Exploring opportunities of spatial relocation to reduce environmental external effects of the North Brabant pig sector

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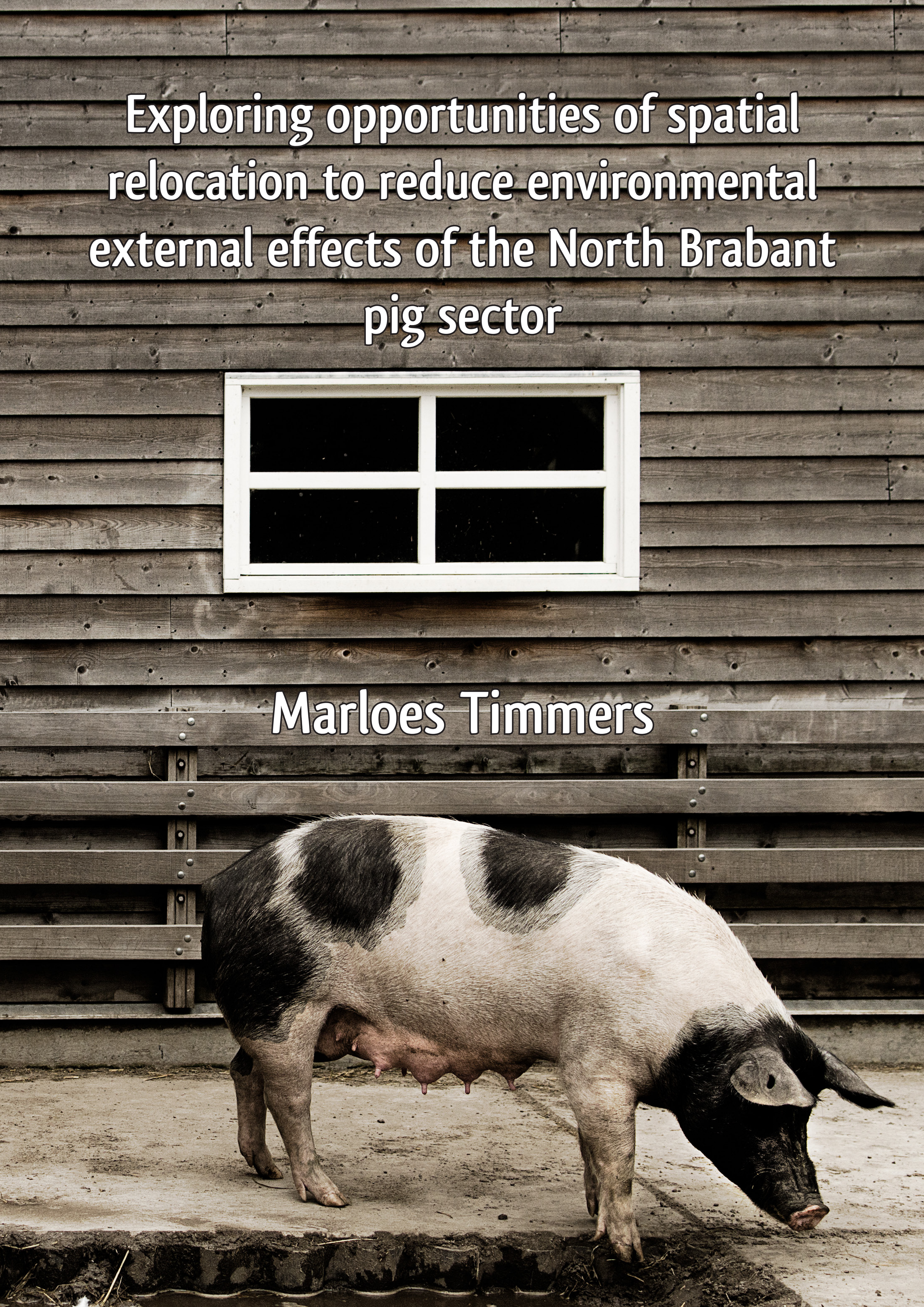

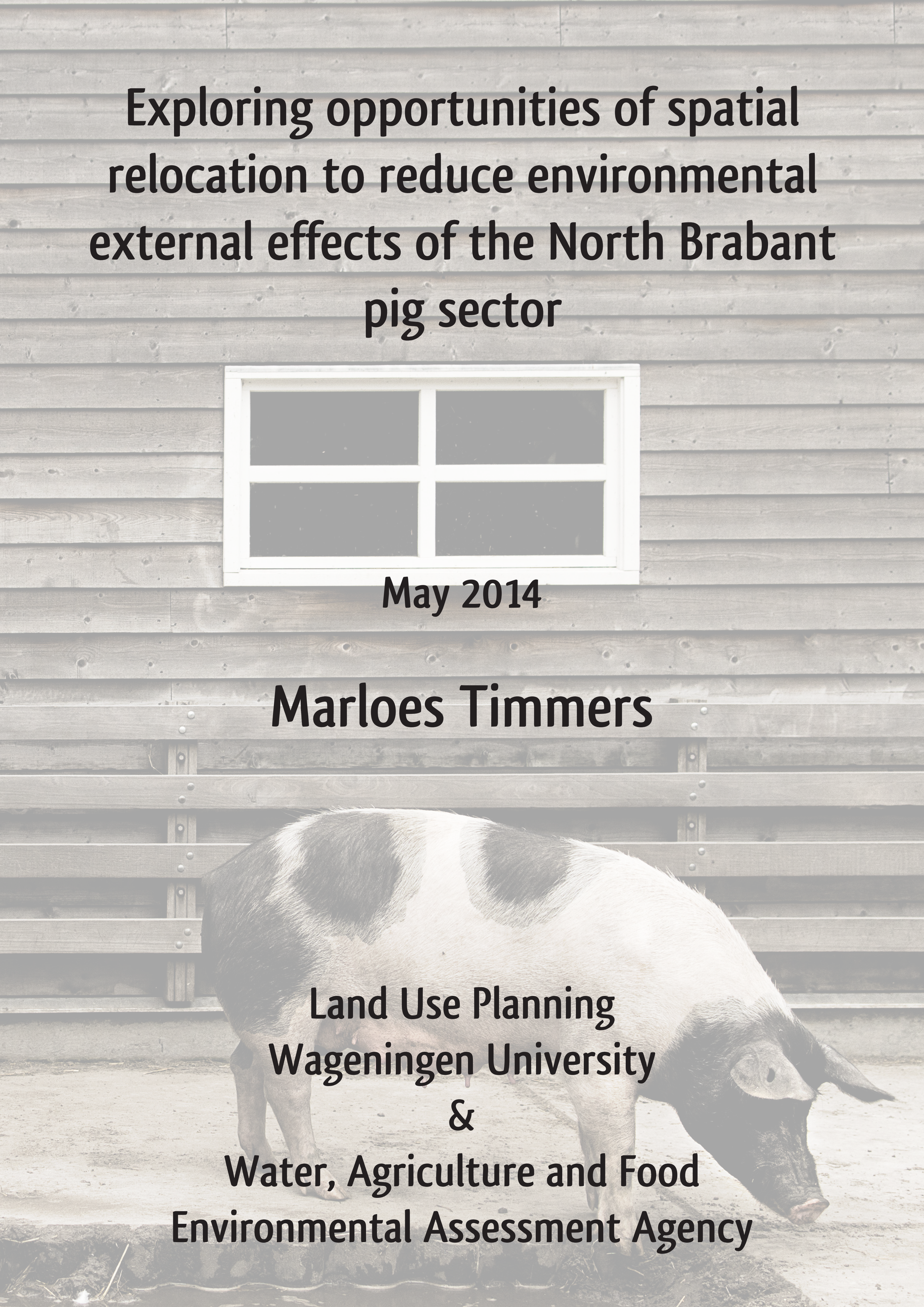

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Abstract

Many of the political and social problems in the pig sector can be traced back to the problem of spatial concentration. Spatial concentration allows reduction of production costs and sufficient pork supply, as well to environmental external effects, such as ammonia volatilization, nitrate runoff and leaching towards groundwater and surface water. Without additional environmental restrictions the concentration of the pig sector will most likely increase, as well as the environmental external effects. The effect of these changes is not yet known. The objective of this thesis is to assess the effects of spatial relocation on the environmental external costs produced by the North Brabant pig sector. The key question is whether environmental external costs decrease when the North Brabant pig sector is relocated to other EU regions. The results indicate that environmental external effects decrease for North Brabant when pigs are relocated in three relocation regions. Although, the total costs for the European Union are higher than the total benefits of relocating the pig sector. However, the choices made for the model have a significant impact on the final result and need to be specified. To specify the results of this thesis it is essential is to find the right balance between concentrating pigs and the costs for the environment.

Keywords: pig sector, spatial concentration, relocation, environmental external effects, cost-benefit analysis, NUTS2 regions

Preface

When I started my Master at the Wageningen University I was convinced I would become a landscape architect, but the story took a small twist. Instead of becoming a landscape architect, I am now studying to become a spatial planner focusing on intensive agriculture. Different themes were considered during the lectures, such as strategic planning, ethics, urban agriculture, but what about the intensive agricultural sector? For me it became clear that the link between spatial planning and intensive agriculture somehow disappeared. My interest for the intensive agricultural sector origins from my youth; I grew up at my parents pig farm. My personal mission is to find this link again between spatial planning and the agricultural sector, to find new possibilities for both sectors to integrate again.

This mission started last September when I had to begin my master thesis at Wageningen University. In collaboration with the Netherlands Environmental Assessment Agency I did research on the opportunities in reducing spatial concentration problems by relocating the North Brabant pig sector in the European Union. It was challenging to step out of my 'qualitative' comfort zone and start quantifying these relocation effects, but the result, a working model and interesting results, is satisfying!

Gerrit Jan and Evelien, you were a great team and motivating supervisors. I am sure your open discussions helped me to bring this thesis to a higher level. Thank you for your feedback, help and understanding, especially during the hard times. Also, many thanks to Hans van Grinsven and Jan van Dam! Without you this model would have never worked, thank you for all your optimism and constructive, critical feedback!

Sietske, as a true ammonia specialist you helped me to understand the basics of nitrogen modelling, thank you! Jaap, for the many pig sector-conservations in the train to Utrecht. Gert-Jan, Anny, Martha, Arno, Marian, Peter, Henk, Frits, Guus, Maria, but also my fellow trainees Albert, Christian, Eef, Joris and Daan, thanks to you all for your help and pleasant time at PBL!

Last, but not least, I would also like to thank my family and friends for supporting me in multiple ways, in advising me and having eye-opening. In particular Hein, thanks for your enthusiasm that kept me going and the critical feedback on my thesis.

Wageningen, May 2014

Marloes Timmers

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Summary

Many of the political and social problems in the pig sector can be traced back to the problem of spatial concentration. Especially, the high spatial concentrated pig sector in the south-east part of the Netherlands encounters problems in relation to societal disapproval, increasing competition on the (manure) market, new environmental regulations and economic pressure. Without additional environmental restrictions the concentration of pigs will most likely increase, as well as the environmental external effects.

The objective of this thesis was to assess the effects of spatial relocation on the environmental external effects produced by the North Brabant pig sector. To investigate whether environmental external costs decrease when North Brabant pigs are relocated in other EU regions it was hypothesized that *'environmental external costs decrease when the North Brabant pig sector is relocated in other EU regions'*.

To test this hypothesis a literature review is done to identify the drivers of spatial concentration. Six drivers could be identified. It can be concluded that the 'natural advantage' of a location is the most important driver out of six in determining spatial concentration. Spatial concentration leads to cheap and sufficient pork meat supply. Simultaneously, this concentration of pigs results in a rise of environmental external effects, such as ammonia volatilization, nitrate run off and leaching towards groundwater and surface water.

With regard to these drivers and the negative effect on the environment three relocation regions are chosen, namely Sachsen (Germany), Tuscany (Italy) and South Romania. Thereby data is collected to create a simple quantitative model in Excel. The main goal of the model was to test whether spreading the spatial concentration of pigs in North Brabant into different NUTS2 regions led to a decrease of environmental external effects. To overcome the simplification and major uncertainty of the model, a concise uncertainty analysis is done to test the major uncertainties in the model.

The results of the model indicate that the environmental external effects decrease for North Brabant when pigs are relocated in three other NUTS2 regions. However, the total costs for the European Union are significant higher than the total benefits by relocating the pig sector. The major uncertainty in this modelled cost-benefit analysis can be traced back in the damage factors. This damage factor has a large influence, because these are required to calculate the costs for each N-component. Other factors investigated in the uncertainty analysis influence only one N-component at a time.

The choices made for the model have a significant impact on the final result. This impact is caused by the choices made on the basis of the literature framework. Changing the choices and assumptions made in this model, could have a major impact on the results as presented in this thesis. However, the results as presented in this thesis offer new insights towards spatial concentration in the pig sector and thereby offer new opportunities for research. To specify the results of this thesis it is essential is to find the right balance between concentrating pigs and the costs for the environment. On the one hand, it is important to reduce spatial concentration of the pig sector in North Brabant with regard to ecosystem and public health problems. On the other hand, it is necessary to reduce the environmental external costs of the pig sector in the European Union.

Samenvatting

Veel politieke en maatschappelijke problemen in de varkenshouderij kunnen teruggevoerd worden naar het probleem omtrent ruimtelijke concentratie. Voornamelijk de varkenshouderij in Zuid-Nederland kampt met verscheidene problemen, zoals maatschappelijke afkeuring, toenemende concurrentiekracht (zowel op de wereldmarkt als nationale mestmarkt), nieuwe milieuvoorschriften en een toenemende economische druk om te kunnen blijven ondernemen. Ondanks deze problemen zal, wanneer er geen nieuwe milieu beperkingen worden opgelegd, de concentratie van de Zuid-Nederlandse varkenshouderij toenemen, evenals de externe milieueffecten in de omgeving.

Het doel in deze scriptie is om de effecten van ruimtelijke verplaatsing van de Noord-Brabantse varkenshouderij op de externe milieukosten te onderzoeken. Om te testen of ruimtelijke verplaatsing naar andere Europese regio's een eventuele oplossing is om de externe milieukosten te verminderen is de volgende hypothese opgesteld 'de externe milieukosten verminderen wanneer de Noord-Brabantse varkenshouderij wordt verplaatst in andere Europese regio's'.

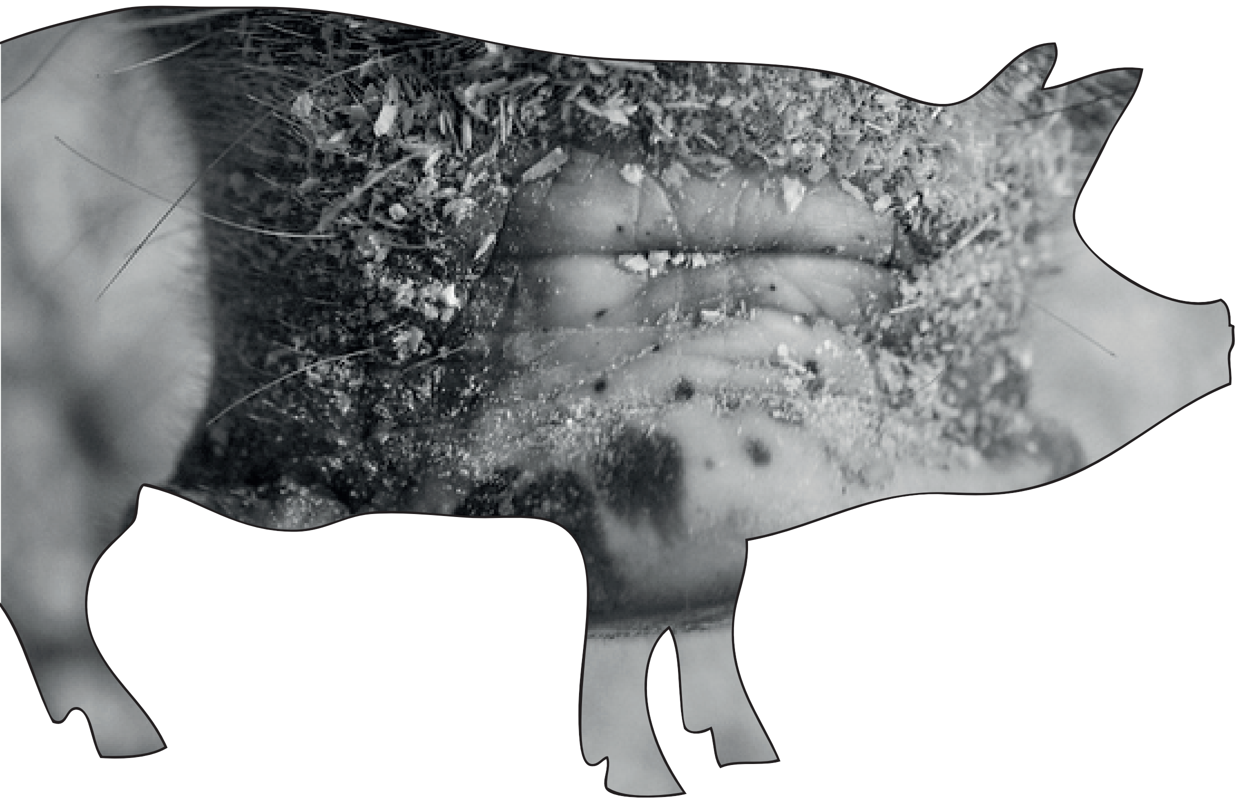
Eerst is een literatuuronderzoek gedaan naar de verschillende drijfveren welke ruimtelijke concentratie veroorzaken. Op basis van dit onderzoek kunnen zes drijfveren geïdentificeerd worden. Voornamelijk het 'natuurlijk voordeel' van een locatie is een belangrijke drijfveer voor het veroorzaken van ruimtelijke concentratie. Ruimtelijke concentratie van varkenshouders zorgt enerzijds voor voldoende en goedkope voorziening van varkensvlees in de regio. Anderzijds stijgen de negatieve externe effecten voor het milieu. Deze uiten zich in grote hoeveelheden ammoniakvervluchtiging en nitraatuitspoeling naar het grond- en oppervlaktewater in het milieu.

Uitgaande van deze drijfveren en negatieve effecten op het milieu van ruimtelijke concentratie zijn drie verplaatsingsregio's gekozen, namelijk Sachsen (Duitsland), Toscane (Italië) en Zuid-Roemenië. Daarnaast is data verzameld om een vereenvoudigd kwantitatief model in Excel te ontwikkelen. De hoofddoelstelling van het model was om te toetsen of dat het verspreiden van de ruimtelijk geconcentreerde Noord-Brabantse varkens naar verschillende EU27 regio's leidt tot vermindering van de externe milieukosten. Om de grootste onzekerheden in dit vereenvoudigd model te vinden is een beknopte onzekerheidsanalyse uitgevoerd.

De resultaten van het model tonen aan dat de externe milieukosten in Noord-Brabant afnemen, wanneer varkens verplaatst worden naar NUTS2 regio's buiten Nederland. Echter, de totale milieukosten zijn hoger dan de baten door het verplaatsen van varkens in Europa. De grootste onzekerheid in deze resultaten wordt veroorzaakt door de schadefactoren die gebruikt zijn in het model. Deze schadefactor heeft een grote invloed in het model. De schadefactoren zijn namelijk verplicht om de externe milieukosten voor alle stikstofcomponenten te kunnen berekenen. De andere factoren in de onzekerheidsanalyse hebben maar invloed op één stikstofcomponent per keer.

De keuzes gemaakt voor het model hebben een significante invloed op de hoofdresultaten in dit onderzoek. Dit effect wordt veroorzaakt door de keuzes die zijn gemaakt op basis van het literatuuronderzoek. Aanpassing van bepaalde keuzes en aannames kan een grote invloed hebben op de resultaten die gepresenteerd zijn in deze scriptie. Echter, deze thesis draagt wel bij aan nieuwe inzichten met betrekking tot ruimtelijke concentratie in de varkenshouderij en het effect hierop voor de omgeving. Dit nieuwe inzicht creëert nieuwe kansen voor wetenschappelijk onderzoek. Het is belangrijk om bepaalde keuzes en aannames te specificeren. Hierbij belangrijk om te zoeken naar de juiste balans. Enerzijds, is het belangrijk om de ruimtelijke concentratie van varkens in Noord-Brabant te reduceren voor de volksgezondheid en kwaliteit van ecosystemen. Anderzijds, is het belangrijk om de externe milieukosten zo veel mogelijk te reduceren door de verspreiding van de varkenshouderij in Europa.

1. Introduction



This chapter will explain the context, problem description, the delineation of the research objective and the research questions of this master thesis.

1.1 Context

After World War II it became important to increase the production of food and it had to be available for affordable prices. For the Dutch livestock sector this growth caused by agricultural modernization was a great opportunity and advantage (Thissen et al., 2011). The production of pig meat increased from 240 million kilograms (in 1950) towards 1.840 million kilograms in 2011 (CBS, 2012). Together with a strong increase in pigs a strong decrease in the number of pig farms occurred due to specialisation and upscaling from 275.000 pig farms in 1950 to 5.918 pig farms in 2012 (Bos and Grin, 2008; Bieleman, 2000; LEI, 2013).

The modernization and this industrialization of farming resulted in a large growth in the amount of pigs, but also environmental externalities started to appear. In the 1980's aspects such as eutrophication, acidification and malodour problems appeared on the political and public agendas, both on European and national level (Bos and Grin, 2008). Another event that raised the debate was the outbreak and major impact of the classical swine fever in 1997. This epidemic disease was seen as indication for the media, politics and non-governmental organisations to debate the sustainability of Dutch intensive livestock farming (Eijsackers and Scholten, 2010). Subsequently, it created political and societal awareness about the fact that environmental problems could not be solved by the primary production system itself (Bleumink, 2007). Political and societal organisations question the long-term sustainability of intensive pig livestock farming (De Olde, 2012).

One of the political responses towards the classical swine fever was the National Reconstruction Act[1]. This spatial planning instrument started in the year 2000 in response to solve the problems that occurred because of the spatial concentrated intensive livestock (Kooiman and Keshkamat, 2011). The main objective was to develop a proper agricultural structure in the regions with sandy soils with the help of spatial planning tools (Waterschap Brabantse Delta, 2006). Environmental issues on ammonia volatilization, eutrophication, malodour and the nature conservation policy were linked to the reconstruction law to enable an integrated approach. The act received a lot of attention, but in practice, it turned out to be very complicated to follow this integral approach and institutional levels. Especially, to solve the problem of intensive livestock concentration on a one-to-one correspondence (Kooiman and Keshkamat, 2011). Other concerns related to animal welfare, public health and environmental pollution joined the political and public debate (De Olde, 2012).

High manure surpluses, malodour, greenhouse gas emissions and reactive nitrogen in the environment are still not under control. Today, the growth of the population and the increase of food production make that the quantity of reactive nitrogen that ends up in the environment is tripled (Westhoek et al., 2011, ibid.). Global livestock production is responsible for around 18% of global greenhouse gas emissions (Steinfeld et al., 2006). These emissions partly originate from animals and manure, feed production and land conversion (forest to pasture or pasture to arable land) (Westhoek et al., 2011).

The emissions per hectare of the agricultural sector in the EU27 are the highest in the Netherlands (Van Grinsven et al., 2011). One third of the nitrogen loss is caused by animal feed (PBL, 2012). The decrease in use of artificial fertilizers and emission restrictions has led to halving of nitrogen surplus since the 1980's. Unfortunately, excessive deposition of nitrogen still leads to a decline of the biodiversity (PBL, 2012). The nitrogen surplus prevents the realisation of the Dutch nature targets in 70-80% of the current nature areas (MNP, 2007).

[1] National Reconstruction Act (Reconstructiewet): After the outbreak of the classical swine fever in 1997 there was the need to improve the quality of the rural areas in southern and eastern parts of the Netherlands, the National Reconstruction Act is designed by the government as a tool to improve the spatial quality of these rural areas (LNV, 2003).

Many of the aforementioned problems can be traced back to the problem of spatial concentration; highly concentrated primary pig production in specific regions. The increased spatial concentration of pig production can be explained by agglomeration economies (Roe et al., 2002; Larue, 2011). Fujita and Thisse (1996) argue that history, and therefore the initial conditions, matter to explain actual spatial concentration patterns. The initial conditions and their environmental externalities are a big centripetal force that engenders a snowball effect. This causes spatial concentration of economic activities (Fujita and Thisse, 1996), in this case the Dutch pig sector.

1.2 Problem description

In 2015 concerns will increase for the highly concentrated Dutch pig sector with the abolishment of the production rights. This will most likely cause extra competition and pressure on the farmers, the environment and the manure market. Without additional spatial planning and environmental restrictions the concentration of pigs will most likely increase, as well as the regional aforementioned externalities (Van Grinsven et al., 2011, ibid.). The highest pig density per hectare in Europe is in the Netherlands with 70,4 pigs per hectare. A substantial part of this high pig density is caused by the province of North Brabant (FAO, 2013a). Of the 12,2 million pigs settled in the Netherlands, about 5,7 million pigs are located in North Brabant (CBS, 2013). The local, regional and (inter)national regulations in the field of environment and spatial planning do not have an answer on limiting the number of livestock (Willems and Van Grinsven, 2011). The past shows with the Reconstruction in the North Brabant that it is more complicated in practice to overcome the spatial concentration of intensive livestock. Extra restrictions even resulted in resistance of farmers and society (Bleumink, 2007).

