904.22	-21,655.08
	3 km MRZ[3]	79	180	150.31	175.41	146.01	157.94	-4.30	-17.47	1.16	-7.99	18,965.91	6,182.36	-10,691.20	-23,474.75
	10 km MRZ[4]	79	180	145.42	173.88	140.97	157.94	-4.45	-15.95	0.65	-6.83	19,442.40	7,496.80	-10,214.71	-22,160.32
	Region[5]	79	180	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
NRW_hd / Vacc_depop	Depopulation	99	174	114.52	127.22	113.83	113.83	-0.69	-13.39	5.57	-4.15	19,544.74	8,591.13	-10,112.37	-21,065.99
	3 km MRZ	99	174	161.20	174.39	157.21	157.94	-3.99	-16.45	2.26	-7.22	17,892.83	7,058.65	-11,764.28	-22,598.46
	10 km MRZ	99	174	156.29	172.87	152.17	157.94	-4.12	-14.93	1.77	-6.05	18,378.15	8,373.09	-11,278.97	-21,284.03
	Region	99	174	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
	Vaccination_ns[6]	99	174	161.20	174.39	112.29	112.81	-48.91	-61.58	-42.65	-52.34	-4,565.60	-15,503.78	-34,222.71	-45,160.89
	Vaccination_s[7]	99	174	145.97	158.67	105.61	105.61	-40.36	-53.06	-34.10	-43.82	-290.09	-11,243.70	-29,947.20	-40,900.81
	Vaccination_b[8]	99	174	120.81	120.81	105.61	105.61	-15.19	-15.19	-10.56	-10.56	-79.14	-79.14	-29,736.25	-29,736.25
NRW_ad / Depop	Depopulation	64	139	108.02	120.72	113.83	113.83	5.81	-6.89	10.68	0.96	24,943.62	13,990.01	-4,713.49	-15,667.11
	3 km MRZ	64	139	142.17	168.46	147.44	157.94	5.27	-10.53	10.14	-2.68	24,672.46	12,170.34	-4,984.65	-17,486.77
	10 km MRZ	64	139	139.46	166.94	144.44	157.94	4.98	-9.00	9.65	-1.51	25,159.00	13,484.77	-4,498.11	-16,172.34
	Region	64	139	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	24,856.51	-4,800.61	-4,800.61
NRW_ad / Vacc_depop	Depopulation	74	151	110.28	123.32	113.83	113.83	3.55	-9.49	8.81	-1.17	23,195.95	11,950.24	-6,461.17	-17,706.88
	3 km MRZ	74	151	147.59	170,50	143.21	157.94	-4.38	-12.56	0.88	-4.24	19,231.12	10,417.76	-10,425.99	-19,239.35
	10 km MRZ	74	151	142.71	168.97	148.04	157.94	5.33	-11.03	10.23	-3.07	24,640.01	11,732.19	-5,017.11	-17,924.92
	Region	74	151	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	24,856.51	-4,800.61	-4,800.61
	Vaccination_ns	74	151	147.59	170.50	102.29	112.81	-45.30	-57.68	-40.04	-49.36	-1,227.31	-12,144.67	-30,884.43	-41,801.78
	Vaccination_s	74	151	141.74	154.78	105.61	105.61	-36.12	-49.16	-30.86	-40.84	3,361.12	-7,884.59	-26,296.00	37,541.71
	Vaccination_b	74	151	120.81	120.81	105.61	105.61	-15.19	-15.19	-10.56	-10.56	-79.14	-79.14	-29,736.25	-29,736.25

1: Hd high-density index farm; ad = average density index farm.
2: Farm is depopulated at day of detection
3: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
4: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
5: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
6: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle
8: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, vaccinated piglets were bought for the next production cycle.

