Master Thesis

Exploring the potential of manure-based energy production in Salland

by

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Exploring the potential of manure-based energy production in Salland

The development of an agent-based model to explore the potential for manure-based energy production in Salland, a region within the province of Overijssel, the Netherlands.

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Summary

As goals are set to increase the share of renewable energy production within the province of Overijssel, the Netherlands, the project group Groen Gas Salland is founded and has taken the initiative to explore the opportunities of green gas production through a biogas infrastructure within the region of Salland. Since within the region of Salland (intensive) livestock farming is practised, it is assumed that the utilisation of manure for the production of green gas by means of the anaerobic digestion process has a considerable potential.

Many challenges are faced with respect to the development of a biogas infrastructure, which constitutes a rather new concept within the Netherlands. A biogas network is not regulated within the Dutch Gas Act, leaving uncertainties with respect to its governance. Furthermore, it is expected that the SDE+ subsidy, which is developed to stimulate the production of renewable energy, is essential as production without subsidy is not considered feasible. This SDE+ subsidy, however, is regulated by a complex piece of legislation, which has been subject to change and consequently more uncertainties are generated.

Biogas producers are considered vital for the development of a biogas infrastructure and as it is assumed that the utilisation of manure constitutes a considerable potential, local farmers are confronted with a decision to be involved in energy production. In addition, due to the innovative character of this concept, it is unclear what the prospects for local green gas production are. Farmers are not naturally involved in energy production: they are mainly concerned with livestock farming. It may therefore not come as a surprise that these actors hesitate to participate in local renewable energy production and this is considered a serous problem.

To comprehend whether the manure can be made available for energy production, it is necessary to learn how manure is currently used and valued by the local farmers within Salland. As manure contains valuable minerals, it is currently used as fertiliser. Due to intensive livestock farming the manure production exceeds the local demand for manure-based fertilisers, which is considered a problem as this (local) abundance of manure urges for a manure distribution system of which the costs are high. Furthermore, circumstances within the (intensive) livestock farming sector are changing especially due to the amendment of policies that monitor farming activities. Changes within these institution rules and especially the perceptions that these changes occur unpredictably, affect the decision making of local farmers and will influence the condition that underlie the manure distribution system.

With respect to the described issues, the main research question to be answered in this thesis is therefor:

Considering the evolving manure distribution system in Salland, what is the potential for manure-based energy production?

The system under study comprises many actors situated within a dynamic institutional environ-

ment. These individuals are considered autonomous and unique with respect to their decision making behaviour. In addition, they are influenced by many different factors and since they have different ways of interacting with each other, it will become clear that - due to these local interactions - the system can emerge in many possible ways, giving rise to a wide variety of possible system behaviours or patterns from bottom-up.

The evolving manure distribution system is complex as changes in the institutions result in different behaviours by the farmers. The introduction of manure-based energy production will only further complicate this evolving social system. To explore the factors that influence the adoption of manure-based energy production, we developed an agent-based model to allow the system to emerge from bottom-up.

Within an agent-based model, agents act according to simple local rules, but generate - due to interaction - a certain coherent, systematic behaviour involving multiple agents. Due to the fact that we were able to simulate the model many times, we were able to vary model settings to explore the effects of different factors.

MAIA

To develop the agent-based model we used the MAIA framework, which is designed by Amineh Ghorbani and supports the use of institutions as a major structure for conceptualising systems for agent-based social simulation. Within this methodology, agents form the key concepts of the modelled system and they are placed within a context comprised of physical and social components. Within this respect, agents should be viewed as intelligent entities with capabilities defined in an operational environment. We used the MAIA concepts to conceptualise and decompose a system for agent-based modelling. The MAIA concepts are organised in five structures:

Collective structure Within this structure actors are defined as agents and their attributes are captured.

Constitutional structure This structure captures the institutional statements and defines what roles the agents are allowed to take.