In the Netherlands farm size and growth perspectives are dependent on regulations in the field of spatial planning, environment and animal welfare. There is a need for an integrated vision of the government on different aspects such as manure policy, the control on environmental effects and structure and organisation of the livestock sector (Willems and Van Grinsven, 2011). A potential extension of the pig sector, because of the abolishment of the production rights, could debouch in more difficulties related to the feasibility of environmental- and nature targets (e.g. ammonia volatilization, nitrate leaching, and greenhouse gas emissions).

1.3 Problem statement

The abolishment of the production rights will most likely cause extra competition and pressure on the farmers, the environment and the manure market. Without additional spatial planning and environmental restrictions the concentration of pigs will probably increase, as well as the environmental external effects on a regional level. The effect of these changes is not yet known. It is important to do research on the balance between the drivers of spatial concentration in the pig sector and the effect on the environmental external costs, in order to find new solutions for the problems related to spatial concentration.

1.4 Objective of the research

The objective of this thesis is to analyse the drivers that cause spatial concentration and to explore opportunities to reduce spatial concentration of the pig sector by assessing the effect of spatial relocating the North Brabant pig sector in the European Union on the environmental external costs.

1.5 Research hypothesis and questions

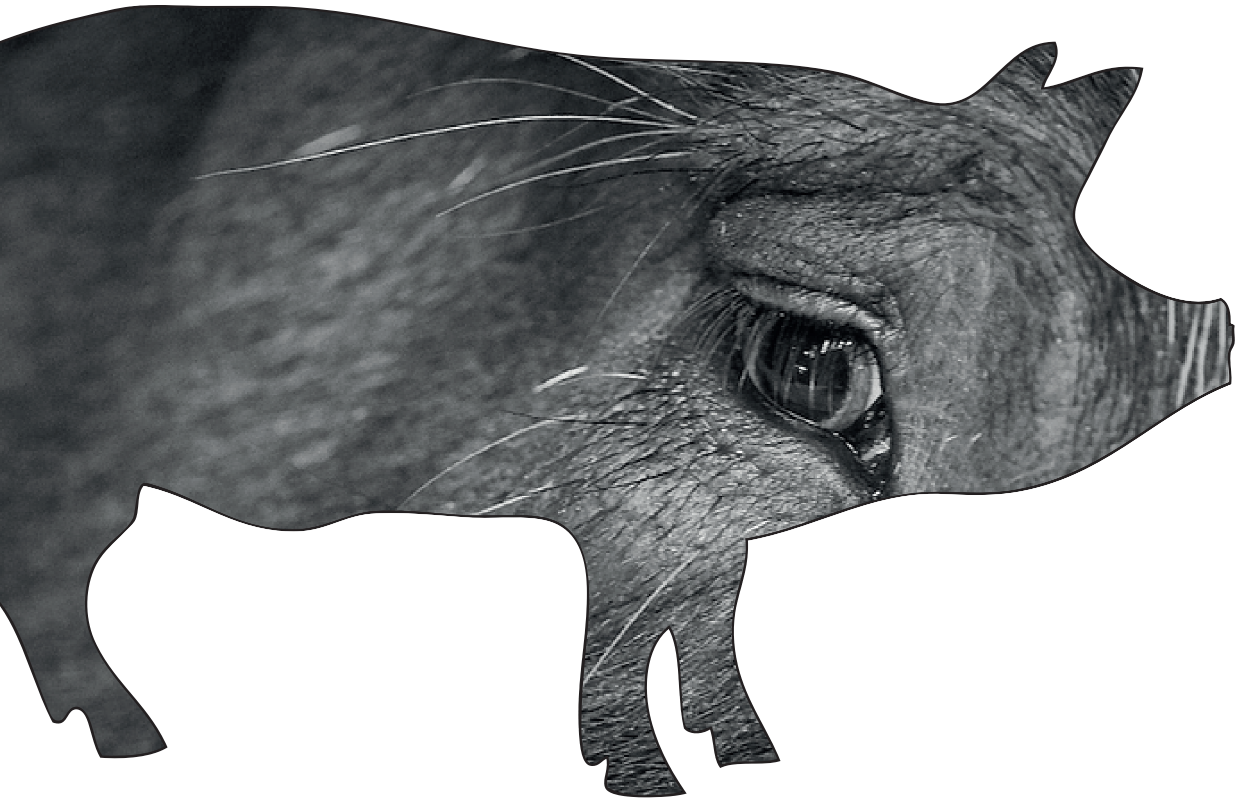
It is hypothesized that *'environmental external costs decrease when the North Brabant pig sector is relocated to other EU regions'*.

To test the hypothesis the following research questions are established:
1. What are the drivers that cause spatial concentration of the North Brabant pig sector?
2. What is the effect of spatial concentration in the North Brabant pig sector on the environmental external costs?
3. What are the effects of spatial relocating the North Brabant pig sector in the European Union on the environmental external costs?

1.6 Guide to the reader

In total this report consists of seven chapters. The second chapter describes the literature review, which is done to find and analyse the drivers behind spatial concentration in the pig sector. In chapter 3 the material and methods, used in this master thesis, are explained. Chapter 4 provides the results of the mathematical model, with regard to the effect of spatial concentration on the environment. The results and literature review provide information to reflect on in the discussion in chapter 5 and the main conclusion in chapter 6. Lastly, recommendations are given in chapter 7 to specify and extend the results in this thesis for further research.

2. Literature review



Current problems caused by environmental external effects in the rural area are often the result of choices made in the past. Therefore in the first section background information is provided about the historic development of the Dutch pig sector. With this information, in the second section, the drivers of spatial concentration are analysed from different perspectives. The effect of these drivers on the environment is reviewed in the third section. In the fourth section some conclusions are drawn to put this review in a broader perspective for this master thesis.

2.1 Background

To understand the current situation of the pig sector this thesis provides background information of the changes during the last two centuries in the Dutch pig sector. Livestock production originally emerged because products, not sufficient for human consumption (e.g. food waste and grass), were fed to livestock to convert them into useful goods, such as meat and milk (Westhoek et al., 2013). The manure of livestock was used to fertilize arable land. The amount of manure that the livestock of the farmers produced determined the amount of land that could be successfully cultivated (Thissen, 1993; Van Och, 2013). This type of cultivation ended with the introduction of artificial fertilizer. Collaborative farming and maintenance of the land could be replaced by individual farming, because the livestock manure could be (partly) replaced by artificial fertilizer (Thissen, 1993; Rijksdienst voor het Cultureel erfgoed, 2011).

Between 1880 and 1970 large-scaled land reclamations in the sand-landscapes were carried out (Rijksdienst voor het Cultureel erfgoed, 2011; Van Och, 2013). Especially in the 1960's the accessibility of the landscape increased with the help of new mechanisation techniques. In fact, the environment was adjusted to fit the new mechanisation techniques. The main drivers behind this transformation were rationalisation, specialisation, up scaling, mechanisation and intensification (Bieleman, 2000). These innovations made it possible for farmers to farm individually. Since 1960 also grains and other agricultural products are used to feed the animals. A strong growth in intensive farming, e.g. intensive crop production and intensive pig farming, was the result. Thereby, the Blair House agreement between the US and European Union in 1992 resulted in the decay of import taxes for oilseeds to the EU, an important ingredient for protein-rich animal meals (OECD, 2013). This resulted in an extra rise in protein rich pig fodder and therefore more pig meat production. The effect of this extra rise in pig meat production became visible in a large rise of meat consumption (Westhoek et al., 2011).

In 2011 the Dutch pig sector, with a total production value of 2,7 billion euro, was the second most important livestock sector after dairy farming (LEI, 2011). At present, about 80% of all pig meat produced in the Netherlands, is produced in 4.250 specialised pig farms, and a further 1.700 farms have pig meat production as a side line (CBS, 2013). There are fewer people producing products on less arable land, which lead to major spatial changes. The number of farms breeding pigs reduced from 275.000 in 1950, to 110.000 in 1975, 20.000 in 1995 and 4.250 in 2011 (Bos and Grin, 2008; LEI, 2013). As shown in figure 2.1 over the same period of time, the number of pigs increased from an average of 35 towards approximately 1.200 per farm (LEI, 2012).

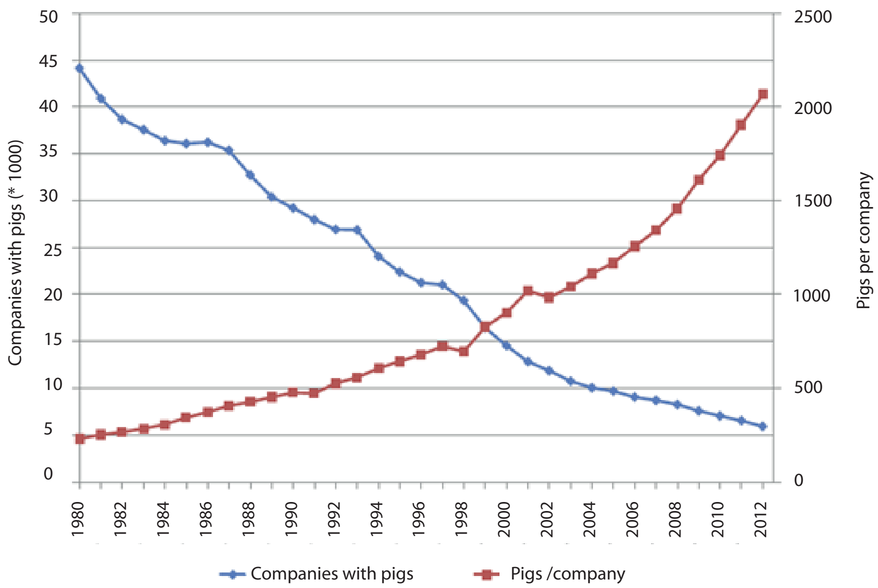


Figure 2.1: Pig farms and the amount of pigs per farm (Source: CBS, 2012)

The pig sector has expanded and became more specialized due to the increasing pig meat production, especially on the south-east sandy soils in the Netherlands. This expansion of the pig sector due to a rising amount of pig meat also occurs in other Western European Countries (Larue, 2011). Currently, this success and expansion of the Dutch pig sector is threatening the environment (Smeets, 2004).

2.2 Drivers of spatial concentration

Many concerns in the pig sector can be traced back to the problem of spatial concentration. The pig sector has become larger, more specialized and more concentrated in specific areas to increase pig meat production (Larue, 2011). This section will elaborate on the drivers behind this change, which encouraged the spatial concentration of the pig sector.

Roe et al. (2002) demonstrate that the pig sector is spatially concentrated due to regional dependent natural conditions and agglomeration economies. Brülhart and Mathys (2008) explain that agglomeration, the clustering of economic activities, is actually a loosely defined term. It is important to be aware of the fact that agglomeration consists of two types of economies. Firstly, agglomeration benefits can be created by localisation economies, e.g. firms of the same sector locate in each other's proximity. Secondly, agglomeration benefits regarding urbanisation economies occur when firms locate in the proximity of a wide array of other, not necessarily related, firms (Brülhart and Mathys, 2008, ibid.). Both economies of scale and their drivers play an important role in the pig sector. Table 2.1 shows these drivers (in blue) for agglomeration and an example of their advantages (in green) in a structured way for the urban and rural environment.

Table 2.1: Schematic overview of types of economy of scale (Inferred from Buytendijk, 2010)

Type of economy of scale and driver				**Example of general agglomeration economies advantages (Aspects resulting in economic demand and supply of the pig production system in the region)**
Internal	1. Pecuniary			Being able to purchase intermediate inputs at volume discounts (cheap pig meat results in more demand)
	Technological		2. Static technological	Falling average costs (more efficient meat production) because of fixed costs of operating a plant
External or agglomeration			3. Dynamic technological	Learning to operate a plant more efficiently (rise in production of pig meat) over time
	Localization	Static	4. 'Shopping'	Shoppers are attracted (more demand for meat) to places where there are many sellers
			5. 'Adam Smith' specialization	Outsourcing allows both the upstream input suppliers and downstream firms to profit from productivity gains (more meat produced by using less money) because of specialization
			6. 'Marshall' labour pooling	Workers with industry-specific skills are attracted to a location (better and more efficient production of meat) where there is a greater concentration.*
		Dynamic	7. 'Marshall-Arrow-Romer' learning by doing	Reductions in costs (rise in production activity) that arise from repeated and continuous production activity over time and which spill-over between firms in the same place
External or agglomeration	Urbanization	Static	8. 'Jane Jacobs' innovation	The more that different things are done locally, the more opportunity there is for observing and adapting ideas (diversity creates new gaps in the market, to engender growth in the production system) from others
			9. 'Marshall' labour pooling	Workers in an industry bring innovations to firms (same as 8) in other industries; similar to no. 6 above, but the benefit arises from the diversity of industries in one location.
			10. 'Adam Smith' division of labour	Similar to no. 5 above, the main difference being that the division of labour is made possible by the existence of many different buying industries in the same place (place available to sell demand of meat)
External or agglomeration	Urbanization	Dynamic	11. 'Romer' endogenous growth	The larger the market, the higher the profit (also for the pig supply chain); the more attractive the location to firms, the more jobs there are; the more labour pools there, the larger the market—and so on

** For a formalization, see Krugman 1991a.*

Numbers 1 through 3 (1. Pecuniary, 2. Statistic technological and 3. Statistic dynamic technological drivers) in table 2.1 represent internal economies. These arise because of the larger size of a pig farm and therefore the farm can better exploit fixed costs. Localization economies, numbers 4 through 7 (4. Shopping, 5. 'Adam Smith' specialization, 6. 'Marshall' labour pooling and 7. 'Marshall-Arrow-Romer' learning by doing drivers in table 2.1), arise from a larger number of pig farms in the same industry and the same place. *'Spatial concentration of enterprises brings an advantage in dynamic processes of knowledge, diffusion through externalities and spill-overs through learning and doing and emulation'* (Van Dijk and Schutjens, 2007, p. 26; cited in Buytendijk, 2010). Urbanization economies arise from a larger number of different industries, such as pig farms, slaughterhouses, supermarkets, in the same place (the four drivers 8. 'Jane Jacobs' innovation, 9. 'Marshall' labour pooling, 10. 'Adam Smith' division of labour and 11. 'Romer' endogenous growth in table 2.1). For the pig sector aspects such as labour pooling, new variations, selection and knowledge diffusions between different sectors create new advantages, which contribute to growth of the pig sector (Hoste et al., 2004).

With the agglomeration factors of Rosenthal and Strange (2004) the spatial concentration of the pig sector can be made even more specific. The drivers of concentration of Rosenthal and Strange (2004) are combined in table 2.2 with the agglomeration advantages for the pig sector as mentioned by Larue (2011) and LEI (2012).

Table 2.2: Definitions of the different advantageous agglomeration effects

Positive agglomeration effects (Rosenthal and Strange, 2004)	**Description definitions**	**Spatial concentration pig sector (Larue, 2011; LEI, 2012; Buytendijk 2010)**
Labour market pooling	The more firms there are in this area, the greater the competition is to obtain workers and therefore results in higher wages for the workers.	Pooling of skilled workers for the pig production activity (Larue, 2011)
Knowledge spill-overs	Facilitating the exchange of ideas that underlies the creation of new goods and new ways of producing existing goods (Carlino, 1987).	Diffusion through externalities and spill-overs through learning and doing and emulation in the Dutch areas with pig concentration (Buytendijk, 2010)
Input sharing	'A dense network of input suppliers facilitates innovation by making it less costly to bring new ideas to fruition' (Helsey, 2002, p. 1)	Access to input services (e.g. feed processing plants, slaughterhouses) (Larue, 2011)
Natural advantage	Environmental factors are an important factor for companies to settle (climate, transport possibilities, natural resources etc.). History and therefore the initial conditions matter to explain actual industrial patterns (Fujita and Thisse, 1996).	The pig sector is mainly located on sandy soils in the south and east, convenient located with respect to the Ruhr area and Paris and beneficial infrastructure (LEI, 2012).
Home market effects	The country with the larger economy tends to be a net exporter where the majority of its goods are consumed in order to minimize shipping costs (Krugman, 1995, p. 1261)	Diffusion of information and knowledge producer organizations and farming extension services (Larue, 2011)
Consumption opportunities	Agglomeration creates more consumption opportunities, more demand, more diversity, more interaction and a bigger change of survival (Rosenthal and Strange, 2004).	Strategic places in the pig sector [see natural advantages] in production processes occur in a wider array of products available for consumption (LEI, 2012; Fujita and Thisse, 1996).
Rent-seeking	Rent-seeking especially occurs in dictatorial countries. Settlement in the capital town, pays back in a compensation in e.g. land (Van den Elshout, 2010)	Irrelevant for the EU pig sector

2.3 Environmental external costs of spatial concentration

Drivers of spatial concentration result in positive effects, such as cheap and sufficient food supply. This rise in supply and demand of e.g. pork meat resulted in a growth of the spatial concentration in the pig sector. Besides advantages this spatial concentration results in environmental problems, so called environmental external costs. These environmental costs are caused by the cornerstones of the agro-industry paradigm: profit maximization, production and distribution cost minimization (Abdalla et al., 1995).

Environmental external costs in the intensive pig sector are the uncompensated environmental effects of intensive pig production and pork meat consumption that affect consumer behaviour, the primary pig production system and the environmental costs outside the market mechanism. As a consequence of these environmental external costs, private costs of pig production tend to be lower than the actual 'social' cost. It is the aim of the 'polluter/user-pays' principle to let consumers and enterprises take a course of action and internalise the social costs of these external costs produced by the pig sector in their plans and budgets (United Nations, 1997, ibid.).

The discussion about the impact of the environmental externalities produced by the intensive livestock is an important topic in the societal and scientific debate for already many years. '*The discussion gradually broadened from manure and environmental problems to a debate on sustainability in a broader sense, a theme which includes also aspects as the spatial capacities and spatial planning opportunities for e.g. the pig sector*' (Van Grinsven et al., 2011, p. 14). Resistance against pig farms started on the regional level because of odour concerns. While time went by also other environmental external effects became topics of concern, such as eutrophication and acidification (Eijsackers and Scholten, 2010).

In intensive pig farming regions manure is often spread in large quantities and concentrations. These quantities are higher than the soil is capable processing of and therefore damage the environment (Young et al., 2005, ibid.). Pig manure contains a large amount of minerals that can damage the environment with their emissions, mainly when it is excessively applied on farmland. According to Van Grinsven et al. (2011) especially ammonia and nitrate emissions have a large impact on the environment. This excessive input of minerals is damaging the environment through eutrophication, soil acidification and contribute to air, groundwater and surface water pollution (Van Bruggen et al., 2013). This leads to loss in biodiversity and endangers the public health and ecosystems in different ways (Velthof et al., 2009).

The expansion of the pig sector resulted '*negative externalities of a [pig] production treadmill*' (Novak, 2003, p.4). This pig 'treadmill' operates on a global scale, but environmental externalities have a strong impact on the regional level (Gould, Schnaiberg and Weinberg, 1996; Yearley, 1996; Novak, 2003). Although technology provides a lot of solutions with regard to emission reduction, it is still difficult to reduce elements such as nitrogen and phosphorus (Young et al., 2005).

Figure 2.2 shows the relation between the problems of inter alia intensive pig farming and the regional effects on the environmental. As the figure shows the current environmental problems of intensive livestock are the result of the interaction between both environmental and societal (e.g. public health and animal welfare debates) forces (Abdalla et al., 1995). This master thesis will only focus on the environmental related topics, as highlighted in figure 2.2. The societal effects of spatial concentration will be excluded. The main source of environmental damage produced by the pig sector is nitrogen pollution. The dominant sources of this nitrogen pollution are ammonia (NH_3) and nitrate (NO_3-) emissions (ENA, 2011). Therefore, in this thesis the environmental costs of these two nitrogen components will be investigated when pigs are relocated.

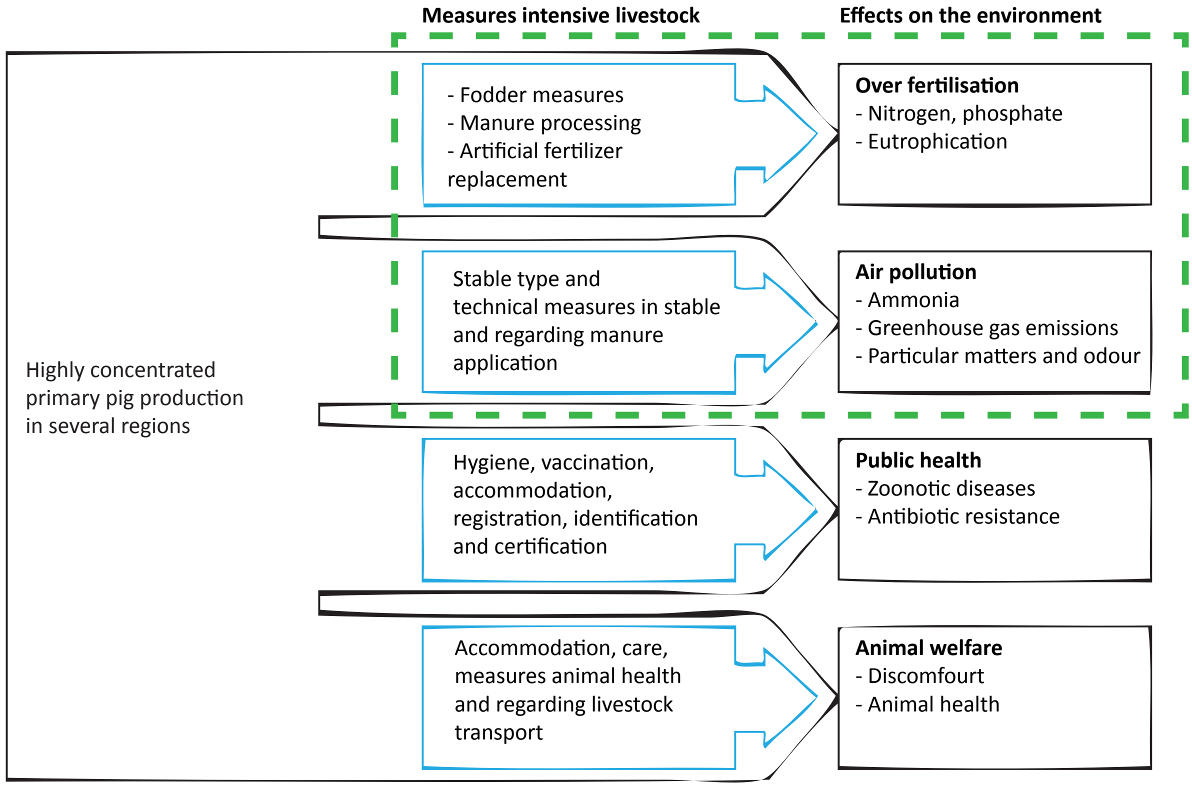


Figure 2.2: Environmental external effects on the environment caused by intensive livestock [pig] farming (Inferred from Van Grinsven et al., 2011)

2.4 Conclusions

Six different drivers of spatial concentration could be identified; natural advantages, labour market pooling, input sharing, knowledge spill-overs, home market effects and consumption opportunities. As Marshall (1920. p. 269) argues '*many various cases [six drivers of spatial concentration] have led to the localization of industry, but the chief causes have been physical conditions [natural advantages], such as the character of the climate or the soil, the existence of mines and quarries in the neighbourhood, or within easy access by land or water*'. Neumann et al. (2009) did research on the spatial distribution of livestock. For the pig sector Neumann et al. (2009, p. 1217) demonstrate that '*the occurrence of these extreme populations [of pigs] ... can be related to historic development of livestock farming and associated infrastructure and market conditions in the region*'. It can be concluded from the literature review that all the six drivers somehow influenced spatial concentration in the pig sector. However, the most important factor to spatial concentrate is the natural advantage a location has over another location.

This is corresponding to the historic development on the sandy soils of the pig sector in the North Brabant region. To successfully relocate the pig sector from North Brabant into the European Union the following natural advantages are taken into account by choosing different relocation regions; nearby harbours, cereal supplies, proximity of vulnerable nature areas, other pig farms, infrastructural network.

Current problems caused by environmental external effects in the pig sector are often the result of rational choices made in the past. The origins of the problem, causing environmental external effects can be traced back to the agro-industry paradigm. Institutions[2] of this paradigm promote profit maximization, pig production and distribution cost minimization (Abdalla et al., 1995) (see figure 2.3). As figure 2.3 also shows the pig sector became larger, more specialized and more concentrated in specific areas to increase pig meat production (Larue, 2011).