Table B5: The net farm income for an individual fattening farm compared with the baseline scenario in case of a CSF outbreak on day 116 of the fattening production cycle

Index farm[1] and control strategy	Location in zone	Duration of outbreak (days)		Costs per fattened animal		Revenues or compensation per fattened animal		Net result per fattened animal		Net labour income per slaughter pig		Annual net labour income (500 pigs)		Difference in annual net labour income (compared with baseline farm)	
		50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th	50th	95th
	Baseline	-	-	139.08		153.62		14.54		19.18		29,657.11			
NRW_hd / Depop	Depopulation[2]	79	180	152.46	169.56	175.71	175.71	23.25	6.15	31.03	17.94	29,164.58	14,413.71	-492.53	-15,243.40
	3 km MRZ[3]	79	180	168.18	185.28	157.94	157.94	-10.24	-27.34	-2.46	-15.55	12,418.62	-2,332.25	-17,238.49	-31,989.36
	10 km MRZ[4]	79	180	166.65	183.76	157.94	157.94	-8.71	-25.82	-1.29	-14.38	13,733.05	-1,017.81	-15,924.06	-30,674.92
	Region[5]	79	180	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
NRW_hd / Vacc_depop	Depopulation	99	174	155.84	168.54	175.71	175.71	19.87	7.17	28.44	18.72	26,243.62	15,290.00	-3,413.50	-14,367.11
	3 km MRZ	99	174	171.56	184.26	157.94	157.94	-13.63	-26.33	-5.05	-14.77	9,497.66	-1,455.96	-20,159.46	-31,113.07
	10 km MRZ	99	174	170.04	182.74	157.94	157.94	-12.10	-24.80	-3.89	-13.61	10,812.09	-141.52	-18,845.02	-29,798.64
	Region	99	174	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
	Vaccination_ns[6]	99	174	171.56	184.26	112.81	112.81	-58.75	-71.45	-50.18	-59.90	-13,064.77	-24,018.39	-42,721.89	-53,675.50
	Vaccination_s[7]	99	174	155.84	168.54	105.61	105.61	-50.23	-62.93	-41.66	-51.38	-8,804.70	-19,758.31	-38,461.81	-49,415.42
	Vaccination_b[8]	99	174	120.81	114.72	105.61	105.61	-15.20	-9.10	-10.56	-4.47	-79.14	-5,812.35	-29,736.25	-35,469.47
NRW_ad / Depop	Depopulation	64	139	149.92	162.62	175.71	175.71	25.79	13.09	32.97	23.26	31,355.30	20,401.69	1,698.19	-9,255.43
	3 km MRZ	64	139	165.63	178.34	157.94	157.94	-7.70	-20.40	-0.52	-10.24	14,609.34	3,655.73	-15,047.77	-26,001.38
	10 km MRZ	64	139	164.11	176.81	157.94	157.94	-6.17	-18.88	0.65	-9.07	15,923.78	4,970.16	-13,733.34	-24,686.95
	Region	64	139	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
NRW_ad / Vacc_depop	Depopulation	74	151	151.61	164.65	175.71	175.71	24.10	11.06	31.68	21.70	29,894.82	18,649.11	237.71	-11,008.00
	3 km MRZ	74	151	167.33	180.37	157.94	157.94	-9.39	-22.43	-1.81	-11.79	13,148.86	1,903.15	-16,508.25	-27,753.96
	10 km MRZ	74	151	165.80	178.84	157.94	157.94	-7.87	-20.91	-0.65	-10.63	14,463.30	3,217.59	-15,193.82	-26,439.53
	Region	74	151	139.08	139.08	144.02	144.02	4.94	4.94	9.58	9.58	24,856.51	20,055.90	-4,800.61	-9,601.22
	Vaccination_ns	74	151	167.33	180.37	112.81	112.81	-54.52	-67.56	-46.94	-56.92	-9,413.57	-20,659.11	-39,070.68	-50,316.39
	Vaccination_s	74	151	151.61	164.65	105.61	105.61	-46.00	-59.04	-38.42	-48.40	-5,153.49	-16,399.20	-34,810.61	-46,056.39
	Vaccination_b	74	151	120.81	114.72	105.61	105.61	-15.20	-9.10	-10.56	-4.47	-79.14	-5,812.35	-29,736.25	-35,469.47

1: Hd high-density index farm; ad = average density index farm.
2: Farm is depopulated at day of detection
3: Farm is located inside the 3-km movement restriction zone, so the animals cannot be transported
4: Farm is located inside the 10-km movement restriction zone, so the animals cannot be transported
5: The region is closed so all animals have to be slaughtered inside the region (transport to other regions is prohibited)
6: Animals at the farm were vaccinated and were kept at the farm until the CSF outbreak has been eradicated, or slaughtered after six weeks at the end of the production process due to welfare problems.
7: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, the remaining days of the outbreak the farm was idle
8: Animals at the farm were vaccinated and slaughtered at the normal slaughter weight, vaccinated piglets were bought for the next production cycle.