Physical structure This structure captures the physical components (e.g. animals, manure, technology) of the system. These components can be used or operated by agents.

Operational structure This structure defines the conditions that allow for the interactions of different system components like for instance the agents that are capable of specific actions under specified conditions.

Evaluative structure We used the evaluative structure for the validation and verification of the modelled system.

Conceptualisation by means of the MAIA framework resulted in an enhanced documentation, which allowed us to translate the system into computer code.

Model description

The model concept comprises a manure distribution system in which farmers are confronted with decisions with respect to their farming activities. Within this modelled system, farmers are introduced to manure-based energy production. As a result, they can start producing manure-based energy next to their farming activities. An overview of this model concept is presented in figure 1.

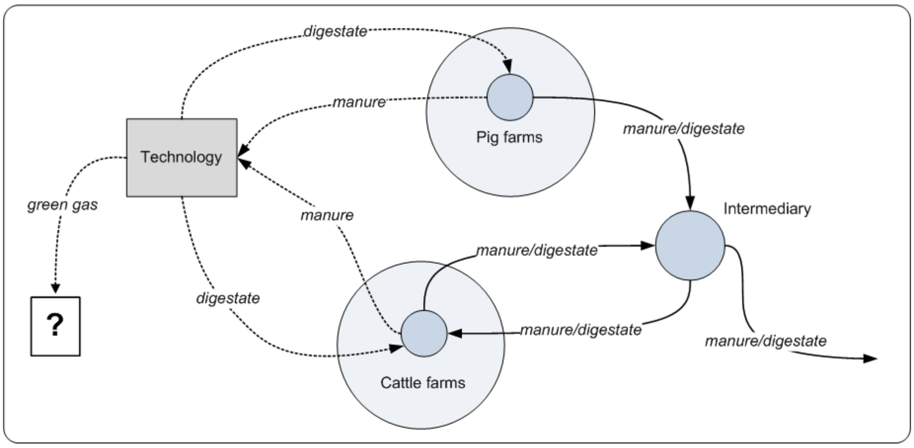

Figure 1: Model concept

Within this model concept, the defined farmer agents possess several properties as they own for instance a farm at a certain location, animals (that produce manure) and land. Furthermore, they may have a successor and a specific amount of (investment) capital. These farmer agents are principally concerned with the distribution of manure for which several options might be available as they can use the manure for own land, distribute the manure to a neighbour or to an intermediary. Within this respect, they follow several rules as they should for instance obey the *fertiliser law*.

Due to amplified regulations, farmer agents may, depending on their local individual circumstances, decide to abandon their farm. On the other hand, some farmers may decide to expand their farm. Each year, all agents are confronted again with these choices.

The production of manure-based energy comprises the adoption of a technology for the production of *green gas* and *digestate* from manure. Digestate is considered to have similar qualities compared to manure and as a consequence, it will be distributed in the manure distribution system. Annual technology costs have to be paid for operating the technology and revenue is obtained by the supply of green gas. We presumed that permits and subsidies (by means of the SDE+ regulation) are granted.

Experiments

With respect to our main research question, we carried out three experiments by means of system simulation:

Dynamics within manure distribution system An extensive institutional framework applies to the livestock farming sector as different policies are concerned with the environmental protection from detrimental consequences of farming and with animal welfare. As many of these policies are currently subject to change[1], we expect that circumstances within the manure distribution system may change. As a result, we simulated the system under different institutional settings to obtain insight with respect to the impact of these settings on the dynamics.

[1] The animal production rights and the EU milk quota regime (both part of the manure policy) are considered for abolition. Furthermore, animal welfare norms will be strengthened and the *action programme ammonia* is introduced, which is concerned with the reduction of ammonia emissions from animal housing systems at farms.

Potential for manure-based energy production by individual farms The production of manure-based energy is a new concept introduced next to the main farming activities of a farmer. To obtain a better understanding of the factors that may influence this potential we allowed the (farmer) agents - who are situated within a manure distribution system - to decide upon the production of manure-based energy. Subsequently, we simulated the system under different economic settings.