[2] *'Institutions are the humanly devised constraints that shape human interaction. They are made up of formal constraints (such as rules, laws, constitutions) and informal constraints (such as norms of behaviour, conventions, self-imposed codes of conduct)' (North, 1991, p. 97)*

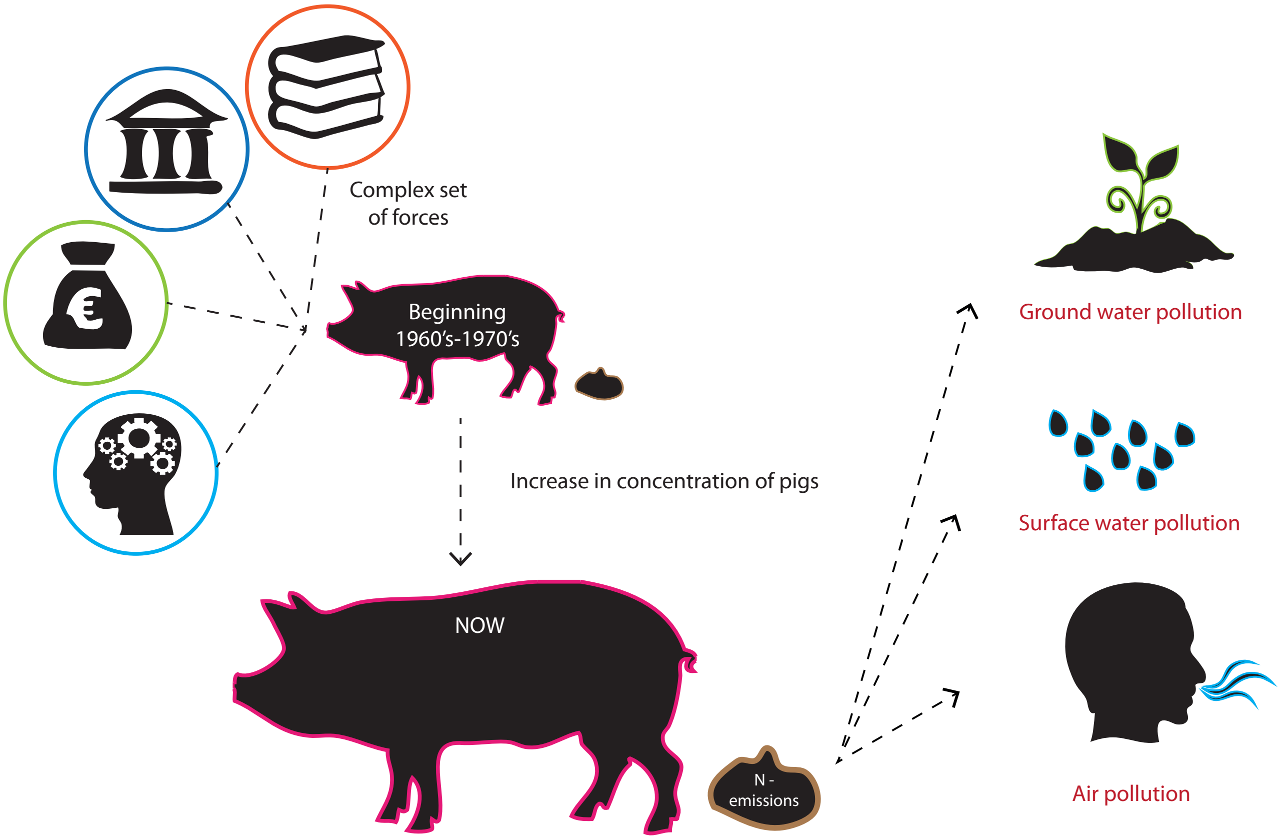


Figure 2.3: Main principle of the model: amount of pigs (independent variable), causing (a surplus of) N-emissions and thereby environmental external effects (dependent variables) that are social costs

Due to spatial concentration excessive emissions of nitrogen (ammonia and nitrate) and phosphate burden the environment. Through over production and over application of pig manure the environment is affected by a nitrogen surplus in the soil, air, groundwater and surface water (see figure 2.3). These effects are undesirable for the environment, public health and animal welfare. Of these effects this thesis will focus on the N-pollution of ammonia (NH_3) and nitrate (NO_3-), since these are dominant sources of environmental damage and external costs produced by the agricultural [pig] sector (ENA, 2011).

The effect of the drivers behind spatial concentration can be called a 'tragedy of the commons'. This 'tragedy of the commons', occurred because commonly owned goods (e.g. soil, air and water) are non-exclusive and became rival as a result of scarcity. Excessive manure production and application results in a threat, namely exhaustion of the environment. The goods (e.g. soil, water and air) are overused and depleted, becoming environmental external costs, due to increasing market demand and cost price reduction. However, if these common owned goods are managed and regulated carefully, continuous use could be possible (Groenewegen et al., 2010).

With the information of the literature review this thesis will investigate whether relocating pigs from North Brabant towards other regions in the European Union is a good way to overcome the exhaustion of the environment. Figure 2.4 shows the conceptual model based on the findings of the literature review. The conceptual model consists of (1) the most important nitrogen emission components and (2) the damage factors to calculate the costs for the environment. These two aspects will amount for (3) the total environmental costs of relocation. The independent variable will be the amount of pigs in a certain region. The dependent variables will be the amount of ammonia that volatizes to (i) the air from stables and (ii) application of manure on arable land. Also the amount of nitrate that (iii) runs off to the surface water and (iv) leaches to surface water and groundwater are included as a dependent variable.

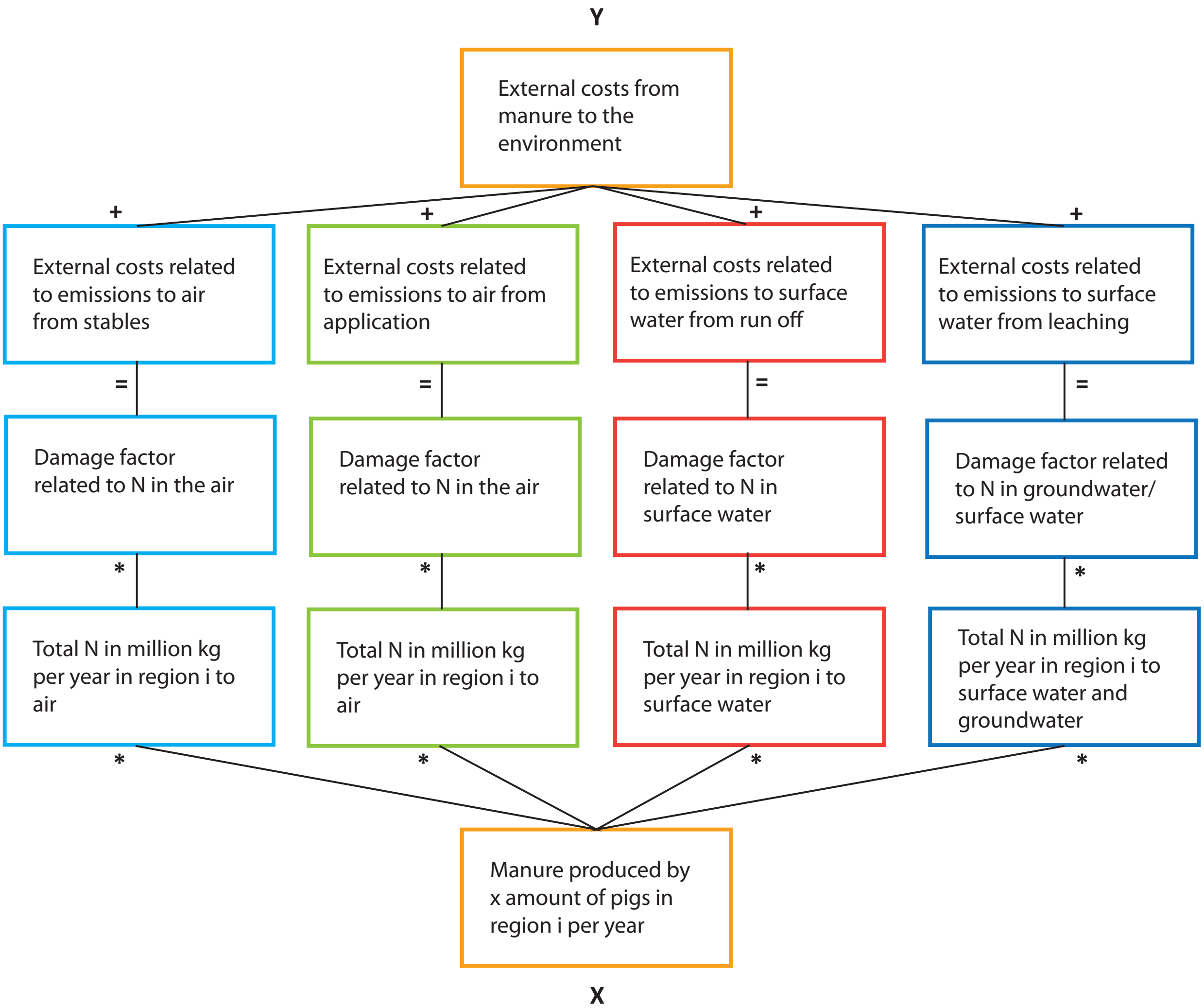
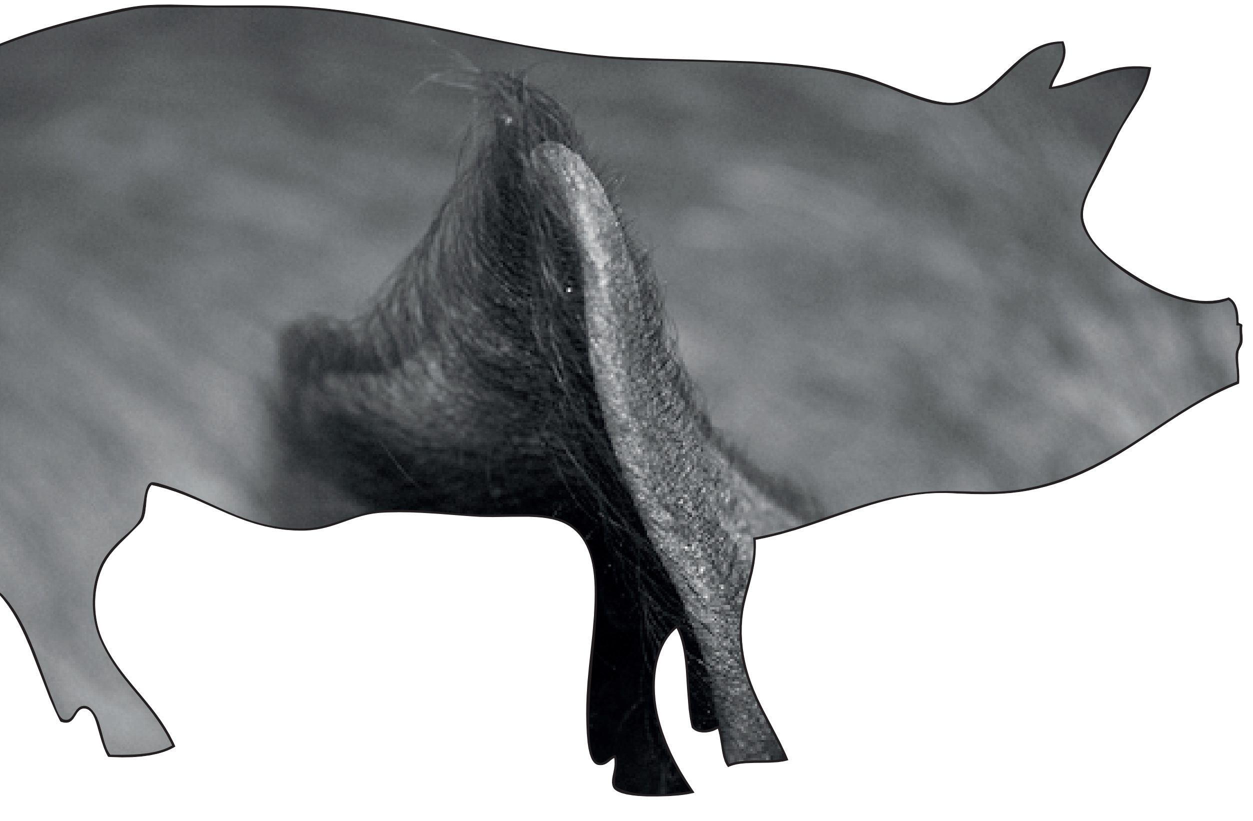


Figure 2.4: Conceptual model based on findings of the literature review

3. Material & Methods



The research is conducted with a combination of quantitative and qualitative approaches. The combination of different methods will result in a more in depth investigation regarding the main research question (Plano and Creswell, 2006). The methods chosen for this research are visualized in figure 3.1 and the thesis is conducted in a sequentially approach (Creswell, 2009).

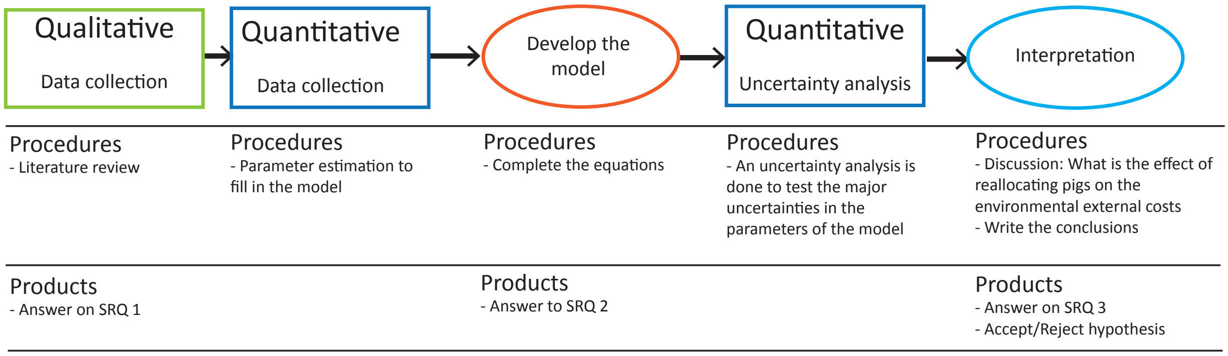


Figure 3.1: Diagram for a sequential design of the research (Inferred from Plano and Creswell, 2006)

The objective of this thesis is to assess the effects of spatial relocation on the environmental external costs produced by the North Brabant pig sector. This thesis started with a literature review and document analysis to identify the drivers of spatial concentration as shown in chapter 2. However, this thesis mainly has a quantitative focus. As a part of this research a simple mathematical model is designed to calculate the environmental external costs when pigs are relocated in Europe. How this model is developed will be explained in section 3.1 until 3.4. The uncertainty analysis, explained in section 3.5, gives a better understanding of the greatest uncertainties in the model. The problem focus is regional, while solutions are considered on an international level.

3.1 Case study areas

The highest pig density per hectare in Europe can be found in the Netherlands with 70,4 pigs per hectare. A substantial part of this high pig density is caused by the province of North Brabant (FAO, 2013a). The Netherlands is followed by Denmark (46,9 pigs per hectare), Belgium (46,3) and Germany (16,0) (FAO, 2013a). As figure 3.2 (see next page) shows in this research the analysis focuses on relocation pigs from the region with the highest density, North Brabant. From North Brabant pigs are relocated to three NUTS2 regions, namely Sachsen (Germany), Tuscany (Italy) and South Romania. The regions North Brabant, Sachsen, South Romania and Tuscany were chosen based on the natural advantages of a location for spatial concentration (as explained in chapter 2).

Germany - Sachsen

Germany is the most important trading country for the Netherlands. In 2011 6.8 million piglets and 4.5 million fattening pigs were exported to this country (PVE, 2012). The pig sector plays an important role in the German agricultural sector, the country has a large-scaled meat industry and is export oriented (Statistische Ämter des Bundes und der Länder, 2011). In the new eastern German states, the pig density is significantly lower in comparison to the western German states. And the farms in the north east of Germany are bigger in comparison to the much smaller farms in the south west (Statistische Ämter des Bundes und der Länder, 2011, ibid.). Sachsen has no problems with high pig densities as in the western part of Germany. The advantage of East Germany is the familiarity with the intensive pig sector and the large housing sizes of pig farms. Also the infrastructural network is well developed to import and export fodder and pork products.

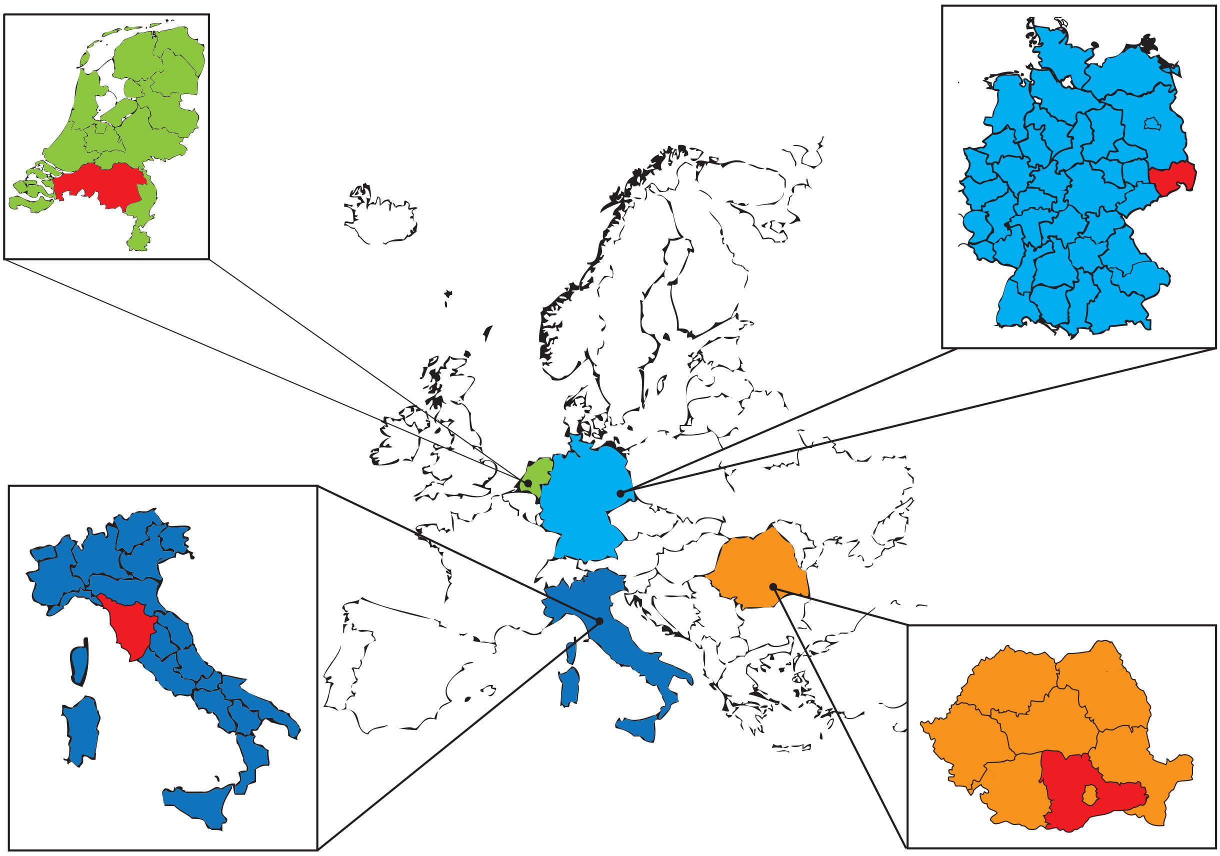


Figure 3.2: Regions of relocation for the model used in this master thesis (Inferred from Eurostat, 2012)

Romania - South Romania

In Romania the sector produces products with few added values, the infrastructural structure is obsolete and the privatization of agriculture led to fragmented agricultural with poor parcelled plots (EC, 2002). However, if Romania produced with optimal efficiency it has the opportunity to produce three times the amount of food feeding the whole Romanian society (Turtoi et al., 2006). Thereby, Rabobank (2011) states Romania is well positioned to become a major pig producer on the long term. Romania has sufficient domestic grain production, a large population with a demand for pork products and foreign investments are available to modernize the pig sector in Romania. Moreover, Extirpate argues in the report of Hoste et al. (2007) that the south of Romania is well suited to start a pig sector. This region has access to fertile and cheap agricultural land, sufficient cereal is produced in the south and geographically it is conveniently located. Thereby, in south Romania the Danube River is well accessible and located nearby the harbour of Constanta (Hoste et al., 2007).

Italy - Tuscany

As in other EU countries the trend of fewer farms with more pigs is also visible in Italy. About 80% of the total number of pigs is situated in the northern part of Italy, namely in Lombardia, Piemonte, Emilia-Romagna and Veneto (Gallo, 2012) However, different experts, including Baldi (2012), are concerned about the amount of pigs (75%) imported. Relocation of North Brabant pig farms in Tuscany could provide an answer to the Italian concerns related to the large import of pigs and pig meat from abroad. Tuscany is a suitable region to relocate pigs, since it is located nearby the knowledge clusters (in relation to the pig sector) of Emilia-Romagna. Tuscany is not highly concentrated by the pig sector as the four earlier mentioned regions. However, agriculture is still an important contributor of Tuscany's economy (Eurostat, 2012). There is sufficient availability of cereals, it is located relatively close nearby larger Italian cities (consumption possibilities) and harbours (export facilities). Thereby the infrastructural system is well developed in Italy.

The details of the four different NUTS2 regions in combination with their drivers of spatial concentration (chapter 2) are summarized in table 3.1. The table provides general information about the spatial differences and opportunities for each NUTS2 region.

Table 3.1: General information of the relocation NUTS2 regions and their spatial relocation drivers (Source: Eurostat 2011, 2012 and 2013)

Country	Population in NUTS2 region	Density (residents/ km2)	Total surface area (in km2)	Number of pigs (x1000)	Area of agriculture (in 1000 ha)	Close to harbour	Cereal supply	Infrastructural network	Consumer opportunities	Knowledge & input sharing
North Brabant	2.470.184	502	4.919	5.236	219	+	+	+	+	+
Sachsen	4.050.204	251	18.338	612	900	+/-	+	+	+	+
South Romania	2.998.643	87	34.489	1211	2328	+	+	+/-	+	+/- +
Tuscany	3.692.828	153	22.990	102	725	+	+	+	+	+/- +

NUTS stands for Nomenclature of Units for Territorial Statistics and this division is made to create uniformity within the European Union (Eurostat, 2003). There are three different NUTS levels, namely country, provincial and regional level as shown in table 3.2. The data of the 27 member states in the European Union is included in these different NUTS levels.

Table 3.2: Different NUTS levels and their scale of population (Source: Eurostat, 2003)

Level	Minimum (population)	Maximum (population)
NUTS 1 (Country level)	3 million	7 million
NUTS 2 (Provincial level)	800 000	3 million
NUTS 3 (Regional level)	150 000	800 000

3.2 Data

The data for the relocation model has been derived from a MITERRA output file. MITERRA includes data that enables to find integrated measures in agriculture to reduce ammonia emission for the European Union (Velthof et al., 2007). The main goal of MITERRA is to find integrated and consistent actions, e.g. regulations and policies, to reduce various environmental impacts of N from agriculture (Velthof et al., 2007). MITERRA is based on other models, such as RAINS and CAPRI, and datasets such as Eurostat and FAO as shown in table 3.3.

Table 3.3: Combination of existing models and datasets used in the MITERRA model (Source:Velthof and Oenema, 2008)

Dataset	**Input in MITERRA**	**Variable in MITERRA model**
FAO and Eurostat	Fertilizer (national), crop yields (N demand, N input, crops) area, number of animals	- Fertilizer and manure distribution on NUTS2 level - Soil balanced: difference between input and output
CAPRI	Area of crops, distribution of animals over NUTS II	
RAINS/GAINS	N excretion factors, emission factors and implementation of ammonia abatement techniques	Emission of NH_3, N_2O, CH_4, N_2O
JRC/CAPRI Dynaspat	Soil and meteorological data with relation to nitrate (Leaching/ denitrification fractions based on manure storage type, soil data, meteorological data, crop type, N input, surface water map)	Leaching and denitrification: - Manure storage - Run off - Large surface water - Groundwater and small surface water
Alterra	NVZ maps, N contents and crop residues, Grassland area and yields	

Table 3.3 shows the origin and type of data, and the related variables. FAO and Eurostat provided data of crop yields, area size and number of animals are derived from databases. Ammonia emissions factors are derived from RAINS. The datasets for leaching and runoff are derived with the help of the CAPRI Dynaspat project, desk studies, data bases and expert knowledge. These datasets contain data necessary to calculate leaching/runoff and how it affects these aspects (Velthof et al., 2007). The runoff percentages of nitrate to surface water used in the relocation model are derived from Velthof et al., 2009. Velthof et al. (2009) provides some details of the MITERRA model that are not discussed in Velthof et al. (2007). A list of runoff percentages for the EU27 can be found in Appendix I. Appendix II provides information about what data of the MITERRA output file is exactly used to make the relocation model run.

The damage factors (in €/ per kg N) are adapted from Van Grinsven et al. (2013). These are necessary to calculate the detailed costs of the amount of ammonia (NH_3) or nitrate (NO_3-) that is released into the environment (see table 3.4 adapted to this research, the complete table is included in appendix III). These costs per unit are based on the economic concept 'willingness-to-pay' (WTP) principle. WTP is 'the maximum amount an individual would be willing to way to secure or prevent a change' (Hanemann, 1991, p. 635). This principle is used to valuate certain risks of premature death, pain or suffering or to protect or restore ecosystems (Van Grinsven et al., 2013).

Table 3.4: Marginal costs and benefits of different N-threats in EU (Inferred from Van Grinsven et al., 2013)

Effect	**Emitted nitrogen form**	**Emission/ loss to**	**Estimated cost - € per kg N emitted, used or produced ***
Ecosystems (eutrophication, biodiversity)	NO_3- (nitrate) deposition	Surface Water	5 – 20 (12)
Human health (particulate matter)	NH_3	Air	2 – 20 (12)
Ecosystems (eutrophication, biodiversity)	NH_3 and NOx	Air	2 – 10 (2)
Human health (drinking water)	NO_3- (nitrate)	Groundwater	0 – 4 (1)

** Values in between brackets are the single values that were inferred from studies on individual effects,*
(For details see SI and Brink et al., 2011)

Brink et al. (2011) explain there are three major damage categories: 1. Loss of life years and public health, 2. Loss of biodiversity and ecosystem services and 3. Climate change. In these three categories costs are created when too much nitrogen is used in agriculture. This thesis focuses only on costs in relation to public health and ecosystems. The estimates for climate change still have a large uncertainty (Butterbach-Bahl et al., 2011) and are therefore excluded in this research.

Due to policy measurements in the Netherlands injection is generally used to apply manure on the land, while in other EU27 countries a cultivator is used more often. Therefore an application factor (1 or 2) is included in the model, which is based on the findings of Webb et al. (2013). Webb et al. (2013) argues when a farmer is broadcast spreading the manure, all the NH_3 volatizes. Therefore this technique is assigned with a factor 1.0. It is assumed that the Netherlands will apply manure by using a 3 centimetre injection. The other European countries will use a rigid tine cultivator to apply manure. As figure 3.3 on the following page shows Webb et al. (2013) indicate that there is twice as much ammonia emission by using a rigid tine cultivator (factor 0.6/factor 2 in model) in comparison to 3 centimetre injection (factor 0.3/ factor 1 in model).

The MITERRA output file with pre-calculated results for the reference year was the main database used to calculate environmental costs for ammonia volatilization, N surface runoff and NO3 leaching to both surface water and groundwater. However, the amount of manure per pig applied to arable land could not be derived from the pre-calculated MITERRA data. In this MITERRA output file no distinction was made in animal manure type in view of ammonia volatilization from manure application, but the model does include this distinction. Therefore, the amount of manure per pig that was applied to arable land was derived from National Emission Model for Ammonia (NEMA), which include the distinction animal manure type. NEMA. NEMA is created by the Statutory Research Tasks Unit for Nature & the Environment (Wettelijke Onderzoekstaken Natuur & Milieu).

Table 3.5 provides a table with the data used to calculate ammonia volatilization and the values for all input variables. Due to the lack of data it was sometimes necessary to first calculate with throughput data in order to provide the main input for the model. In table 3.5 the data used and the values for all throughput variables to calculate the environmental damage of ammonia volatilization, nitrate runoff and leaching to surface water and groundwater is shown.

Table 3.5: Input variables and values to calculate ammonia (NH3) volatilization and nitrate (NO3-) surface runoff and leaching

Description	Data input and values	Obtained with
Ammonia volatilization stables	Number of pigs (in region i, time t)	MITERRA (s7)*
	Volatilization stable pigs (in region i, time t, in 1000 kg N)	MITERRA (s35)
	Damage factors (in €/ kg N)	Van Grinsven et al. (2013)
Ammonia volatilization manure application	Number of pigs (in region i, time t)	MITERRA (s7)
	Amount of manure --> Excretion N pigs housing (in region i, time t, in 1000 kg N)	MITERRA (s15)
	Application factor (in region i)	Webb et al. (2013)
	Damage factors (in €/ kg N)	Van Grinsven et al. (2013)
Surface runoff nitrate to surface water	Number of pigs (in region i, time t)	MITERRA (s7)
	Amount of manure --> Excretion N pigs housing (in region i, time t, in 1000 kg N)	MITERRA (s15)
	Runoff fraction (in region i)	Velthof et al. (2009)
	Damage factors (in €/ kg N)	Van Grinsven et al. (2013)
Leaching nitrate to groundwater / Leaching nitrate to surface water	Number of pigs (in region i, time t)	MITERRA (s7)
	Surplus N in soil after manure application on other agricultural land (in region i, time t, in 1000 kg N)	MITERRA (s89)
	Fraction N disposed by plants (in region i)	Obtained by throughput (see table 3.6)
	Fraction N from pig manure (in region i)	Obtained by throughput (see table 3.6)
	Leaching fraction for groundwater/ surface water	Obtained by throughput (see table 3.6)
	Damage factors (in €/ kg N)	Van Grinsven et al. (2013)

** Refers to the identification number in the MITERRA output file*

By combining the literature and data an overview of the different variables (for each NUTS2 region) is provided in table 3.6 before relocation. Since MITERRA is a static model that represents relocation in the current situation the variables related to pigs, manure production, stables and application techniques will stay constant after relocation. The effect of spatial concentration is excluded from these components in the model. However, the variables related to nitrate leaching will decrease when pigs leaving a NUTS2 region and increase when pigs entering a NUTS2 region. The more pigs entering a region, the more nitrate will leach from the soil and resulting in more environmental costs. Although, due to an increase in pigs the drivers of spatial concentration it probably will become possible to spread fixed costs over more units of output created by the pig sector due to its increasing scale. Table 3.7 provides the different damage factors used in the model.

Table 3.6: Variables per N-pollution, per NUTS2 region, before relocation

NUTS2 region	North Brabant	Sachsen*	South Romania	Tuscany
Total number of pigs (pigs) (MITERRA) ($P_{i,t}$)	5,236,168	611,837	1,211,000	101,505
Manure production (in kg/pig) (MITERRA) (K_i)	9	12	12	11
Emission stables (NH3 per pig, in kg N) (MITERRA) ($N_{i,t}$)	0.12	0.19	0.16	0.16
Application factor (NH3 per pig, in kg N) (NEMA and Webb et al., 2013) ($F_{i,t}$)	1	2	2	2
*Nitrate runoff (NO3 per pig, in kg N) (Velthof et al., 2009)** ($R_{i,t}$)*	0.03	0.04	0.08	0.04
Fraction applied N from pig manure (-) (MITERRA) ($A_{i,t}$)	0.86	0.75	0.12	0.04
Manure volatilization from applied manure (in kg N/pig) NEMA (M)	0.82	0.82	0.82	0.82
Surplus N from pigs (in kg N/pig) (MITERRA) ($Z_{i,t}$)	0.004	0.038	0.003	0.007
Surplus N in soil after manure application on other agricultural land (in kg N) (MITERRA) ($U_{i,t}$)	26,793,000	30,601,000	31,498,000	17,132,000
Leaching fraction of manure to groundwater (-) (MITERRA) ($Lg_{i,t}$)	0.33	0.11	0.09	0.10
Leaching fraction of manure to surface water (-) (MITERRA) ($Ls_{i,t}$)	0.07	0.09	0.15	0.16

** Sachsen has significant higher variables, this is probably caused by the NUTS2 specific data of the MITERRA output file*
*** The fractions for runoff are a translation of the runoff percentages as mentioned by Velthof et al. (2009)*

Table 3.7: Damage factors per Nitrogen component (Adapted from: Van Grinsven et al., 2013)

Damage factor air (in €/ kg N) (Van Grinsven et al., 2013) (D^{air})	14
Damage factor surface water (in €/ kg N) (Van Grinsven et al., 2013) (D^{sw})	12
Damage factor surface water (in €/ kg N) (Van Grinsven et al., 2013) (D^{gw})	1

The input, throughput and eventual output are visualised in figure 3.4. It shows the basic structure of the model developed during the thesis. The numbers displayed in this figure match with the formulas explained in section 3.4.

3.3 The nitrogen cycle

The mathematical model (explained in section 3.4) is a simplification of the nitrogen cycle in the pig sector. The numbers of the main formulas are linked to the nitrogen cycle and visualised in figure 3.4. The figure also shows how the nitrogen components end up into the environment.

Of these effects this thesis will focus on the N-pollution of ammonia (NH_3) and nitrate (NO_3-). These nitrogen components are the dominant sources of environmental damage and external costs produced by

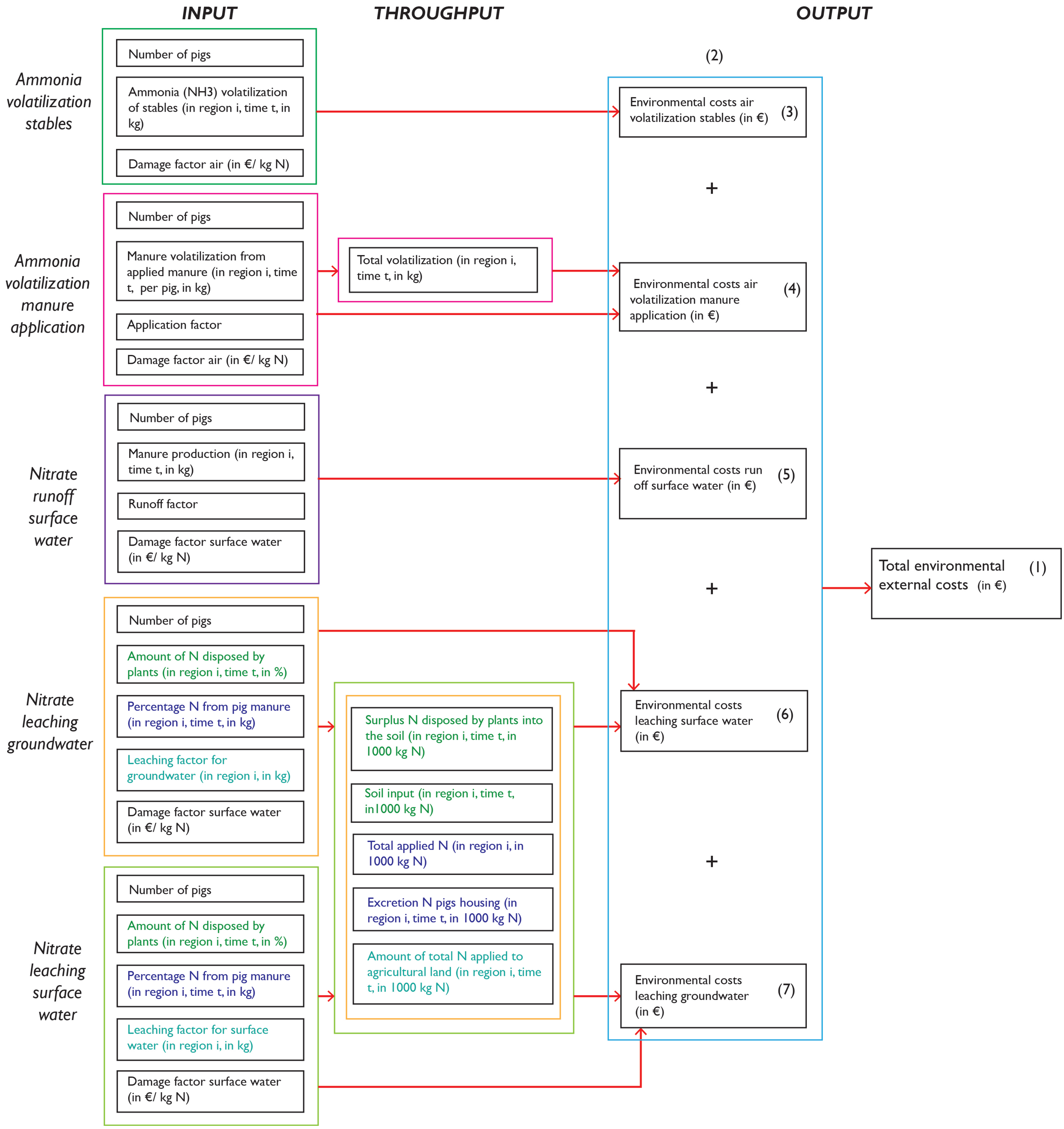


Figure 3.4: Visualization of the structure of the mathematical model

the agricultural [pig] sector (ENA, 2011). Pig manure also other large amounts of minerals that can damage the environment, such as gaseous nitrogen compounds (NO, N_2O and N_2), methane (CH_4), phosphate (P_2O_5) (Van Bruggen et al., 2013). Since this thesis is only focusing on the main components of the nitrogen cycles these components are excluded in the mathematical model.

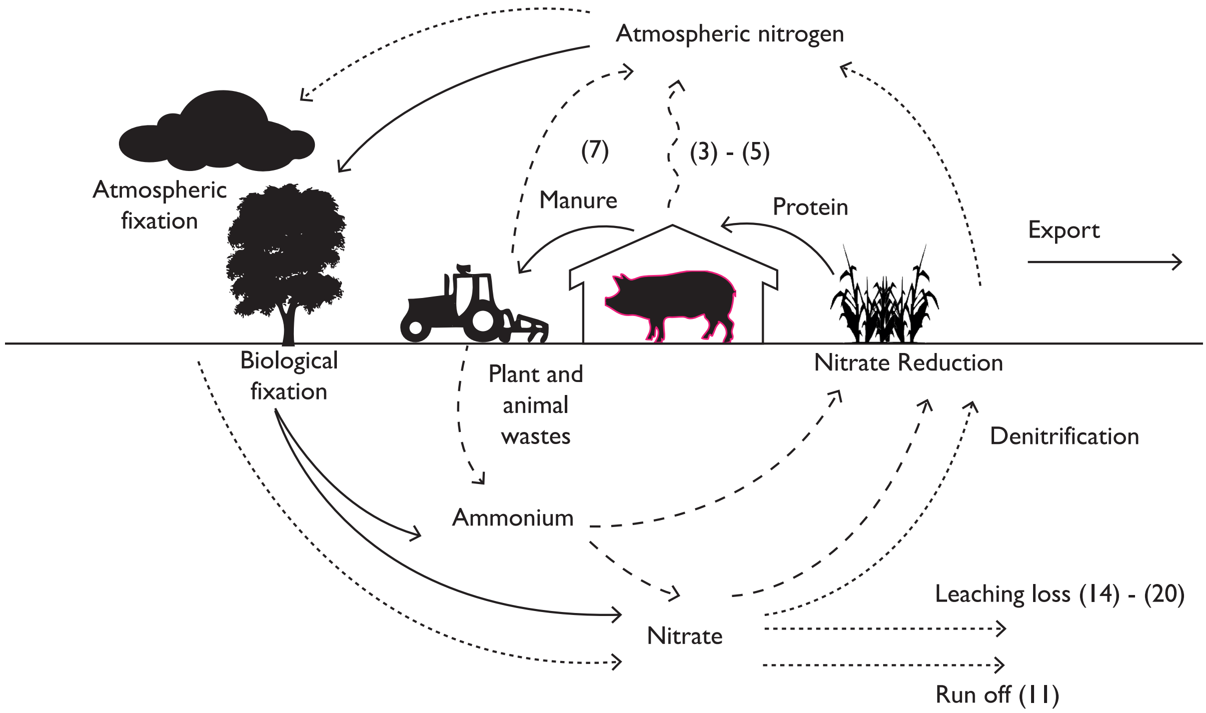


Figure 3.4: The nitrogen cycle including main formulas used in the relocation model (Source: http://www.epa.gov, adapted to this thesis)

3.4 Mathematical model

The mathematical model was developed in Microsoft Office Excel by Marloes Timmers. The model calculates the environmental costs associated with the number of pigs relocated to a NUTS2 region outside the Netherlands in the EU27. For this model the output file of MITERRA was used to determine the different nitrogen emission(s) (factors) for the chosen NUTS2 regions. With this information new formulas were setup to calculate the environmental costs based on literature from Van Grinsven et al. (2013), Webb et al. (2013) and Velthof et al. (2009).

3.4.1 Main formulas

The results of this model were used to calculate the change in external costs of nitrogen pollution. The benefits for North Brabant comes at the expense of extra environmental costs for the three selected NUTS2 regions, because extra pigs also entail extra emissions. The different costs and benefits for these NUTS2 regions are translated into a cost-benefit analysis. The main formula of the model (see formula 1) describes the change in the environmental costs (in €) when X number of pigs is relocated:

$$\Delta E = \sum_{i=1}^{4} (E_{i,t=1} - E_{i,t=0}) \qquad (1)$$

Where:

ΔE = Change in total external costs after relocating pigs (in €)
$E_{i,t=0}$ = Total external costs before relocation (in €)
$E_{i,t=1}$ = Total external costs after relocation of X number of pigs from North Brabant to Tuscany, South Romania and Sachen (in €)
i = NUTS2 region, i.e. North Brabant, Tuscany, South Romania and Sachen

In this model the total external costs ($E_{i,t}$) are obtained from the total external costs per region i before and after reallocation of pigs.

These are calculated as;

$$E_{i,t} = EAi_{i,t} + EAp_{i,t} + ER_{i,t} + ES_{i,t} + EG_{i,t} \quad (2)$$

Where:

$E_{i,t}$ = Total external costs of NUTS2 region i (in €)
$EAi_{i,t}$ = Total external costs of ammonia volatilization of stables to air (in €)
$EAp_{i,t}$ = Total external costs of ammonia volatilization of manure application to air (in €)
$ER_{i,t}$ = Total external costs of nitrate run off to surface water (in €)
$ES_{i,t}$ = Total external costs of nitrate leaching to groundwater in region i and time t (in €)
$EG_{i,t}$ = Total external costs of nitrate leaching to surface water in region i and time t (in €)

Each cost is calculated from two variables. Firstly, the amount of N (NH_3 or $NO3^-$) released into the environment is calculated (in kg) with the help of the MITERRA data. Secondly, this is multiplied with the estimated cost (in €/ per kg) of N emitted. This factor is adapted from Van Grinsven et al. (2013), known as the damage factor (D) in this model. The upcoming formulas represent the different nitrogen components in the model and their environmental costs when pigs are relocated.

Environmental costs of NH_3 to the air by stables is given by formula (3);

$$EAi_{i,t} = N_{i,t} * K_i * P_{i,t} * D^{air} \quad (3)$$

Where:

$EAi_{i,t}$ = Total external costs of ammonia volatilization of stables to air in region i and time t (in €)
$N_{i,t}$ = Ammonia (NH3) volatilization of stables (in kg N/pig)
K_i = Manure production (in kg N/pig)
$P_{i,t}$ = Total number of pigs (pigs)
D^{air} = Damage factor air (in €/kg N)

Formula (4) calculates the environmental costs of the second nitrogen component; NH_3 to the air by pig manure application.

$$EAp_{i,t} = M * P_{i,t} * F_i * D^{air} \quad (4)$$

Where:

$EAp_{i,t}$ = Total external costs of ammonia volatilization of manure application to air; in region i and time t (in €)
M = Manure volatilization from applied manure (in kg N/pig)
$P_{i,t}$ = Total number of pigs (pigs)
F_i = Application factor (-)
D^{air} = Damage factor air (in €/kg N)

The amount of N surface runoff from agricultural soils to surface water due to animal manure was calculated as:

$$ER_{i,t} = K * P_{i,t} * R_i * D^{sw} \quad (5)$$

Where:

$ER_{i,t}$ = Total external costs of nitrate running of to surface water (in €)
K_i = Manure production (in kg N/pig)
$P_{i,t}$ = Total number of pigs (pigs)
R_i = Surface runoff fraction (-)
D^{sw} = Damage factor surface water (in €/kg N)

The surface runoff fraction (R_i) were calculated per EU27 country based on Velthof et al. (2009). Contrary to volatilization of NH_3 from stables and application, the modelling nitrate leaching to surface water and groundwater is more complex. To calculate the environmental external costs for nitrate leaching to surface water formula (6) was used and formula (7) was used to calculate the environmental external costs of nitrate leaching to groundwater.

$$ES_{i,t} = Z_{i,t} * Ls_{i,t} * P_{i,t} * D^{sw} \tag{6}$$

Where:
$ES_{i,t}$ = Total external costs of nitrate leaching to surface water (in €)
$Z_{i,t}$ = Surplus N from pigs (in kg N/pig)
$Lg_{i,t}$ = Leaching fraction of manure to surface water (-)
$P_{i,t}$ = Total number of pigs (pigs)
D^{sw} = Damage factor surface water (in €/kg N)

$$EG_{i,t} = Z_{i,t} * Lg_{i,t} * P_{i,t} * D^{gw} \tag{7}$$

Where:
$EG_{i,t}$ = Total external costs of nitrate leaching to groundwater (in €)
$Z_{i,t}$ = Surplus N from pigs (in kg N/pig)
$Lg_{i,t}$ = Leaching fraction of manure to groundwater(-)
$P_{i,t}$ = Total number of pigs (pigs)
D^{gw} = Damage factor groundwater (in €/kg N)

The N surplus per pigs, in region i, at time t (in 1000 kg) is calculated as:

$$Z_{i,t} = \frac{U_{i,t} * A_{i,t}}{P_{i,t}} \tag{8}$$

Where:
$Z_{i,t}$ = Surplus N from pigs (in kg N/pig)
$P_{i,t}$ = Total number of pigs (pigs)
$U_{i,t}$ = Surplus N in soil after manure application on other agricultural land (in kg N)
$A_{i,t}$ = Fraction of applied N from pig manure (-)

3.4.2 Export of manure

North Brabant is the most intensive pig production region in Europe. As a result a fair amount of the produced pig manure has to be exported, because a large surplus of pig manure cannot be applied on the land. The EU Nitrate directive has set a maximum application rate of 170 kg nitrogen from manure. This makes it mandatory for livestock farmers in intensive production regions to transport the manure surplus outside the region, unprocessed or processed. Manure transport costs are paid by pig farmers and can constitute a substantial proportion of production costs, amount to e.g. 5% for Dutch pig farmers (Van Dam et al., in prep.). Relocating pigs to other NUTS2 regions outside the Netherlands would mean a decrease in pig manure production. This could result in a significant decrease of costs that will not be made in relation to manure export. North Brabant is the main relocation region in the model. A decrease of pig manure, due to relocating pigs, will have a significant effect on the total benefits for the Netherlands. Therefore, it is important to take this aspect into account.

However, there is no specific data available in the MITERRA output file about a division within the distribution of manure from North Brabant towards which specific region. Due to this missing data this thesis could not predict the complete influence of export in North Brabant. MITERRA provides information on the amount of N exported (in 1000 kg N) distributed from North Brabant to other parts of the Netherlands. Considering the low economic value of manure and high costs of transport it is assumed manure is exported to areas close to the primary production area within the Netherlands.

From this assumption an additional calculation sheet was created. It is capable of calculating the external costs of manure produced in North Brabant, but applied in the Netherlands. The manure originating from relocated pigs is directly subtracted from the applied manure in North Brabant. Due to missing data the export sheet is not complete and therefore not included in the main model yet. The amount of manure exported is known, however the destination of this amount is unknown. The setup of the model is included in Appendix V and could eventually be added into the main model.

3.5 Uncertainty analysis

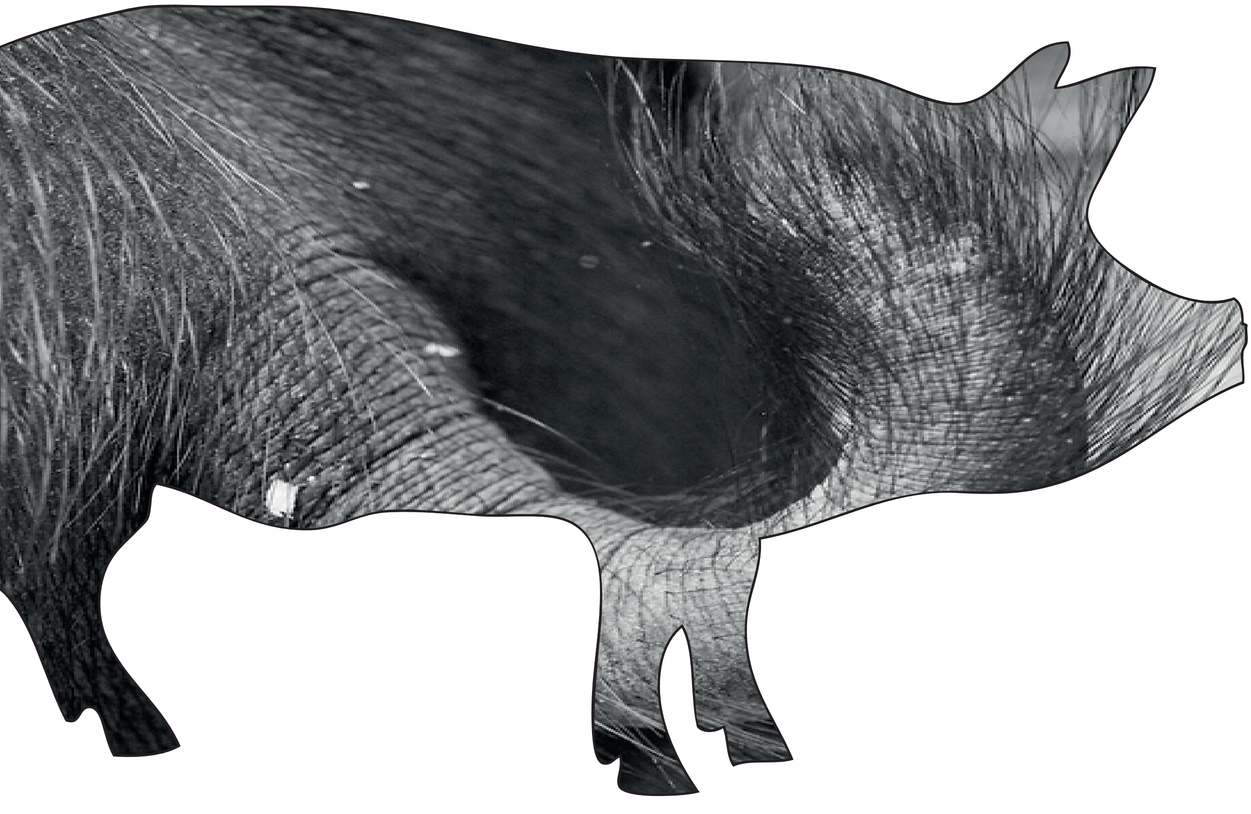
A concise uncertainty analysis is done to test the uncertainty in the output of the relocation model. This is performed by changing values of different selected parameters according to their uncertainty range. The different ranges showed in table 3.5 were selected by a quick review of the used literature. The largest ranges were selected per nitrogen component (ammonia volatilization, nitrate leaching and nitrate runoff) and used for the uncertainty analysis. The uncertainty analysis aims to make a technical contribution to decision-making through the quantification of uncertainties in the relevant variables. Thereby this concise analysis helps in better substantiating the different parameters and assumptions in the mathematical model. Lastly, this analysis is a valuable addition for the discussion and recommendations at the end of this master thesis.