Effect of cooperation on the potential for manure-based energy production Farmers may decide to cooperate when confronted with the decision to produce manure-based energy. Cooperating can be an advantage as costs can be reduced due to economy of scale. To explore the effect of cooperation on the potential for manure-based energy production, we simulated the system under different economic settings.

Model outcome

Simulating the social system resulted in the following model outcome:

Manure distribution system We observed that both pig and cattle farms decreased over time and this decrease is observed to be more abrupt with respect to pig farms. Furthermore, the volume of manure that is abundantly present did not decrease. As a result, high costs remain associated with the distribution of manure.

Potential for manure-based energy production In case of individual production only a few farmers were involved in green gas production. Based on an annual technology cost of €$80,000$ and a revenue of €1.04 per Nm^3, we observed a production potential of approximately $3.92 \cdot 10^7$ m^3. These farmer agents all have a successor, possess a large-scale farm (pig farms with 3000 pigs or more and cattle farms with 150 cattle or more) and were able to invest a large amount of capital. In case of cooperation, we observed the formation of groups and the production was increased to $2.14 \cdot 10^8$ m^3 in accordance with the largely increased number of farmer agents involved in green gas production.

Conclusions and Recommendations

Based on the outcome of this research, we consider the potential for manure-based energy low as outlined in the following argumentation:

- The feasibility of manure-based energy production is influenced by rules and regulations of the institutions (e.g. the granting of subsidy) and the costs of technology. With the uncertainties about both the amount of subsidy that will be granted and the order of the specific technology costs, a clear expectation of what will be gained is lacking. As a result, risks are present and these risks will decrease the willingness to invest in manure-based energy.
- A sufficient production capacity is required to allow for a feasible production. As a consequence, many small-scale to middle-scale farms will not consider manure-based energy production, due to the above mentioned uncertainties about benefits and costs.
- The production of manure-based energy requires a considerable investment by the farmer, requiring sufficient investment capital. This puts a lot of pressure upon the farmers, who often experience at the same time poor financial situations and ongoing changes in the policies. Their main source of income is and will be farming, hence their main attention is farming. This makes it unlikely to consider their own manure-based energy production.

- In addition to the aforementioned statement, farmers do not obtain a clear benefit with respect to the production of manure-based energy. We consider the production of manure-based energy production not beneficial for the manure distribution system: current issues with respect to the abundance of manure are not solved and meanwhile the produced digestate, almost identical in volume and composition to manure, had to find its way back to the manure distribution system.

Although cooperation between farmers should not be taken for granted, in case farmers do cooperate, the potential for manure-based energy production is highly increased as cooperation allows for the involvement of a broader variety of farms. Furthermore, by means of cooperation the production capacity can be increased, resulting in increased gains (and reduced risks) due to economy of scale.

To increase the potential for manure-based energy production, we recommend the following:

- We suggest to create a clear benefit from a farmer's point of view. The fact that high costs remain associated with the distribution of digestate is perceived as a burden. As a result, it is suggested to improve this situation by exploring the opportunities for manure - and therefore digestate - processing as this may promote the reuse of minerals.
- In order to decrease the indecisiveness of local farmers to investment in manure-based energy production, their knowledge and understanding regarding manure-based energy production (with respect to the development of biogas infrastructure) should be improved. Subsequently, it is suggested to promote cooperation as this will possibly result in an increased potential.
- We suggest to reduce institutional barriers, especially with respect to the SDE+ regulation which is perceived as complex. To stimulate the production of renewable energy, a clear supportive legal framework should be formulated that does not give rise to uncertainties. Furthermore, this framework should provide guarantees for the long run, this is specifically required taking into account the poor financial situation of most farmers.