Table 3.5: Different ranges used to perform the concise uncertainty analysis

Parameter	Best case	Standard model	Worst case	Unit	Literature
Application factor	1.5	2	3	-	Webb et al. (2013)
Damage factor ammonia emission to air	4	14	30	€/ kg N	Van Grinsven et al. (2013)
Damage factor nitrate emission to surface water	5	12	20	€/ kg N	Van Grinsven et al. (2013)
Damage factor nitrate emission to groundwater	0	1	4	€/ kg N	Van Grinsven et al. (2013)
Volatilization stable (emission factor NH_3)	0.75	NUTS dependent	1.25	in kg NH_3 per animal per year	Van Oorschot (2001)*
Volatilization application (emission factor NH_3)	0.5	0.32	1.5	in kg NH_3 per animal per year	Van Oorschot (2001)*
Volatilization application (application technique)	0.23	0.32	0.48	in kg NH_3 per animal per year	De Haan et al. (2009)
Run off factor towards surface water	-2%	0	+2%	in kg NH_3 per animal per year	Velthof et al. (2009)

**The NEMA uncertainty analysis carried out in 2001 is still used to determine the uncertainty for the model in 2013, in 2015 a new uncertainty analysis will be done to investigate whether the ranges are still correct.*

4. Results



This chapter contains the results of relocating pigs into the three chosen NUTS2 regions in the European Union and the effect of this relocation on the environmental costs.

4.1 Effect of spatial relocation on the environmental external costs

To get a clear representation of what the effect is of relocating North Brabant pigs, it is decided to work with different scenarios for the three relocation NUTS2 regions. Four scenarios are considered; relocating 50.000, 100.000, 200.000 and 400.000 pigs to each of the three receiving regions. The results of these different scenarios are shown in figure 4.1 until 4.4. The figures show from left to right: Benefits for Brabant (1), costs for Sachsen (2), South Romania (3) and Tuscany (4), Total costs after relocation (5) and total costs minus benefits after relocation (6). A list of detailed numbers of the effect by relocating 50.000, 100.000, 200.000 or 400.000 pigs on the environmental costs per N-component is given in Appendix VI. In these calculations it is assumed that pigs are relocated in the current situation, no changes are made in the emission factors, type of stables and application techniques. It is very likely that these aspects will change in the long term for the different NUTS2 regions. However, this change on the long term is currently not taken into account in the relocation scenarios.

In each of the four scenarios the model shows that North Brabant receives benefits between 3.99 million Euro (150.000 pigs) and 31.96 million Euro (1.200.000 pigs) when pigs of this region are relocated elsewhere in the EU27. However, this relocation costs the three relocation regions between 17.10 million Euro until 71.41 million Euro as shown in figure 4.1 until 4.4. In total for all the four scenarios it shows these costs outweigh the benefits. The chart graphs show a total cost side of -13.12 till -39.45 million Euro depending on the amount of pigs that is relocated.

The changes in the different scenarios show that the environmental external costs are mostly influenced by 'volatilization in stables' and 'leaching surface water'. The changes in the scenarios are helpful in defining the focus for new policy inventions. For example, it could be taken into account that N-leaching to surface water is very region dependent on specific soil types and the amount of pig slurry that is applied in these regions. Thereby these different scenarios show that it is useful to focus on EU-policies to reduce ammonia emission from stables. The slight increase in the amount of runoff to the surface water, leaching to surface water and groundwater are probably the result of the fixed values that are used to calculate the change in the % N-leaching and % N-disposal, as explained in section 3.4.4.

The positive effects of spatial concentration become clear in table 4.1. This table visualises the cost price of relocation per pig. It shows spatial concentration of the pig sector in North Brabant leads to a lower environmental cost price, compared to lower concentrations. The more pigs are relocated in the concerning NUTS2 region, the more these costs decrease per pig. The more pigs are located in a certain region, the more costs for the environment can be spread over this amount of pigs and the other way around. As visualised in table 4.1 by relocating 50.000 pigs in Sachsen (131.05 Euro per pig), in comparison to 200.000 pigs relocated in the same region (costs 62.02 Euro per pig).

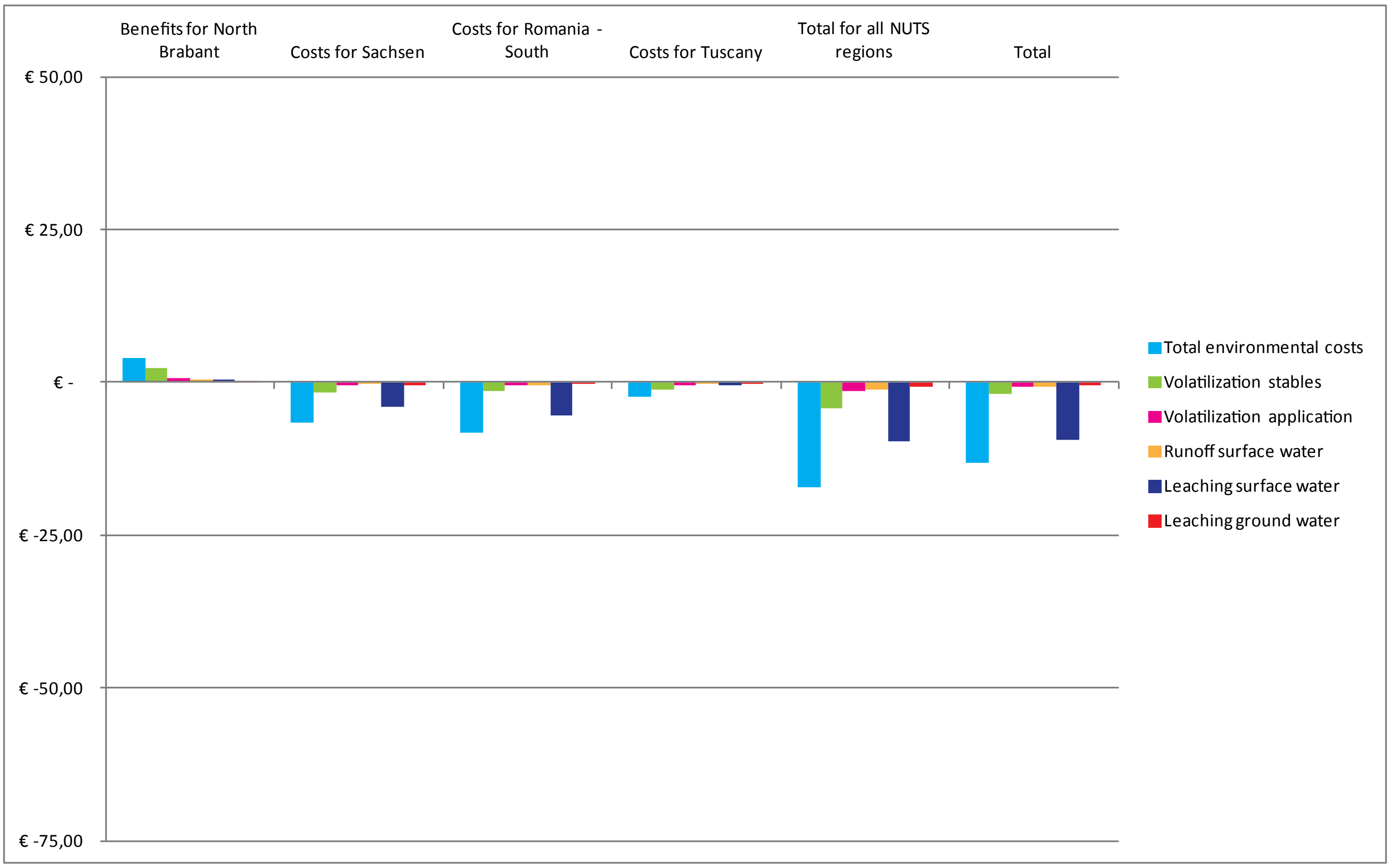


Figure 4.1: Results relocating 150.000 pigs visualised in chart graph

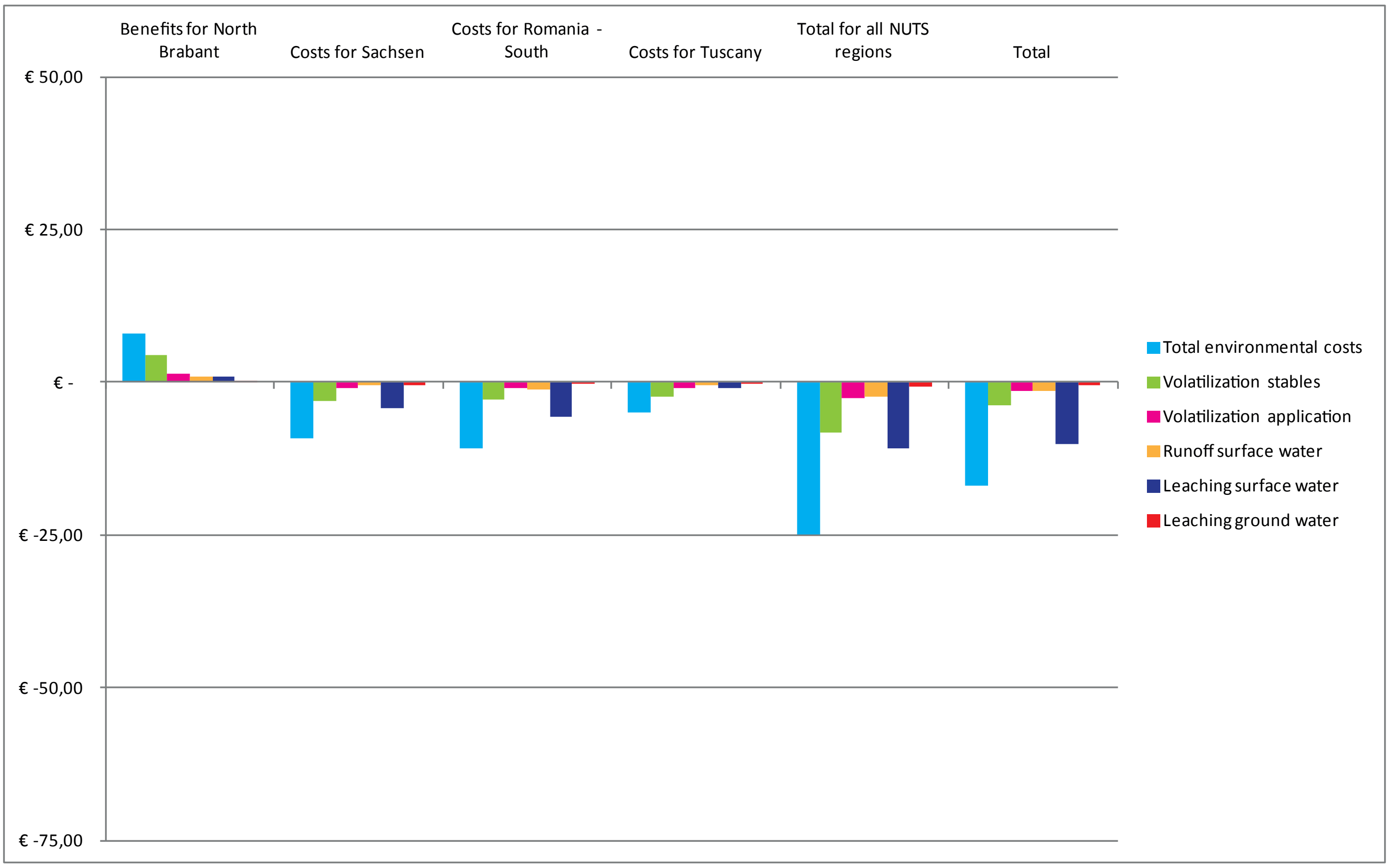


Figure 4.3: Results relocating 600.000 pigs visualised in chart graph.

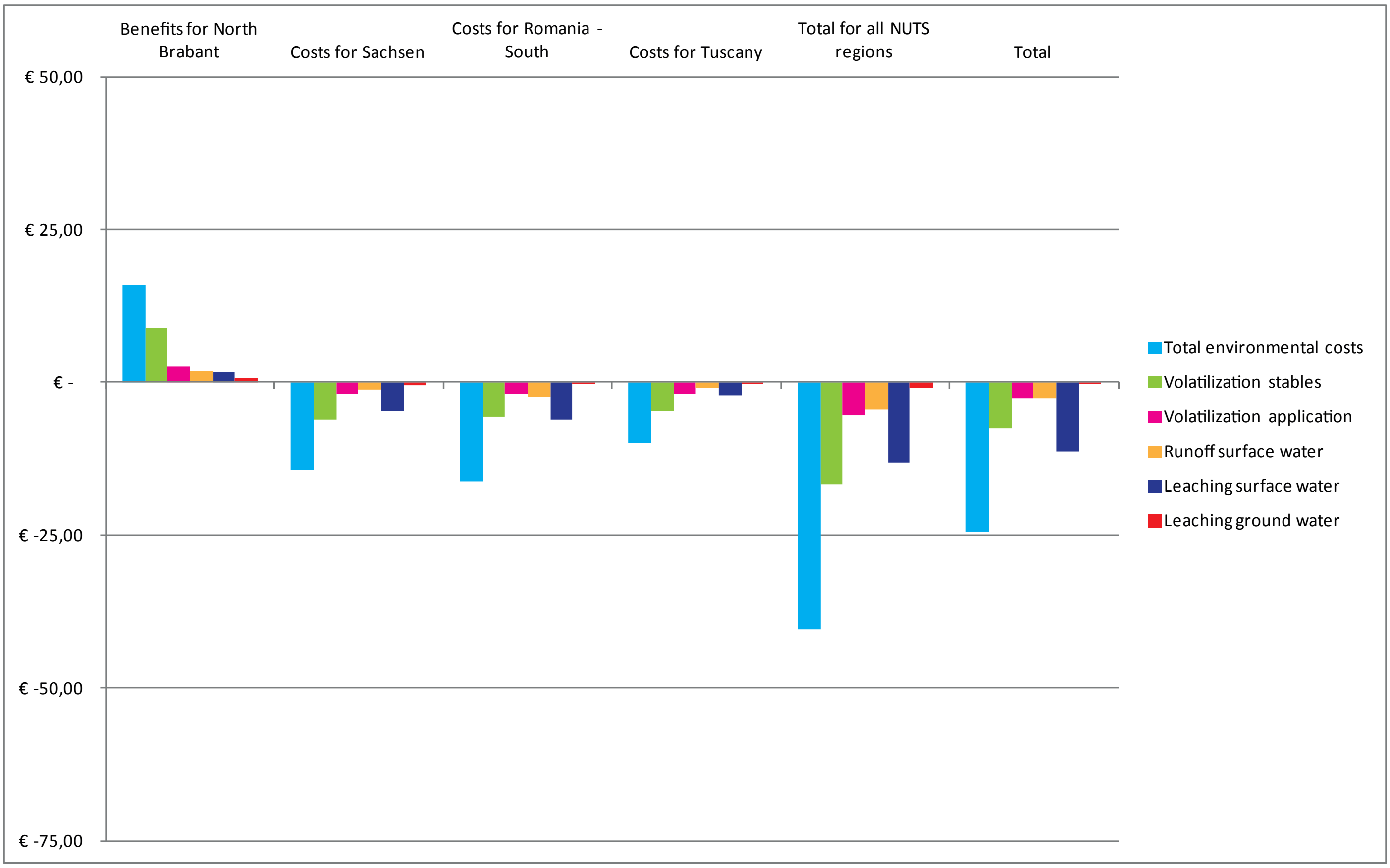


Figure 4.2: Results relocating 300.000 pigs visualised in chart graph

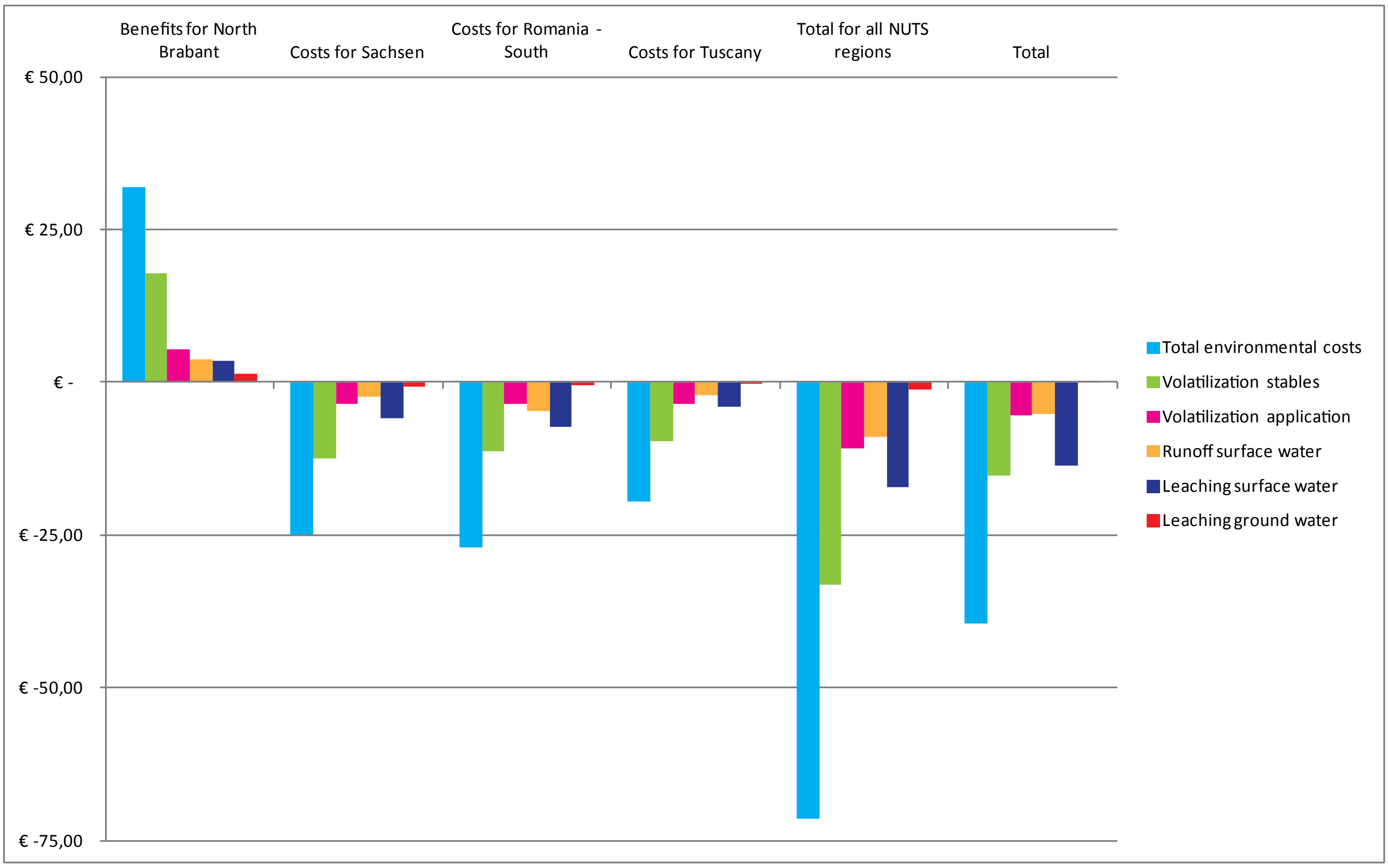


Figure 4.4: Results relocating 1.200.000 pigs visualised in chart graph.

Table 4.1: Costs per pig when relocating pigs to other NUTS2 region Costs and benefits per pig by a relocation of (1)150.000 pigs, (2) 300.000 pigs, (3) 600.000 pigs and (4) 1.200.000 pigs

Region	Number of pigs after reallocation	Costs per pig total	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water
	Number	in euro's	in euro's	in euro's	in euro's	in euro's	in euro's
NUTS region 1 (Sachsen)	50.000	€ 131,05	€ 30,88	€ 8,96	€ 5,72	€ 77,64	€ 7,85
NUTS region 2 (South Romania)	50.000	€ 162,44	€ 27,99	€ 8,96	€ 11,68	€ 108,44	€ 5,37
NUTS region 3 (Tuscany)	50.000	€ 48,58	€ 24,00	€ 8,96	€ 5,18	€ 8,69	€ 1,75
Concentration region North-Brabant	-150.000	€ 26,58	€ 14,93	€ 4,48	€ 3,19	€ 2,90	€ 1,08

Region	Number of pigs after reallocation	Costs per pig total	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water
	Number	in euro's	in euro's	in euro's	in euro's	in euro's	in euro's
NUTS region 1 (Sachsen)	100.000	€ 91,83	€ 30,88	€ 8,96	€ 5,72	€ 42,02	€ 4,25
NUTS region 2 (South Romania)	100.000	€ 108,27	€ 27,99	€ 8,96	€ 11,68	€ 56,82	€ 2,81
NUTS region 3 (Tuscany)	100.000	€ 49,15	€ 24,00	€ 8,96	€ 5,18	€ 9,86	€ 1,15
Concentration region North-Brabant	-300.000	€ 26,59	€ 14,93	€ 4,48	€ 3,19	€ 2,90	€ 1,08

Region	Number of pigs after reallocation	Costs per pig total	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water
	Number	in euro's	in euro's	in euro's	in euro's	in euro's	in euro's
NUTS region 1 (Sachsen)	200.000	€ 72,09	€ 30,88	€ 8,96	€ 5,72	€ 24,09	€ 2,44
NUTS region 2 (South Romania)	200.000	€ 81,19	€ 27,99	€ 8,96	€ 11,68	€ 31,02	€ 1,54
NUTS region 3 (Tuscany)	200.000	€ 49,21	€ 24,00	€ 8,96	€ 5,18	€ 10,23	€ 0,84
Concentration region North-Brabant	-600.000	€ 26,60	€ 14,93	€ 4,48	€ 3,19	€ 2,91	€ 1,08

Region	Number of pigs after reallocation	Costs per pig total	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water
	Number	in euro's	in euro's	in euro's	in euro's	in euro's	in euro's
NUTS region 1 (Sachsen)	400.000	€ 62,02	€ 30,88	€ 8,96	€ 5,72	€ 14,94	€ 1,51
NUTS region 2 (South Romania)	400.000	€ 67,67	€ 27,99	€ 8,96	€ 11,68	€ 18,13	€ 0,90
NUTS region 3 (Tuscany)	400.000	€ 48,84	€ 24,00	€ 8,96	€ 5,18	€ 10,03	€ 0,67
Concentration region North-Brabant	-1.200.000	€ 26,63	€ 14,93	€ 4,48	€ 3,19	€ 2,93	€ 1,09

4.2 Export of manure

The results of the mathematical model in figure 4.5 clearly show the effect of the export of manure on the demand for artificial fertilizer in North Brabant. As expected the demand for artificial fertilizer in North Brabant increases to supplement the missing nutrients to the crops, which normally comes from the exported manure. The complementing of fertilizer will mainly occur in provinces around North Brabant. These provinces normally intercept the N-surplus of Brabant. At a later stage, when the manure surplus is distributed out of North Brabant. On the long term also North Brabant will probably supplement this missing amount of nutrients with artificial fertilizers as can be derived from the results in figure 4.5.

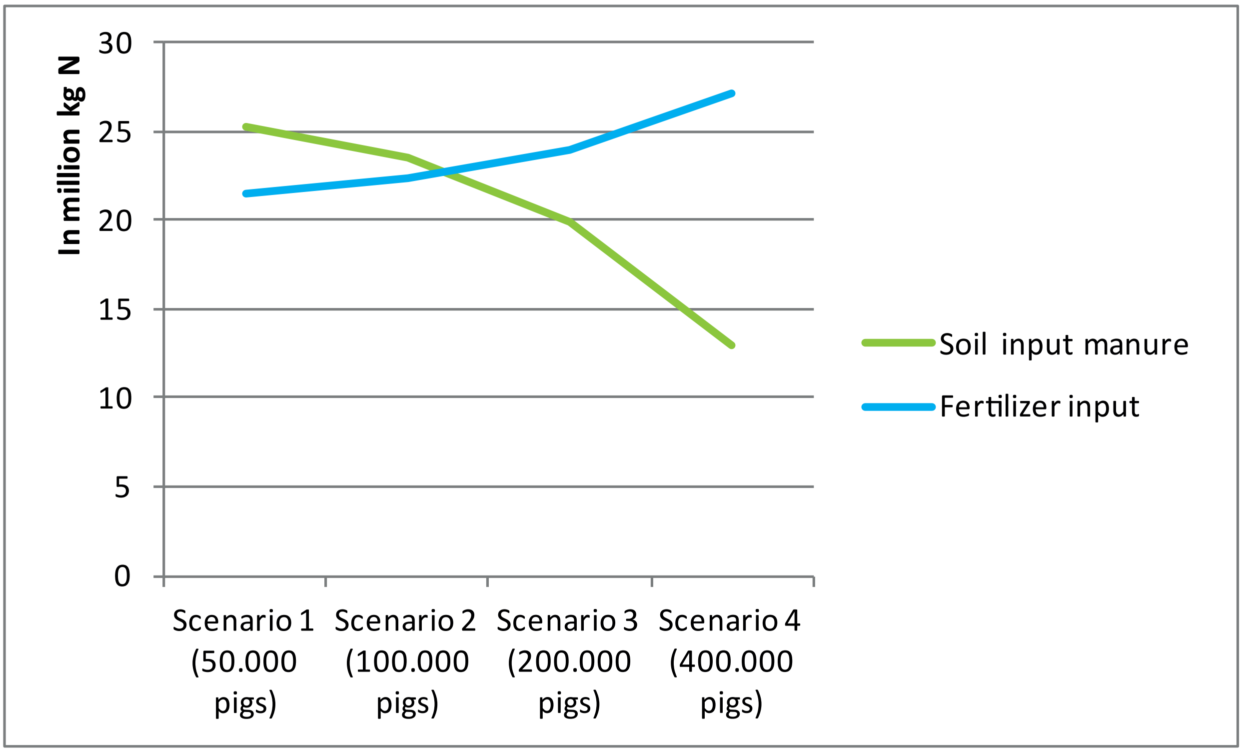


Figure 4.5: Effect of manure export on the demand for artificial fertilizer in the Netherlands

The results of the beta calculation sheet of manure export show that the total costs of export increase linear with the amount of manure exported. Table 4.2 shows the results when 100.000 pigs are relocated to every of the three NUTS2 regions. Appendix VII shows the detailed results for the other scenarios. As explained before there are large uncertainties in the model. It cannot be concluded yet what the influences of manure export are for the region North Brabant or how many pigs should be exported to overcome the N surplus in North Brabant.

Table 4.2: External costs in relation to manure export when 300.000 pigs are relocated

	Total volatilization application manure (in kg N)	Total run off surface water (in kg N)	Total leaching surface water (in kg N)	Total leaching ground water (in kg N)	Total costs and benefits due to export (in €)
Manure of exported pigs (North Brabant) (in kg N)	96.048	79.820	86.804	184.291	
Fertilizer compensation	0	47.892	52.083	110.575	
Damage factor (Van Grinsven et al., 2013)	14	12	12	1	
Benefit manure	€ 1.344.665	€ 957.844	€ 1.041.653	€ 184.291	€ 3.528.454
Cost fertilizer	€ 0	€ 574.706	€ 624.992	€ 110.575	€ 1.310.273
Total savings by export per category (in €)	€ 1.344.665	€ 383.138	€ 416.661	€ 73.717	**€ 2.218.181**

4.3 Uncertainty analysis

To determine the impact of the different input parameters on the output of the model an uncertainty analysis was performed on the mathematical model. The analysis is done for a total of 300.000 pigs relocated to three different NUTS2 regions. The results in figure 4.6 show how different input parameters affect the output of the model. Appendix VIII provides detailed information on the detailed uncertainty ranges.

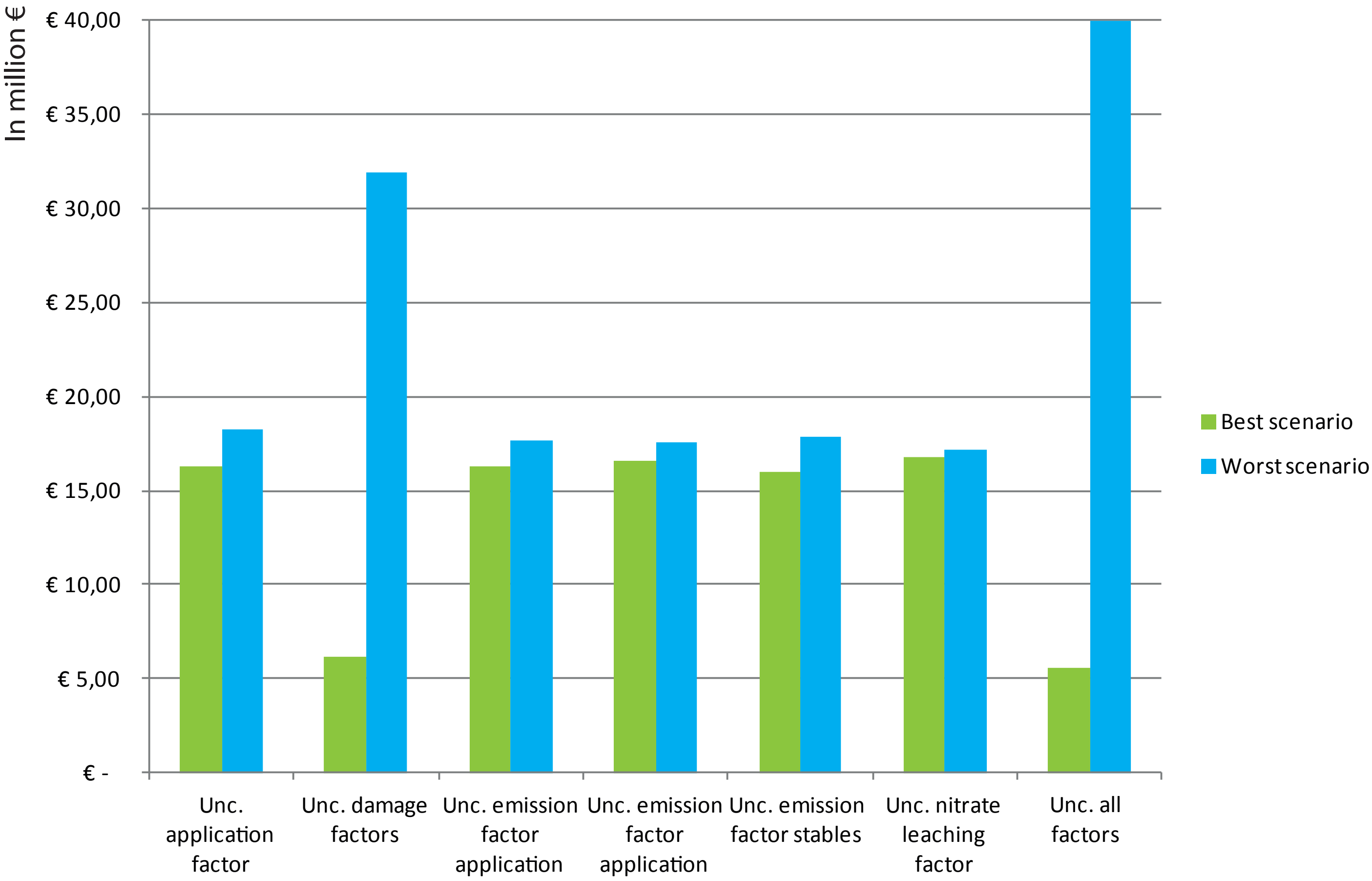


Figure 4.6: Results of the concise uncertainty analysis

The majority of the factors have a relatively small uncertainty range between 16.0 (best case) and 18.3 (worst case) million Euro damage to the environment. However, the damage factors are the critical factor resulting in 6.18 million Euro total costs in the best case. The worst case scenario results in a total of 31.86 million Euro damage for the environment. This critical factor has a large influence, since the damage factors are required for each N-component to calculate the costs. Other factors used in the model influence only one N-component at a time. The uncertainty range for the complete model ranges between 5.54 million Euro in the best case, up to 39.99 million Euro in the worst case.

4.4 Conclusions

The main effects of relocating pigs can be explained with the help of table 4.3. The table shows the effects of spatial relocation for North Brabant (spatial concentration region), the rest of the Netherlands (due to decreasing manure export) and the NUTS2 regions (relocation regions).

Table 4.3: Review on the main results proven by mathematical model

	I : North Brabant	II : Rest of NL	III : NUTS2 regions
N-excretion	↓	o	↑
Artificial fertilizer	o > ↑	↑	o > ↓
Pig manure	↓	↓	↑
Nitrogen surplus	o > ↓	↓	↑
Ammonia volatilization	↓	↓	↑
Nitrate run off	↓	o	↑
Nitrate leaching	o > ↓	↓	↑

As the mathematical model and table 4.3 show; when a selected amount of pigs is relocated to different NUTS2 regions the environmental benefits increase for North Brabant. These benefits occur, because there is a decrease in pig manure. A decrease in pig manure directly affects aspects such as N-excretion, ammonia volatilization and nitrate runoff, which also decrease. Nitrate leaching will stay the same, because it is likely that due to the absence of manure, the vacant space of nitrogen will be replaced by artificial fertilizer. Eventually, nitrate leaching will decrease since the fertilizer equivalency of pig slurry is 60% in comparison to artificial fertilizer with a fertilizer equivalency of 100%. The application rate of 170 kg nitrogen per hectare will be used to its maximum to gain maximum yields. As long as the excretion from pigs is higher than the export of manure, the application of manure and the amount of artificial fertilizer on arable land stay the same for North Brabant. Eventually, if the excretion is lower than the amount of pig manure exported the use of artificial fertilizer will increase for North Brabant.

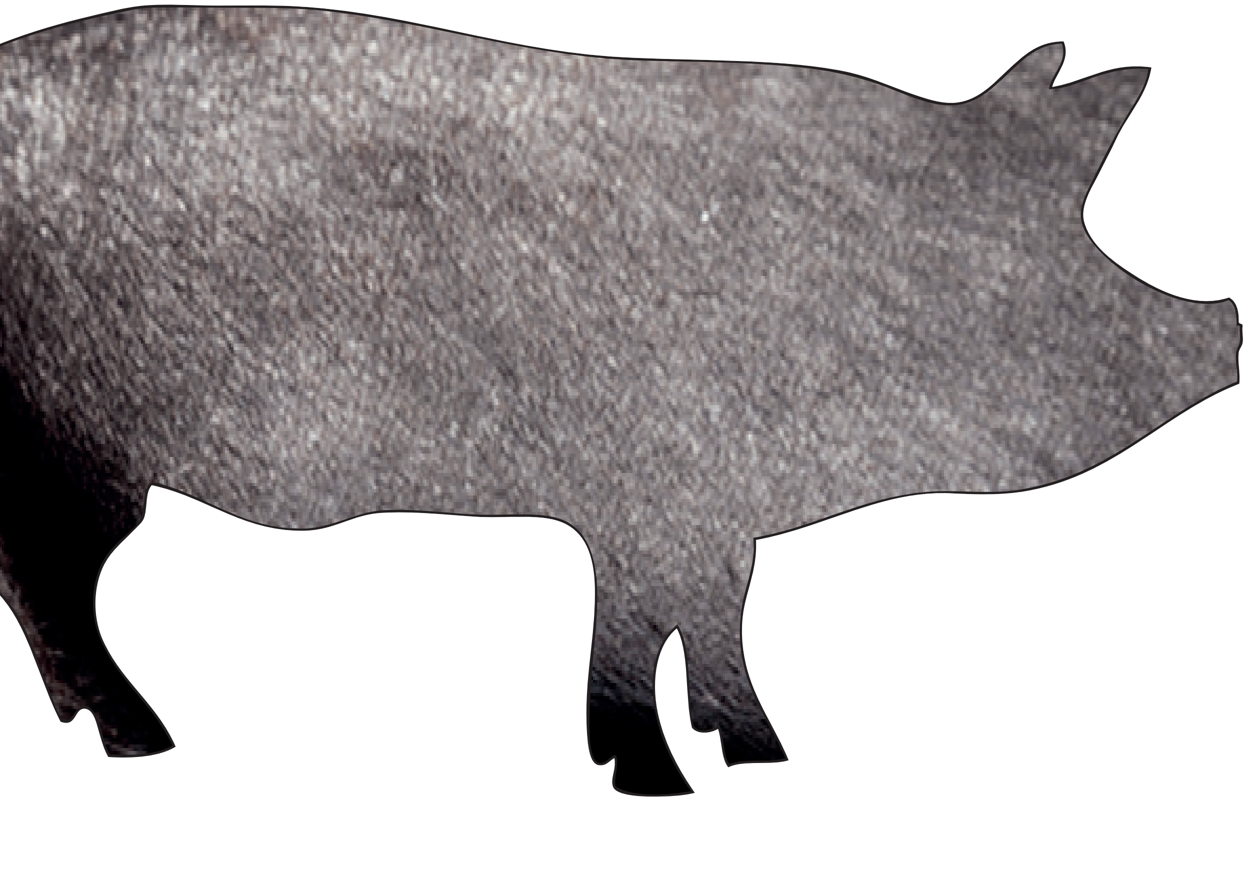
The rest of the Netherlands especially plays an important role in this model with relation to the increase in use of artificial fertilizer. The model gives a clear indication of the relation between manure supply and artificial fertilizer demand. As expected the demand for artificial fertilizer increases to supplement the missing nutrients from manure to the crops. The effect of relocating pigs will be noticeable at first for the rest of the Netherlands, because the manure that is relocated to Europe normally is transported to neighboring provinces. This means that the emissions related to manure application on arable land decrease. The effect of relocation is positive for the environment, but the costs for artificial fertilizer will increase for the farmer.

The extra amount of pigs results in an increase in the different N-components for the three NUTS2 regions and therefore an increase of environmental costs. The use of artificial fertilizer probably remains unchanged in the NUTS2 regions, on the longer term it will probably decrease. This can be explained as following; in the model is calculated with numbers for the current situation. Therefore it is assumed that the artificial fertilizer probably remains unchanged or decreases on the long term in the NUTS2 regions. The soil nutrients will be supplemented with the extra amount of relocated manure. This conclusion could be better substantiated when the current environment is included in the model with e.g. extra data that is provided in nutrient critical load maps.

The effect of spatial concentration becomes partly visible in the cost-benefit analysis. When 300.000 or 1.200.000 pigs from North Brabant are relocated into the EU27 this results in a decrease of only 4 eurocent per pig. For the NUTS2 regions the price ranges from 48,58 until 162,44 Euro per pig, when one of the three NUTS2 regions receives 100.000 pigs. The price ranges from 48,48 until 67,67 Euro per pig according to the results when 300.000 pigs are relocated to each NUTS2 region. This shows that cost spreading is one of the advantages that occurs due to spatial concentration in North Brabant.

However, it should be mentioned that the assumptions in the model result in an enlargement of this spatial concentration effect. The calculations are based on data that reflects the current situation of the different NUTS2 regions. Future data and complex sets of societal and environmental forces are not considered in this research towards the environmental effects of relocating pigs. It is likely that the differences in type of stable and application techniques will converge on the long term, due to EU regulations and measurements. This entails that the differences in cost price and the effect of spatial concentration will eventually decrease on the long term.

5. Discussion



In this chapter the results of the three research questions will be discussed respectively. Research questions 1 and 2 will be answered and research question 3 is incorporated in this discussion. In chapter 7 'Conclusions' the research hypothesis is examined.

5.1 Drivers of spatial relocation

To understand how choices made in the past shaped the current situation a literature study was carried out to answer the research question *'What are the drivers that cause spatial concentration of the North Brabant pig sector?'*. Combining the literature of Fujita and Thisse (1996), Rosenthal and Strange (2004), Roe et al. (2002), Larue (2011), LEI (2012) and Buytendijk (2010) the following core drivers of spatial concentration could be identified: input sharing, knowledge spill-over, home market effects, labour market pooling, natural advantages and consumption opportunities.

It can be concluded from the literature review that all the six drivers somehow influenced spatial concentration in the pig sector, but the most important factor is the natural advantage a location has over another location. This can be clarified by Marshall (1920. p. 269) who argues that *'many various cases [six drivers of spatial concentration] have led to the localization of industry, but the chief causes have been physical conditions [natural advantages], such as the character of the climate or the soil, the existence of mines and quarries in the neighbourhood, or within easy access by land or water'*. Thereby, Neumann et al. (2009) did research on the spatial distribution of livestock. For the pig sector Neumann et al. (2009, p. 1217) demonstrate that *'the occurrence of these extreme [pig] populations … can be related to historic development of livestock farming and associated infrastructure and market conditions in the region'*. Both Marshall (1920) and Neumann et al. (2009) indicate the major importance of a natural advantage of a location in comparison to the other five drivers for spatial concentration. This is corresponding to the historic development of the pig sector on the sandy soils in the North Brabant region.

In this thesis the literature review and the six drivers of spatial concentration only focussed on the industrial dimension. *'An important aspect that has not been previously emphasized is that the effects of agglomeration extend over at least three different dimensions'* (Rosenthal and Strange, 2004, p. 2120). Besides the industrial dimensions, also the geographic and temporal scope influences the spatial concentration of the pig sector. The industrial 'natural advantage' of a spatially concentrated location has several links with the geographic scope of spatial concentration.

In the industrial scope the spatial lags are ignored (Rosenthal and Strange, 2004). In contrast to the geographic scope this is focussing on proximity between different industries. When agents are physically closer, then there is more potential for interaction, which is advantageous for spatial concentration (Rosenthal and Strange, 2004). The industrial scope is characterised by concentration advantages *within* industries, which has two advantages as already discussed by Brülhart and Mathys (2008). The first one, localisation economies, is concerning about advantages *within* an industry (natural advantage, labour market pooling, input sharing and knowledge spill- overs). The second one, urbanisation economies, regards all the economic activities *within* an urban region (home market effects and consumption opportunities).

This puts the effect of a 'natural advantage' of a location for the pig sector in a different perspective. The term 'natural advantage' is more applied as a 'geographic scope advantage' in this thesis. The choice for the different relocation regions in this thesis is based on *proximity* between different locations. This can be confirmed by looking at the 'natural advantages' a relocation region is chosen in thesis on: *proximity* of harbours, cereal supplies, *proximity* of vulnerable nature areas, *located nearby* other pig farms, infrastructural networks. 'Proximity' links to the geographic scope and not the natural advantage of a location itself in an industrial scope. Natural advantages are only partly included (e.g. cereal supplies) with regard to the environmental advantages of a location. Both scopes can cause spatial concentration, but in a different way.

It is very likely that the driver 'natural advantage' is replaced by the 'geographical scope' of spatial concentration, due to the regional scale the research is performed on. It is performed on a regional level

(NUTS2; Scope of geographical dimension) and not on a local level (NUTS3; Scope of natural advantage). Generally, information on the chosen NUTS2 regions is mostly about the distribution of different functions in the region. Less information could be found about the location and its specific local advantages.

However, it is partly possible to take in account the local 'natural advantages' of a (regional) NUTS2 region. The data (e.g. amount of pigs, land division, nitrogen components) in the model is NUTS2 specific, since MITERRA is working on this scale. Although, some MITERRA data, such as ammonia emission from pig stables is gathered on a local (NUTS3) scale. This local data (NUTS3) is transformed into regional data and is used to calculate the most important effects of ammonia volatilization on the environment on a regional level (NUTS2).

It should be mentioned that it is not possible to conclude whether relocating pigs is a natural advantage or natural disadvantage for a NUTS2 region in the current model. It is not known how much nitrogen the specific location already contains. Therefore, the current costs and benefits for the environment are somehow distorted. To find out what the critical load of nitrogen is for a specific NUTS2 region, it is necessary to implement critical load maps with respect to nitrogen (see figure 5.1). With these maps, on the one hand, it will be better specified until what level nitrogen is a natural advantage (benefit) for the environment in a NUTS2 region. On the other hand, this map also shows when the nitrogen level is exceeded and becomes a natural disadvantage (cost). The last situation applies currently for the Netherlands as shown in figure 5.1.

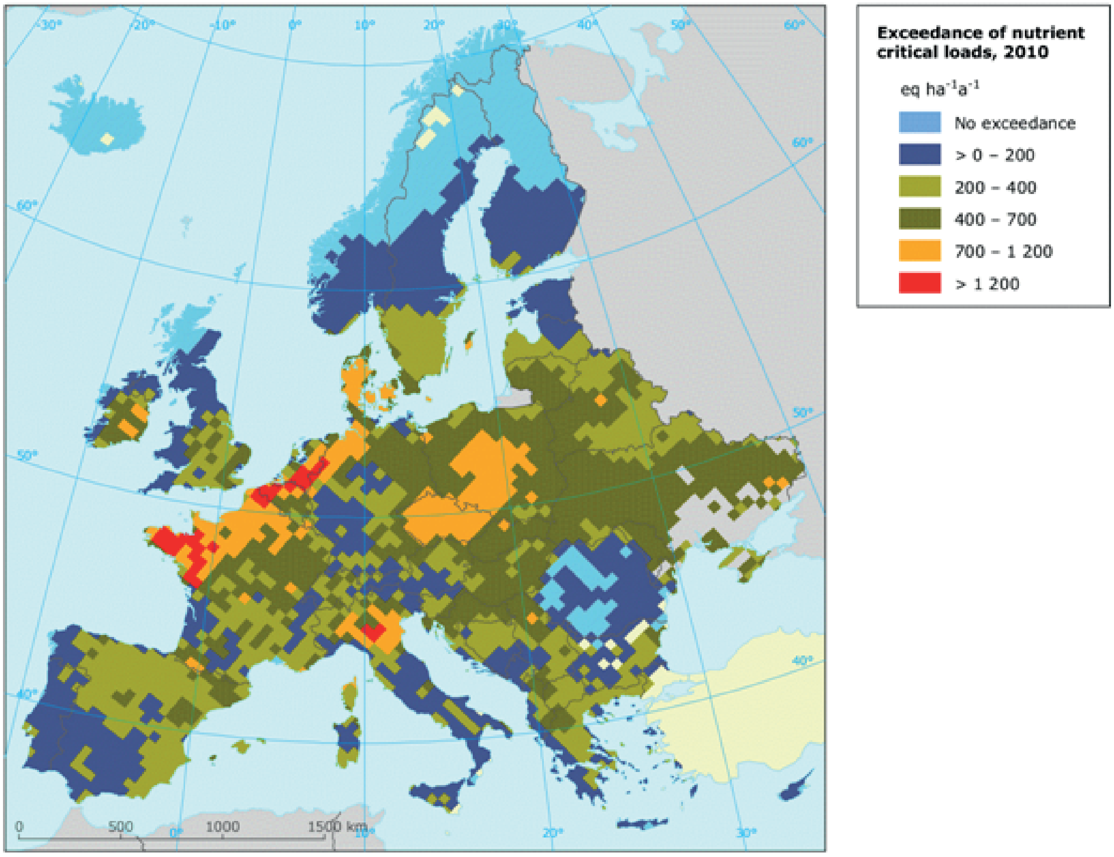


Figure 5.1: Example of a nitrogen critical load exceedance map (Source: www.eea.europa.eu, 2012)

The six drivers and importance of spatial concentration are clarified in this thesis. It is difficult to take these drivers into account in the model. This is due to the different level of scales used in the literature and used in the model. However, the phenomenon spatial concentration is not ignored in this thesis. Aspects that link to both the industrial and geographical scope of spatial concentration are included in the relocation model.

5.2 Effect of spatial concentration in the North Brabant pig sector

In this thesis a model is created to calculate the environmental external effects (costs for society as defined in this thesis) of the output of N-components into the environment. It is created in order to answer the second research question *'What is the effect of spatial concentration in the North Brabant pig sector on the environmental external costs?'*. Conventional models, such as NEMA and MITERRA, calculate the N-components ending up directly in the environment. This model calculates both nitrogen output and the costs of this output. This is innovative, because both in the scientific literature, as well as in mathematical modelling, there is relatively little research done on the environmental external (indirect) effects. The direct environmental effects received significant more attention in scientific research, in contrast to the indirect environmental effects.

As the results show spatial concentration leads to economies of scale for the pig sector. This entails a lower cost price per unit compared to other locations (Peerlings, 2014). The costs per unit decreases when more pigs (from 50.000 towards 400.000 pigs per region) are relocated in the NUTS2 regions (e.g. South Romania from 162,44 Euro per pig towards 67,67 Euro per pig). In North Brabant the costs per pig increases 4 eurocents, depending on relocating 150.000 (26,58 Euro) or 1.200.000 (26.63 Euro) pigs to other European countries. To compensate for the environmental damage the cost price of North Brabant (26,63 Euro per pig) is by far the least amount per pig, in comparison to the other three NUTS2 regions. This cost reduction is caused by spatial concentration drivers, such as input sharing, knowledge spill-overs and labour market pooling. These drivers make it possible to spread fixed costs over more units of output created by the pig sector due to its increasing scale. This confirms the lower cost price per unit compared to other locations for spatial concentration.

The main results of this model exactly show the complexity of the problem for the pig sector. A relocation of pigs results in benefits for Brabant. However, in total the relocation results in more damage and costs for the environment in the three NUTS2 regions. The crucial question for this model now is where is the right equilibrium to be found in this model? On the one hand, it is essential to find the right balance (break-even point) in North Brabant by decreasing the spatial concentration of the pig sector to decrease the risks linked to public health and the ecosystems. On the other hand, it is important to find the lowest total external environmental costs for the European Union after relocation.

To find the break-even point Abdalla et al. (1995), Bleumink (2007) and Velthof et al. (2007) argue that solving one aspect of a complex problem cannot solve the core of the problem (Abdalla et al., 1995; Bleumink, 2007; Velthof et al., 2007). This is one goal of the model developed in this thesis; integrating these complex problems [spatial relocation *and* the costs for the environment]. Therefore, it was inevitable to simplify several nitrogen processes to calculate the environmental external effect of spatial concentration. Moreover, some aspects are simplified due to time and data constraints. Some of these assumptions were necessary, but have a significant impact on the final result, as discussed below.

Firstly, it is assumed that pigs are relocated to three of the 172 NUTS2 regions. To specify the effect of relocation on the environment it is recommended to expand the model with the remaining NUTS2 regions. However, it should be noted, that the three regions are deliberately chosen considering the drivers of spatial concentration and the succession rate of relocating pigs in a certain NUTS region. Expansion of the model is definitely useful, but not all NUTS regions are equally suitable (thinking for example of the spatial drivers in combination with e.g. The Alps, Pyrenees and Scandinavian mountains).

Secondly, in the model there are considerable uncertainties in the predicted nitrate concentrations. First, this uncertainty is caused by the (unknown) rate of denitrification. Second, this is due to the reference depth at which is nitrate concentration is measured and/or simulated for the EU27. Third, nutrient losses are very location specific (Oenema et al., 1998; Oenema et al., 2008). The question remains in the scientific debate how good the indicators are to calculate nutrient loss from agriculture (Oenema et al., 2008). The data of Velthof et al. (2009) and the MITERRA model only consider the basic processes on nitrate leaching.

This is sufficient for this master thesis. However, when it is desirable to specify the model the simplified leaching losses may not represent the N concentrations in surface waters and groundwater (Velthof et al., 2007).

Thirdly, it is assumed in this model that pig manure is only applied on arable land (known as 'other agricultural land' in MITERRA). Firstly, of the total amount of pig manure 10 times the amount ends up on arable land, rather than on grassland (Van Bruggen et al., 2013). Secondly, Velthof et al. (2007, p. 77) state that there are '*major uncertainties are the areas and the yields of grassland*' in MITERRA. Only a small amount of pig manure is ending up on grassland and is therefore excluded in this research. Thereby, the simplification to arable land is necessary to determine other leading components in the model. In this case the percentage N from pig manure that is absorbed by the soil is such a component in the model. It is needed to determining the total amount of nitrate is damaging the environment.

Fourth, the choice to fix the values in relation to N-disposal (25) and the percentage N-leaching (26) has a significant influence on the total amount that is leaching to surface water and groundwater. Two reasons to fix these values; (i) they are subordinate to equations that calculate the 'change in manure' and 'change in N-leaching'; (ii) the main goal of this thesis is to make the model work. However, it is very likely, that when there is an increase of N-input into the soil, there is an increase in nitrogen output to the environment. This causes a suite of adverse impacts (Van Grinsven et al., 2013), which are currently not included in the model. Unfortunately, the data to calculate the change in N-leaching and N-disposal was not available. If the data and/or expertise are available it is recommended to review the fixed variables.

Fifth, in this model the pig sector only causes damage to the environment by ammonia volatilization and nitrate leaching (Van Grinsven et al., 2011). Therefore these two nitrogen components are chosen as the main dependent variables in the model. Although, in practice there are many more aspects of the pig sector that cause damage to the environment. It is possible to expand the model with extra features, such as cereal input, transport costs and other N-components (e.g. N2, N2O, NOx). However, during this thesis it was only possible to model the effect of the two main nitrogen components. If data, expertise en time is available it is recommended to expand the model, since this will probably specify the results significantly.

5.3 Effect of relocating Brabant pigs on the environmental costs for the EU

With the model the environmental external effects of relocating pigs are calculated for three different NUTS2 regions in Europe. This is done in order to answer the third research question *'What are the effects of spatial relocating the North Brabant pig sector in the European Union on the environmental external costs?'*. When Brabant pigs are relocated to other NUTS2 regions the damage to ecosystems and public health decrease for North Brabant. However, the total costs of relocating pigs increase for Europe.

It can be concluded on the results of this thesis that the environmental external costs are larger than the benefits, when the pig sector is spatially relocated in Europe. However, this can only be concluded for the current situation when pigs are relocated, because the industrial scope only discusses the static [current] development of spatial relocation. The dynamic aspect of spatial relocation is ignored in this thesis. The industrial and geographic scope are already discussed. The third, and last, scope of spatial concentration is the temporal scope. This temporal scope encounters the dynamic aspect of spatial concentration; *'The idea [of the temporal scope] is that if knowledge were to take time to accumulate, having a lot of activity a few years ago could directly influence today's [and future's] productivity'*(Rosenthal and Strange, 2004, p. 2139).

The results of this thesis, with regard to the relocation of pigs and the costs for the environment, only focus on one scenario, the static and current situation. As explained in chapter 3 the current emission factors for ammonia volatilization and nitrate leaching are used in the model. Only looking at the current situation, and ignoring the future situation probably has a major impact on the results. The temporal scope suggests looking at more scenarios, different time frames with relation to the dynamic component of spatial concentration (Rosenthal and Strange, 2004). It would be useful to come up with more scenarios, such as different future situations. It could be that the differences between countries in the European Union decrease in the future, this depends on the influence of different policies. Different policies, such as the CAP (Common Agricultural Policy), CFP (Common Fisheries Policy), but also the European Cohesion policy are embedded on contributing to e.g. economic and social cohesion in the European Union (FAO, 2013a). Such scenarios are not taken into account, but could be an important contribution with respect to specifying the results of this thesis.

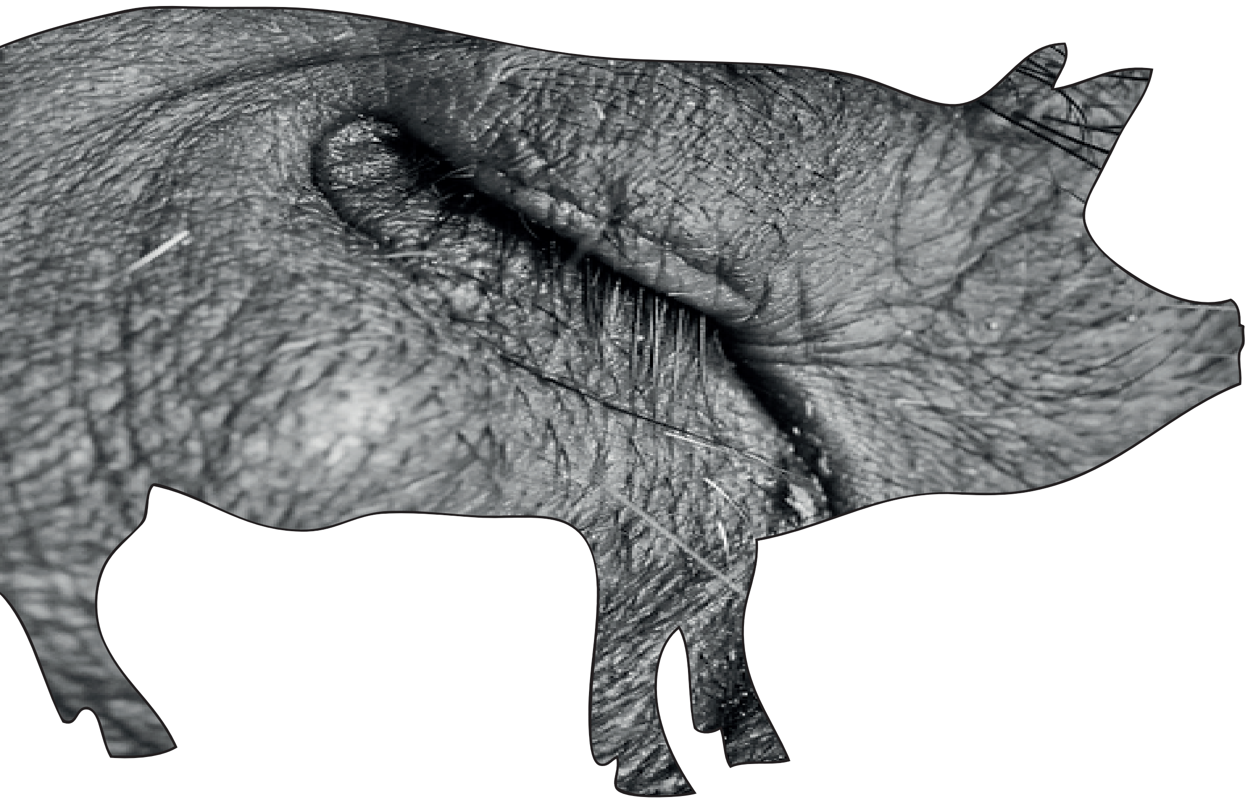
Because the temporal scope is dynamic, future scenarios of the effect of spatial concentration can take multiple forms and can affect the results of this thesis in multiple ways. This entails great uncertainties with it, besides a cost decrease also a cost increase could occur. Different dynamic scenario about the future could provide a better answer. However, to overcome the greatest uncertainties in the model an uncertainty analysis was done. This analysis shows that the damage factors have a major impact on the total costs and benefits relocating pigs in Europe. This large impact can be explained, because these are required to calculate the costs for each N-component. Other factors investigated in the uncertainty analysis influence only one N-component at a time.

The uncertainty that the temporal dynamic scope brings along in spatial concentration becomes even more evident when the theory of the temporal scope of Rosenthal and Strange (2004) is combined with the theory on spatial concentration of pigs of Wossink and Wefering (2003): *'Production externalities most often result from specific inputs that have the characteristics of joint inputs (animal, feed), as any quantity simultaneously produces the intended agricultural output (meat and the unintended externality; water quality problems). The combination in which these marketable outputs and negative externalities are generated is not fixed, but rather depends on the production method chosen [knowledge and choices made in the past influences today's and future's productivity (Rosenthal and Strange, 2004)] '* (Wossink and Wefering, 2003, p.4).

This citation shows the complexity of modelling the effect and costs of spatial relocating the pig sector in the European Union. The total environmental costs for the European Union of relocating pigs depend on different [dynamic] locations and with different [dynamic] 'production methods chosen'. Simultaneously, it is also an argument for the choices made with regard to inter alia stable types, application techniques, run off percentages in the different NUTS2 regions.

The main goal of this thesis is to provide an answer on the unknown effect of relocating spatially concentrated pigs, in which this thesis succeeded. Before this thesis it was not known what the effect of spatial relocating pigs into Europe on the environmental external costs was. Now it is known for the current situation that it costs the European Union more to relocate pigs, than it affords benefits for North Brabant with regard to the environment. However, it should be noticed that the choices and assumptions made in this thesis had a major effect on the final results. The mathematical model is a helpful tool for this complex problem in specifying and finding the right break-even point between relocating pigs of North Brabant and the costs for the environment in the European Union.

6. Conclusions



It was hypothesized that '*environmental external costs decrease when the North Brabant pig sector is relocated to other EU regions*'. In order to test the hypothesis a mathematical model was created. The results show that the environmental external costs decrease for the province of North Brabant when pigs are relocated in three NUTS2 regions in the European Union. These benefits for the environment are achieved with regard to public health and ecosystems. However, the total costs for the three NUTS2 regions, and therefore the European Union, are larger than the total benefits after relocation. It can be concluded on the results found during this thesis that the environmental external costs are larger than the benefits when the North Brabant pig sector is relocated in Europe. Therefore, the hypothesis should be rejected.

However, after analysing the literature and the results of this thesis it became clear that the impact of the choices made for the model are significant. Although, it was inevitable in the short period of time to simplify several nitrogen processes. This is done in order to make it possible to test the hypothesis of this thesis. To specify the results of this thesis it is essential is to find the right balance between concentrating pigs and the costs for the environment. On the one hand, it is important to reduce spatial concentration of the pig sector in North Brabant with regard to ecosystem and public health problems. On the other hand, it is necessary to reduce the environmental external costs of the pig sector in the European Union.

The scientific literature about the static industrial scope on spatial concentration provides sufficient information for this thesis in order to test the hypothesis. However, it is still necessary to specify several aspects in order to understand the effect of spatial relocation on the environment better. The scope of spatial concentration can be broadened as shown in the discussion and thereby offers new opportunities for research. Thereby, specifications and recommendations that emanate from the discussion can help in better defining this balance in the research and the mathematical model.

7. Recommendations

This thesis made a start in creating a model able to calculate the environmental costs when pigs are relocated in other NUTS2 regions in the European Union. The main N-components are included in the model. However, to have more insight in the environmental external effects created with relocation first some scientific and policy recommendations for further development of the mathematical model are given. Secondly, some policy recommendations are given.

7.1 Research recommendations

As a part of this research a model is developed, which is able to calculate the environmental external effects that are released into the environment when pigs are relocated throughout the EU27. In the short period of time different assumptions had to made and there are different uncertainties are discussed, which influence the final results. However, the main components have been identified and it is possible to calculate the main environmental costs of relocation. Thereby, a clear list of recommendations is provided to improve the model and thereby decrease the uncertainties:

1. Link the model with a critical load card in e.g. Arc-GIS would strengthen the results and put the environmental external costs more in perspective. The existing environment is treated as a 'black box' in the current model. Linking the existing environment by using a critical load card also visualises the room for manoeuvre with relation to nitrogen exceedance, this information can be found in EU environmental policy measures.
2. Export and the effect of export are partly included in the mathematical model. A part of the external costs is compensated by the decrease in pig manure in North Brabant and the increase of artificial fertilizer. This decreased amount of manure is converted into a benefit for Brabant. The setup of this model is included in Appendix V and it is recommended to expand the export model with missing data about the destination of this amount.
3. To have a better understanding of the model it is recommended extend the uncertainty analysis and add a sensitivity analysis. It is recommended to analyse parameters separately, also combinations of changing parameters are useful to test. As this gives insights in the importance of the different parameters, and thus on which parameters time is spent wisely to find the right balance in the least environmental costs and the amount of pigs that should relocated.
4. Of the different assumptions made, the assumptions on the N-disposal and percentage N-leaching initially need a reassessment. Since the N-disposal and percentage N-leaching variables are fixed, currently, these have major influence on the final amount N that is leaching into groundwater and surface water.
5. The pig sector is treated as one and the same unit, while in practice there is a major difference in e.g. nitrogen emissions with relation to breeding pigs, fattening pigs, boars and piglets. Unfortunately, the MITERRA database only provides information of the number of pigs per NUTS2 region; no subdivision is made or found in the different types of pigs. When information is available on the subdivision of pigs in the different NUTS2 regions, it is recommended to include this subdivision in the model.
6. There is more data available on ammonia emission during application, with relation to the application techniques and their emission factors (e.g. in the NEMA model; De Haan et al., 2009). If the distribution of application techniques is available of the other NUTS2 regions besides the Netherlands, this could also be a reliable way in determining the volatilization of ammonia during application in a certain region.
7. Currently the main outputs of the nitrogen cycle are included in the relocation model. To specify the mathematical model it is recommended to add other aspects, such as cereal input, because they fulfil an important role in the nitrogen cycle of the pig sector.

7.2 Policy recommendations

As the final results of the mathematical model show the external costs are mostly dependent on the amount of ammonia that volatilizes out of stables and nitrate leaching towards surface water. Some policy recommendations could be derived from these results:

1. Policies should focus on surface water regulations in relation to nitrate leaching. Nitrate leaching is very region dependent on specific soil types and the amount of pig slurry that is applied in this region.
2. EU-policies could give direction with regard to decreasing ammonia volatilization out of stables. The literature also mentions technical measurements can partly decrease the environmental external effects that occur from ammonia volatilization of the intensive pig sector.
3. It is recommended to use an integrative approach to find opportunities for a complex problem as the spatially concentrated pig sector in North Brabant. Relocation of pigs is one of the many integrated solutions, as well as related policy measurements. This thesis only focuses on environmental aspects and policy recommendations for the pig sector. Although, there are many more aspects that are important in the pig sector, such as animal welfare, public health, but also ageing in the Dutch pig sector and upscaling. Also these topics are important and could provide extra information to find new opportunities in solving the spatial concentration problems of the North Brabant pig sector.

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Appendices

Appendix I: Leaching and run off fractions of EU27 countries

Table A: Mean runoff fractions and mean leaching fractions for N losses to groundwater and small surface waters, and large surface waters (Velthof et al., 2009)

Country	Runoff fractions (% of applied fertilizer and manure N)	Leaching and denitrification fractions		
		Groundwater and small surface waters	Large surface waters	Denitrification
		% of N surplus, corrected for NH3 losses, and runoff		
Austria	3	9	0	91
Bulgaria	11	25	1	74
Belgium	5	31	2	67
Cyprus	3	14	0	86
Czech. Rep	9	31	1	68
Germany	4	20	1	79
Denmark	3	29	1	70
Estonia	5	23	4	73
Greece	2	8	0	92
Spain	3	14	0	85
Finland	1	3	2	96
France	3	18	1	82
Hungaria	5	17	3	81
Italy	4	17	1	82
Lithuania	8	35	4	62
Luxembourg	7	26	3	71
Latvia	5	24	4	72
Malta	3	14	0	86
Netherlands	3	26	4	70
Poland	5	19	2	79
Portugal	3	12	0	88
Romania	8	24	1	75
Sweden	1	5	1	94
Slovenia	3	13	1	86
Slovakia	5	22	1	77
United Kingdom	3	24	2	75

Appendix II: Data used linked to datasets

The MITERRA dataset is the main database used to calculate environmental costs for ammonia volatilization, nitrate leaching and run off to surface water and groundwater. The amount of NH3 when manure is applied (per pig, in kg N) could not be calculated with the MITERRA database. Therefore the data of NEMA (National (Dutch) Emission Model for Ammonia) is used. Table B shows which data is used to calculate NH3 and whereof it originates.

Table B: Numbers used to calculate environmental costs related to air
(Source: NEMA, 2012; Van Grinsven et al., 2013 and Webb et al., 2013)

General numbers to calculate NH3	
Excretion per pig (in kg N)	MITERRA (s15)
Volatilization stable per pig (in kg N)	MITERRA (s35)
Amount of NH3 when manure is applied, per pig (in kg N)	NEMA (0.32)
Damage factor air (in €) (see section 3.2.2)	Van Grinsven et al. (2013)
Application factor	Based on Webb et al. (2013)

In table C the data used to calculate the environmental damage of nitrate (NO3) runoff and leaching produced by the pig sector caused to surface water and groundwater is shown. The damage factors and run off percentages are adapted from Van Grinsven et al. (2013) and Velthof et al. (2007).

Table C Numbers used to calculate environmental costs related to air
Source: NEMA, 2012; Van Grinsven et al., 2013 and Webb et al., 2013)

General numbers to calculate No3- runoff and leaching	
Damage factor surface water and groundwater (in €) (see section 3.2.2)	Van Grinsven et al. (2013)
Runoff percentage (see section 3.2.2)	Velthof et al. (2009)
Manure (in 1000 kg N)	MITERRA (s62)
Fertilizer (in 1000 kg N)	MITERRA (s64)
Atmospheric deposition (in 1000 kg N)	MITERRA (s65)
Biological fixation (in 1000 kg N)	MITERRA (s66)
Surplus N, soil other agricultural land (in 1000 kg N)	MITERRA (s89)
Surplus N, soil grass land (in 1000 kg N)	MITERRA (s88)
Leaching large surface water (in 1000 kg N)	MITERRA (s112)
Leaching groundwater (in 1000 kg N)	MITERRA (s113)
Excretion N pigs housing (in 1000 kg N)	MITERRA (s15)
Applied N total (in 1000 kg N)	MITERRA (s68 until s71)

Appendix III: Damage factors

Table D: Marginal Cost and Benefits between 1995 and 2005 of different Nr-Threats in EU. (Source:Van Grinsven et al., 2013)

Effect	Emitted nitrogen form	Emission/ loss to	Estimated cost € (per kg N_r) emitted, used or produced [1])
Human health (particulate matter, NO_2 and O_3)	NO_x	Air	10 – 30 (18)
Crop damage (ozone)	NO_x	Air	1 – 2
Ecosystems (eutrophication, biodiversity)	N_r (nitrate) N_r deposition	Surface Water	5 – 20 (12)
Human health (particulate matter)	NH_3	Air	2 – 20 (12)
Climate (greenhouse gas balance)	N_2O	Air	4 – 17 (10)
Climate (secondary particulate matter)	NO_x	Air	-9 – 2 (-3)
Climate (secondary particulate matter)	NH_3,	Air	-3 – 0 (-1)
Ecosystems (eutrophication, biodiversity)	NH_3 and NO_x	Air	2 – 10 (2)
Human health (drinking water)	N_r (nitrate)	Groundwater	0 – 4 (1)
Human health (increased ultraviolet radiation from ozone depletion)	N_2O	Air	1 – 3 (2)
Climate (N-fertilizer production)	N_2O, CO_2	Air	0.03 – 0.3
Crop yield increase (benefit): 1st year Crop yield increase(benefit): long term	N-fertilizer	Soil	0.5 – 3 (1.7) 1.5 – 5 (3.7)

[1] Values in between brackets are the single values that were inferred from studies on individual effects, for details see SI and Brink et al

Appendix IV: Nitrogen application standards in the Netherlands

Table E: Nitrogen application standards for different types of arable crops in 2014-2017, in kg N per hectare (Source: http://www.mineralemeststoffen.nl)

Crop	Clay	Sandy*	Loess	Peat
Consumption potatoes	250	235	230	245
Seed potatoes	120	120	120	120
Starch potatoes	240	230	230	230
Sugar beet	150	145	145	145
Winter wheat	245	160	190	160
Spring wheat	150	140	140	140
Winter barley	140	140	140	140
Spring barley	80	80	80	80
Maize (with derogation)	160	140	140	150
Maize (without derogation)	160	140	140	150
Grass seed	185	140	140	150
Onion seed	165	150	150	155
Oil seedrape (winter)	205	190	190	195
Oil seedrape (spring)	120	120	120	120
Flax	70	70	70	70
Not legume fertilizers	60	50	50	60

Table F: Nitrogen application standards for different types of field-scale vegetables in 2014-2017, in kg N per hectare (Source: http://www.mineralemeststoffen.nl)

Crop	Clay	Sandy*	Loess	Peat
Spinache (first cultivation)	260	190	190	200
Spinache (follow cultivation)	185	145	145	150
Lettuce crops (first cultivation)	180	165	165	170
Lettuce crops (follow cultivation)	105	105	105	105
Endive (first cultivation)	180	170	170	170
Endive (follow cultivation)	90	90	90	90
Leek	245	225	225	235
Brussels sprouts	290	265	265	275
White cabbage	320	290	290	305
Cauliflower	230	210	210	220
Broccoli	270	235	235	245
Production strawberries	170	155	155	160
Asparagus	85	75	75	80
Winter and baby carrots	110	110	110	110
Chicory roots	100	100	100	100

**For the southern sandy and loess soils a discount of 20% is introduced per 1 January 2015 on the nitrogen application standards for arable and horticultural crops sensitive to leaching (including maize crops)*

Appendix V: Setup manure export model

During this thesis a start is made with modeling the export of manure from North Brabant to elsewhere. Since this amount is significant it is recommended to specify this model and integrate it with the main model. Due to time constraints and the lack of data this thesis has not succeeded in finishing this sub model. The main formula to calculate the export savings for North Brabant is as following (31):

$$Export_{sav} = Ben_{exp} - Costs_{exp} \quad (31)$$
$$Ben_{exp} = Ben_{vol\_app} + Ben_{run\_sur\_water} + Ben_{lea\_sur\_water} + Ben_{lea\_gr\_water} \quad (32)$$
$$Costs_{exp} = Costs_{fert\_vol\_app} + Costs_{fert\_run\_sur\_water} + Costs_{fert\_lea\_sur\_water} + Costs_{fert\_lea\_gr\_water} \quad (33)$$

Where:

$Export_{sav}$ = Total savings by export reduction in 'other provinces' (in €)
Ben_{exp} = Total benefits by exports reduction in 'other provinces' (in €)
$Costs_{exp}$ = Total costs due to increased fertilizer use in the Netherlands (in €)

The main structure of the export model and the associated formulas is visualized in figure AI. The following provinces are referred to, when the term 'other provinces' is mentioned; Groningen, Friesland, Drenthe, Flevoland, North Holland, South Holland and Zealand. These provinces import manure, instead of export as derived from the MITERRA model, column S56. Provinces such as North Brabant, Limburg, Gelderland, Overijssel and Utrecht export manure. In view of the mostly negative economic value of liquid manure, there is no economic incentive to import more manure into provinces, such as North Brabant, Limburg, Overijssel and Gelderland (Van Dam et al., prep.).

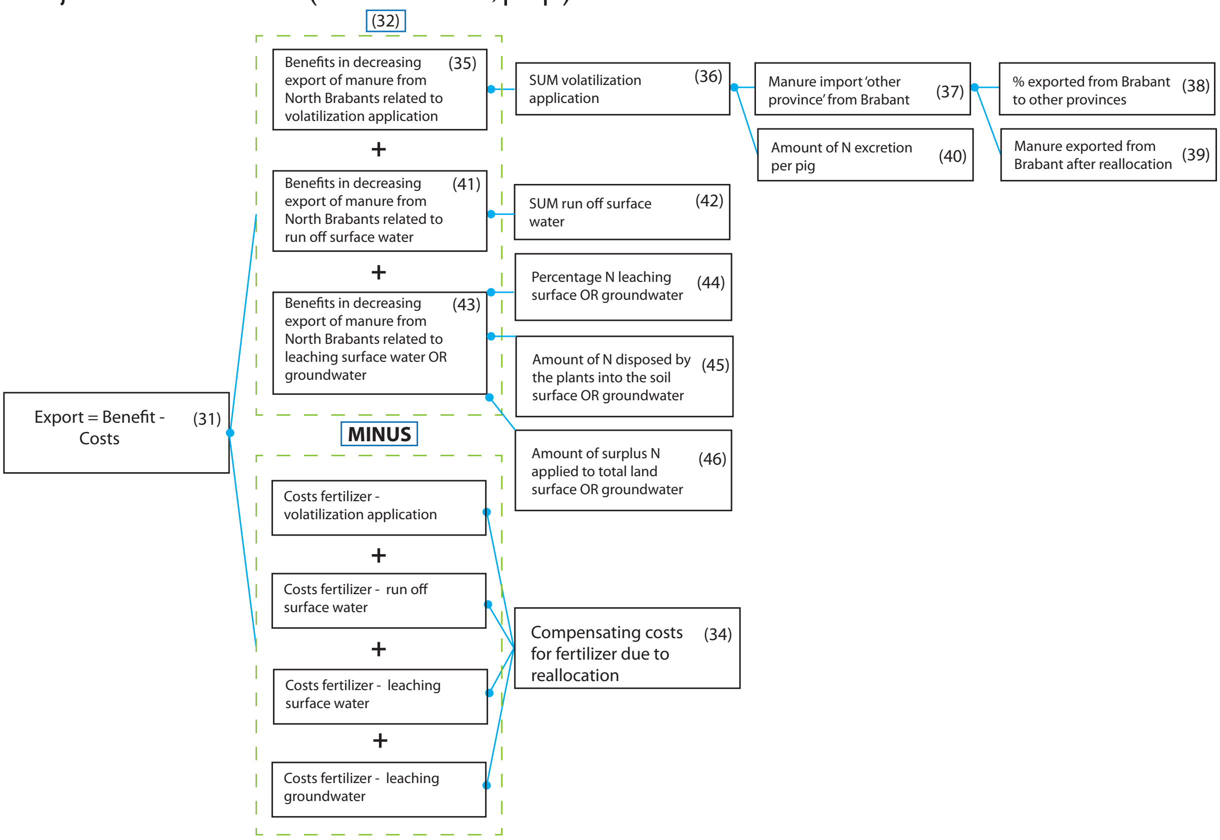

Figure A1: Export model and associated formulas visualized

The benefits of the decrease in manure import and the associated nitrogen emissions in the Netherlands (32) are calculated for the volatilization of application (Ben_{vol_app}, (35)), the benefits in relation to run off of nitrogen in surface water ($Ben_{run\_sur\_water}$ (41)), leaching of nitrogen to surface water ($Ben_{lea\_sur\_water}$(43)) and to the groundwater ($Ben_{lea\_gr\_water}$ (43)). The amount that volatizes in stables is already included in the main relocation model in 'before' and 'after' reallocating in North Brabant.

It is likely that the absence of manure, due to the reallocated pigs, and therefore the vacant space for nitrogen will be replaced by artificial fertilizer. The EU Nitrate directive has set a maximum application rate of 170 kg nitrogen from manure per hectare arable land. For many crops this amount of N is needed to achieve maximum yield (as shown in appendix IV), therefore it is assumed that the missing amount of N in the other provinces of the Netherlands will be supplemented with artificial fertilizers. These artificial fertilizer do cost money, the exact amount is calculated with (33) (the costs of $Costs_{fert\_vol\_app}$, $Costs_{fert\_run\_sur\_water}$, $Costs_{fert\_lea\_sur\_water}$ and $Costs_{fert\_lea\_gr\_water}$). Costs of each aspect (volatilization, run off or leaching) are calculated as following:

$$Costs_{exp} = (SUM_{asp\_N} * 0.6) * D \qquad (34)$$

Where:
$Costs_{exp}$ = Costs made by exporting manure to other EU NUTS2 regions (in €)
SUM_{asp_N} = Sum of aspect (volatilization, run off or leaching) (in kg N)
D = Damage factor (in €) (depending on aspect)

Generally, for pig slurry a fertilizer coefficient of 60% applies on arable land, in comparison to artificial fertilizer (100%) (Minerale Meststoffen Federatie, 2013). The factor 0.6 is included in formula (34) and should be compensated until 100% with artificial fertilizers due to the loss of exported pig manure. This extra amount of fertilizers could be labelled as costs for the 'other provinces'.

Volatilization application export manure North Brabant
To calculate the volatilization of nitrogen that disappears due to export of manure, the main formula (35), further explained in (36) is needed to calculate the benefits of the decrease in manure due to reallocation of pigs in other NUTS2 regions in Europe. The exact amount of manure imported from North Brabant (37) is necessary to calculate the benefits, as well as (38), which calculates the percentage per 'other province' and the total amount of manure exported (39) from Brabant. Lastly, the amount of manure excreted per pig specifies the calculation (these formulas are visualised in figure B1):

$$Ben_{vol\_app} = SUM_{vol\_app\_prov} * D_{air} \qquad (35)$$
$$SUM_{vol\_app\_prov} = (M_{imp\_NB} / P_{excr\_pig}) * Vol_{pig} \qquad (36)$$

$$M_{imp\_NB} = Perc_{imp} * M_{exp\_NB} \qquad (37)$$
$$Perc_{imp} = Man_{imp\_prov} / Man_{imp\_tot} \qquad (38)$$
$$M_{exp\_NB} = MB - MA \qquad (39)$$

$$P_{excr\_pig} = MB / P_{before\_NB} \qquad (40)$$

Where:
Ben_{vol_app} = Total benefits by reduction in volatilization application in 'other provinces' (in €)
$SUM_{vol\_app\_prov}$ = Total volatilization application of manure exported to the EU (in kg N)
P_{excr_pig} = Excretion per pig (in kg N)
Vol_{pig} = Volatilization per pig (in kg N)
M_{imp_NB} = Manure imported in province from North Brabant (in kg N)
$Perc_{imp}$ = Total amount of manure exported from North Brabant to the other provinces (in %)
Man_{imp_prov} = Manure imported in provinces (in 1000 kg N) (MITERRA S56)
M_{exp_NB} = Manure exported from North Brabant after reallocation (in kg N)
MB = Amount of manure before reallocation in North Brabant (in kg)
MA = Amount of manure after reallocation in North Brabant (in kg)
P_{before_NB} = Number of pigs before reallocation in North Brabant
D_{air} = Damage factor air (in €)

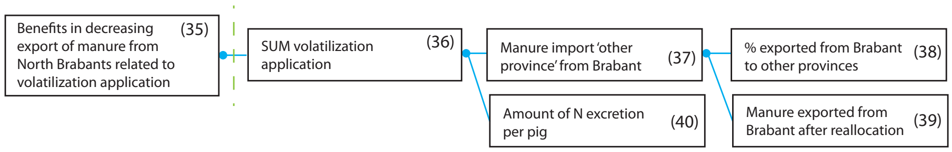

Figure B1: Formulas and their links with regard to export of manure and the effect on volatilization for the rest of the Netherlands

Run off surface water export manure North Brabant

The run off to surface water is calculated the same as in the main reallocation model. Although, the export model calculates the benefits per 'other province', (41) and (42), gained by reallocating pigs from North Brabant in other EU countries. The structure of the formulas is visualized in figure C1;

$$Ben_{run\_sur\_water} = SUM_{run\_sur\_water} * D_{sur\_water} \quad (41)$$
$$SUM_{run\_sur\_water} = M_{imp\_NB} * N_{run\_sur\_water} \quad (42)$$

Where:

$Ben_{run\_sur\_water}$ = Total benefits by reduction in run off to surface water in 'other provinces' (in €)
$SUM_{run\_sur\_water}$ = Total surface water run off of manure exported to the EU (in kg N)
M_{imp_NB} = Manure imported in province from North Brabant (in 1000 kg N)
$N_{run\_sur\_water}$ = Runoff fraction nitrate to surface water (in %)
D_{sur_water} = Damage factor surface water (in €)

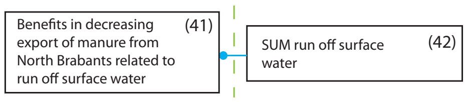

Figure C1: Formulas and their links with regard to export of manure and the effect on run off for the rest of the Netherlands

Leaching surface water or groundwater export manure North Brabant

As with the formulas with regard to run off to the surface water of nitrogen, the same applies to the formulas in relation to leaching of nitrogen to surface water and groundwater. The formulas used in the export model are the same as in the main model (highlighted in figure D1), only specified with data of the NUTS2 regions labelled as 'other provinces':

$$Ben\ (sur\ OR\ gr)_{lea\_water} = N\ (sur\ OR\ gr)_{lea\_water\_i} * PercN\ (sur\ OR\ gr)_{lea\_water\_i} * PercN_{soil} \quad (43)$$
$$PercN\ (sur\ OR\ gr)_{lea\_water\_i} = N\ (sur\ OR\ gr)_{lea\_water\_i} / N_{sp\_tot\_i} \quad (44)$$
$$PercNsoil = N_{sp\_other\_i} / (MB_{other\_i} + Fert_{other\_i} + Dep_{other\_i} + Fix_{other\_i}) \quad (45)$$
$$N_{sp\_tot\_i} = N_{sp\_grass\_i} + N_{sp\_other\_i} \quad (46)$$

Where:

Ben_{lea_water} = Total benefits by reduction in run off to surface water in 'other provinces' (in €)
(sur OR gr) = Surface water OR groundwater (formula is the same for both elements)
$PercN_{soil}$ = Amount of N disposed by the plants into the soil (in %)
MB_{other_i} = Input manure other agricultural land in NUTS i (in 1000 kg N)
$Fert_{other\_i}$ = Input fertilizer other agricultural land in NUTS i (in 1000 kg N)
Dep_{other_i} = Input atmospheric deposition other agricultural land in NUTS i (in 1000 kg N)
Fix_{other_i} = Input biological fixation other agricultural land in NUTS i (in 1000 kg N)
$PercN_{lea\_water\_i}$ = N leaching nitrate to surface water/groundwater (in %)
$N_{lea\_water\_i}$ = Total amount of N leaching to surface water/groundwater (in million kg N)
$N_{sp\_tot\_i}$ = Surplus N soil total agricultural land after reallocation (in 1000 kg N)
$N_{sp\_grass\_i}$ = Surplus N grassland (in 1000 kg N)
$N_{sp\_other\_i}$ = Surplus N soil other agricultural land after reallocation (in 1000 kg N)

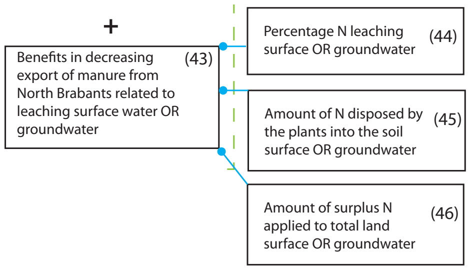

Figure D1: Formulas and their links with regard to export of manure and the effect on leaching for the rest of the Netherlands

Appendix VI: Detailed results cost-benefit analysis

	Total environmental costs	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water	Total Environmental costs
	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)
Before reallocation (in North-Brabant)	€ 145,93	€ 78,19	€ 23,47	€ 16,72	€ 20,09	€ 7,47	€ 145,93
After reallocating (in North-Brabant)	€ 141,94	€ 75,95	€ 22,80	€ 16,24	€ 19,65	€ 7,31	€ 141,94
Before reallocation Germany - Sachsen	€ 55,70	€ 18,89	€ 5,48	€ 3,50	€ 25,27	€ 2,55	€ 55,70
After reallocating Germany - Sachsen	€ 62,25	€ 20,44	€ 5,93	€ 3,78	€ 29,15	€ 2,95	€ 62,25
Before reallocation Romania - South	€ 65,77	€ 33,90	€ 10,86	€ 14,15	€ 6,55	€ 0,32	€ 65,77
After reallocating Romania - South	€ 73,89	€ 35,30	€ 11,30	€ 14,73	€ 11,97	€ 0,59	€ 73,89
Before reallocation Italy - Tuscany	€ 5,24	€ 2,44	€ 0,91	€ 0,53	€ 1,31	€ 0,07	€ 5,24
After reallocating Italy - Tuscany	€ 7,67	€ 3,64	€ 1,36	€ 0,78	€ 1,74	€ 0,15	€ 7,67
Benefits for North Brabant	€ 3,99	€ 2,24	€ 0,67	€ 0,48	€ 0,43	€ 0,16	€ 3,99
Costs for Sachsen	€ -6,55	€ -1,54	€ -0,45	€ -0,29	€ -3,88	€ -0,39	€ -6,55
Costs for Romania - South	€ -8,12	€ -1,40	€ -0,45	€ -0,58	€ -5,42	€ -0,27	€ -8,12
Costs for Tuscany	€ -2,43	€ -1,20	€ -0,45	€ -0,26	€ -0,43	€ -0,09	€ -2,43
Total for all NUTS regions	€ -17,10	€ -4,14	€ -1,34	€ -1,13	€ -9,74	€ -0,75	€ -17,10
Total	€ -13,12	€ -1,90	€ -0,67	€ -0,65	€ -9,30	€ -0,59	€ -13,12

Figure E1: Detailed costs when 150.000 pigs in total are reallocated

	Total environmental costs	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water	Total Environmental costs
	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)
Before reallocation (in North-Brabant)	€ 145,93	€ 78,19	€ 23,47	€ 16,72	€ 20,09	€ 7,47	€ 145,93
After reallocating (in North-Brabant)	€ 137,96	€ 73,71	€ 22,12	€ 15,76	€ 19,22	€ 7,15	€ 137,96
Before reallocation Germany - Sachsen	€ 55,70	€ 18,89	€ 5,48	€ 3,50	€ 25,27	€ 2,55	€ 55,70
After reallocating Germany - Sachsen	€ 64,88	€ 21,98	€ 6,38	€ 4,07	€ 29,47	€ 2,98	€ 64,88
Before reallocation Romania - South	€ 65,77	€ 33,90	€ 10,86	€ 14,15	€ 6,55	€ 0,32	€ 65,77
After reallocating Romania - South	€ 76,60	€ 36,69	€ 11,75	€ 15,31	€ 12,23	€ 0,61	€ 76,60
Before reallocation Italy - Tuscany	€ 5,24	€ 2,44	€ 0,91	€ 0,53	€ 1,31	€ 0,07	€ 5,24
After reallocating Italy - Tuscany	€ 10,16	€ 4,84	€ 1,81	€ 1,04	€ 2,29	€ 0,18	€ 10,16
Benefits for North Brabant	€ 7,98	€ 4,48	€ 1,34	€ 0,96	€ 0,87	€ 0,32	€ 7,98
Costs for Sachsen	€ -9,18	€ -3,09	€ -0,90	€ -0,57	€ -4,20	€ -0,42	€ -9,18
Costs for Romania - South	€ -10,83	€ -2,80	€ -0,90	€ -1,17	€ -5,68	€ -0,28	€ -10,83
Costs for Tuscany	€ -4,92	€ -2,40	€ -0,90	€ -0,52	€ -0,99	€ -0,12	€ -4,92
Total for all NUTS regions	€ -24,92	€ -8,29	€ -2,69	€ -2,26	€ -10,87	€ -0,82	€ -24,92
Total	€ -16,95	€ -3,81	€ -1,34	€ -1,30	€ -10,00	€ -0,50	€ -16,95

Figure F1: Detailed costs when 300.000 pigs in total are reallocated

	Total environmental costs	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water	Total Environmental costs
	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)
Before reallocation (in North-Brabant)	€ 145,93	€ 78,19	€ 23,47	€ 16,72	€ 20,09	€ 7,47	€ 145,93
After reallocating (in North-Brabant)	€ 129,97	€ 69,23	€ 20,78	€ 14,80	€ 18,34	€ 6,82	€ 129,97
Before reallocation Germany - Sachsen	€ 55,70	€ 18,89	€ 5,48	€ 3,50	€ 25,27	€ 2,55	€ 55,70
After reallocating Germany - Sachsen	€ 70,12	€ 25,07	€ 7,28	€ 4,64	€ 30,09	€ 3,04	€ 70,12
Before reallocation Romania - South	€ 65,77	€ 33,90	€ 10,86	€ 14,15	€ 6,55	€ 0,32	€ 65,77
After reallocating Romania - South	€ 82,01	€ 39,49	€ 12,65	€ 16,48	€ 12,75	€ 0,63	€ 82,01
Before reallocation Italy - Tuscany	€ 5,24	€ 2,44	€ 0,91	€ 0,53	€ 1,31	€ 0,07	€ 5,24
After reallocating Italy - Tuscany	€ 15,09	€ 7,24	€ 2,70	€ 1,56	€ 3,35	€ 0,23	€ 15,09
Benefits for North Brabant	€ 15,96	€ 8,96	€ 2,69	€ 1,92	€ 1,75	€ 0,65	€ 15,96
Costs for Sachsen	€ -14,42	€ -6,18	€ -1,79	€ -1,14	€ -4,82	€ -0,49	€ -14,42
Costs for Romania - South	€ -16,24	€ -5,60	€ -1,79	€ -2,34	€ -6,20	€ -0,31	€ -16,24
Costs for Tuscany	€ -9,84	€ -4,80	€ -1,79	€ -1,04	€ -2,05	€ -0,17	€ -9,84
Total for all NUTS regions	€ -40,50	€ -16,57	€ -5,38	€ -4,52	€ -13,07	€ -0,96	€ -40,50
Total	€ -24,54	€ -7,61	€ -2,69	€ -2,60	€ -11,32	€ -0,31	€ -24,54

Figure G1: Detailed costs when 600.000 pigs in total are reallocated

	Total environmental costs	Volatilization stables	Volatilization application	Runoff surface water	Leaching surface water	Leaching ground water	Total Environmental costs
	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)	(in million €)
Before reallocation (in North-Brabant)	€ 145,93	€ 78,19	€ 23,47	€ 16,72	€ 20,09	€ 7,47	€ 145,93
After reallocating (in North-Brabant)	€ 113,98	€ 60,27	€ 18,09	€ 12,89	€ 16,57	€ 6,16	€ 113,98
Before reallocation Germany - Sachsen	€ 55,70	€ 18,89	€ 5,48	€ 3,50	€ 25,27	€ 2,55	€ 55,70
After reallocating Germany - Sachsen	€ 80,51	€ 31,25	€ 9,07	€ 5,79	€ 31,25	€ 3,16	€ 80,51
Before reallocation Romania - South	€ 65,77	€ 33,90	€ 10,86	€ 14,15	€ 6,55	€ 0,32	€ 65,77
After reallocating Romania - South	€ 92,84	€ 45,09	€ 14,44	€ 18,82	€ 13,80	€ 0,68	€ 92,84
Before reallocation Italy - Tuscany	€ 5,24	€ 2,44	€ 0,91	€ 0,53	€ 1,31	€ 0,07	€ 5,24
After reallocating Italy - Tuscany	€ 24,78	€ 12,04	€ 4,50	€ 2,60	€ 5,32	€ 0,33	€ 24,78
Benefits for North Brabant	€ 31,96	€ 17,92	€ 5,38	€ 3,83	€ 3,52	€ 1,31	€ 31,96
Costs for Sachsen	€ -24,81	€ -12,35	€ -3,59	€ -2,29	€ -5,98	€ -0,60	€ -24,81
Costs for Romania - South	€ -27,07	€ -11,20	€ -3,59	€ -4,67	€ -7,25	€ -0,36	€ -27,07
Costs for Tuscany	€ -19,54	€ -9,60	€ -3,59	€ -2,07	€ -4,01	€ -0,27	€ -19,54
Total for all NUTS regions	€ -71,41	€ -33,15	€ -10,76	€ -9,03	€ -17,24	€ -1,23	€ -71,41
Total	€ -39,45	€ -15,23	€ -5,38	€ -5,20	€ -13,72	€ 0,08	€ -39,45

Figure H1: Detailed costs when 1.200.000 pigs in total are reallocated

Appendix VII: Detailed results of export of manure

	Total volatilization application manure (in kg N)	Total run off surface water (in kg N)	Total leaching surface water (in kg N)	Total leaching ground water (in kg N)	Total costs and benefits due to export (in €)
Manure of exported pigs (North Brabant) (in kg N)	48.024	39.910	43.402	92.146	
Fertilizer compensation	0	23.946	26.041	55.287	
Damage factor (Van Grinsven et al., 2013)	14	12	12	1	
Benefit manure	€ 672.333	€ 478.922	€ 520.827	€ 92.146	€ 1.764.227
Cost fertilizer	€ 0	€ 287.353	€ 312.496	€ 55.287	€ 655.137
Total savings by export per category (in €)	€ 672.333	€ 191.569	€ 208.331	€ 36.858	€ 1.109.090

Figure II: External costs 150.000 pigs manure export

	Total volatilization application manure (in kg N)	Total run off surface water (in kg N)	Total leaching surface water (in kg N)	Total leaching ground water (in kg N)	Total costs and benefits due to export (in €)
Manure of exported pigs (North Brabant) (in kg N)	192.095	159.641	173.609	368.583	
Fertilizer compensation	0	95.784	104.165	221.150	
Damage factor (Van Grinsven et al., 2013)	14	12	12	1	
Benefit manure	€ 2.689.331	€ 1.915.688	€ 2.083.306	€ 368.583	€ 7.056.908
Cost fertilizer	€ 0	€ 1.149.413	€ 1.249.984	€ 221.150	€ 2.620.546
Total savings by export per category (in €)	€ 2.689.331	€ 766.275	€ 833.322	€ 147.433	€ 4.436.362

Figure JI: External costs 600.000 pigs manure export

	Total volatilization application manure (in kg N)	Total run off surface water (in kg N)	Total leaching surface water (in kg N)	Total leaching ground water (in kg N)	Total costs and benefits due to export (in €)
Manure of exported pigs (North Brabant) (in kg N)	384.190	319.281	347.218	737.166	
Fertilizer compensation	0	191.569	208.331	442.300	
Damage factor (Van Grinsven et al., 2013)	14	12	12	1	
Benefit manure	€ 5.378.662	€ 3.831.377	€ 4.166.612	€ 737.166	€ 14.113.816
Cost fertilizer	€ 0	€ 2.298.826	€ 2.499.967	€ 442.300	€ 5.241.093
Total savings by export per category (in €)	€ 5.378.662	€ 1.532.551	€ 1.666.645	€ 294.866	€ 8.872.723

Figure KI: External costs 1.200.000 pigs manure export

Appendix VIII: Detailed uncertainty analysis

Regions	Before reallocating (NB) (in million €)	After reallocating (NB) (in million €)	Before reallocation (GER) (in million €)	After reallocating (GER) (in million €)	Before reallocation (ROM) (in million €)	After reallocating (ROM) (in million €)	Before reallocation (IT) (in million €)	After reallocating (IT) (in million €)	Total benefits (in million €)	Costs after reallocation (in million €)	Total costs (in million €)
Application factor (Webb et al., 2013)											
Total costs (in million €) (1,5)	€ 145,93	€ 137,96	€ 54,33	€ 63,29	€ 63,06	€ 73,66	€ 5,02	€ 9,71	€ 7,98	€ 24,25	€ -16,28
Total costs (in million €) (2)	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total costs (in million €) (3)	€ 145,93	€ 137,96	€ 58,44	€ 68,08	€ 71,20	€ 82,47	€ 5,70	€ 11,06	€ 7,98	€ 26,27	€ -18,29
Damage factor (Van Grinsven et al., 2013)											
Total costs (in million €) (4-5-0)	€ 44,38	€ 41,95	€ 18,95	€ 22,08	€ 21,41	€ 25,32	€ 1,72	€ 3,29	€ 2,43	€ 8,61	€ -6,18
Total costs (in million €) (14-12-1)	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total costs (in million €) (30-20-4)	€ 309,06	€ 292,24	€ 110,41	€ 128,60	€ 131,68	€ 152,14	€ 10,49	€ 20,52	€ 16,82	€ 48,68	€ -31,86
Uncertainty range - Emission factor application (Van Oorschot, 2001)											
Total costs (in million €) -50%	€ 134,20	€ 126,89	€ 52,96	€ 61,69	€ 60,34	€ 70,72	€ 4,79	€ 9,26	€ 7,30	€ 23,58	€ -16,28
Total costs (in million €) 0	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total costs (in million €) +50%	€ 157,67	€ 149,02	€ 58,44	€ 68,08	€ 71,20	€ 82,47	€ 5,70	€ 11,06	€ 8,65	€ 26,27	€ -17,62
Emission application rate (De Haan et al., 2009)											
Total costs (in million €) 0,23	€ 139,32	€ 131,72	€ 54,16	€ 63,09	€ 62,71	€ 73,29	€ 4,99	€ 9,65	€ 7,60	€ 24,17	€ -16,57
Total costs (in million €) 0,32	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total costs (in million €) 0,46	€ 156,18	€ 147,62	€ 58,10	€ 67,67	€ 70,51	€ 81,73	€ 5,64	€ 10,95	€ 8,56	€ 26,10	€ -17,54
Uncertainty range - Emission factor stables (Van Oorschot, 2001)											
Total costs (in million €) -25%*	€ 126,39	€ 119,53	€ 50,98	€ 59,39	€ 57,30	€ 67,42	€ 4,63	€ 8,95	€ 6,86	€ 22,85	€ -16,00
Total costs (in million €) 0	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total costs (in million €) +25%*	€ 165,48	€ 156,38	€ 60,43	€ 70,38	€ 74,24	€ 85,77	€ 5,85	€ 11,37	€ 9,10	€ 27,00	€ -17,90
Run off percentages (Velthof et al., 2009)											
Total costs (in million €) -2% (absolute)	€ 134,79	€ 127,45	€ 53,95	€ 62,85	€ 62,23	€ 72,77	€ 4,98	€ 9,64	€ 7,34	€ 24,09	€ -16,75
Total costs (in million €) 0	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total costs (in million €) +2%	€ 157,08	€ 148,46	€ 57,45	€ 66,92	€ 69,31	€ 80,43	€ 5,51	€ 10,68	€ 8,62	€ 25,76	€ -17,15
All uncertainty ranges											
Total best case scenario	€ 30,80	€ 29,15	€ 15,89	€ 18,52	€ 15,58	€ 19,00	€ 1,27	€ 2,40	€ 1,65	€ 7,18	€ -5,54
Total medium case scenario	€ 145,93	€ 137,96	€ 55,70	€ 64,88	€ 65,77	€ 76,60	€ 5,24	€ 10,16	€ 7,98	€ 24,92	€ -16,95
Total worst case scenario	**€ 394,67**	**€ 372,94**	**€ 138,14**	€ 160,86	€ 184,81	€ 209,66	€ 14,67	€ 28,81	€ 21,73	€ 61,72	€ -39,99

Appendix IV: Mathematical model

Appendix V: MITERRA output file

“Those who say it cannot be done, should not interrupt those doing it”

George Bernard Shaw