Acknowledgements

At the beginning of 2011 I started looking for a Master Thesis Project. By May I was invited to carry out my research project at Witteveen+Bos (in Deventer) and I participated a couple of times in the project meetings of the GGS project group, which I rather enjoyed.

I experienced my research as challenging as I was introduced with many new concepts related to content matter as well as the way I carried out this research project. Considering this, I like to emphasis that I learnt a lot with respect to renewable energy projects, uncertainties in decision making, farming issues within the Netherlands and the modelling with respect to complex systems. But above all, I learnt about myself and my own capabilities to make the right decisions at the right time.

I would like to thank my graduating committee members: Igor Nikolić who always showed me the broader picture, Aad F. Correljé who was able to give me advice whenever I was in need of it (I really enjoyed our discussions about farmers), Raphaël van der Velde who gave me the opportunity to obtain a new experience, Gerard P.J. Dijkema for his ongoing support during the process, Margot C.P. Weijnen for her valuable criticism during the graduation meetings and especially Amineh Ghorbani for her patience, support and understanding during the process.

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Abbreviations

ABM	Agent-based model(ling)
AD	Anearobic Digestion
GGS	Groen Gas Salland
IAD	Institutional Analysis and Development
LHS	Latin Hypercube Sampling
MAIA	Modeling Agent systems based on Institutional Analysis
MCDA	Multi Criteria Decision Analysis
ME	Manure-based Energy

Chapter 1

Introduction

Within the province of Overijssel, the Netherlands, goals are set to increase the share of renewable energy with 20% in 2020 and to reduce the carbon dioxide emission by 30% in 2017 (in relation to 1990), both by increased energy savings and the production of renewable energy. Due to the presence of rural areas within the province of Overijssel, it is assumed that the production of bioenergy will enable realisation of 52% of the sustainability goals (Ene, 2011). Bioenergy comprises all renewable energy produced from biological sources.

1.1 Exploring opportunities for green gas production in Salland

To explore the opportunities for bioenergy production the province of Overijssel has initiated a bioenergy programme. A part of this programme is carried by the *Groen Gas Salland* (GGS) project group, who has taken the initiative to explore the opportunities of green gas production through a biogas infrastructure within the region of Salland.

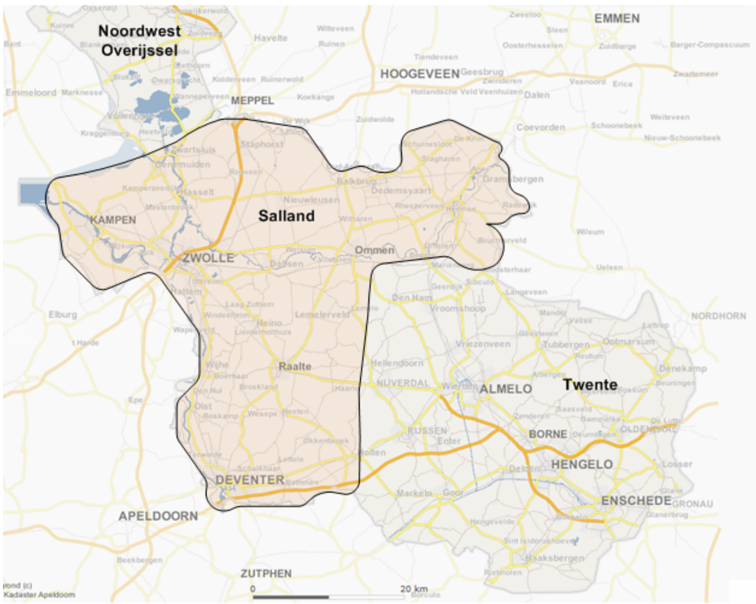

Figure 1.1: The region of Salland within the province of Overijssel

Green gas is a renewable gaseous energy carrier produced by upgrading biogas. Since green gas has the same quality standard compared to natural gas, it can be injected into the Dutch pipeline system. Biogas can be produced from biomass by means of the *anaerobic digestion* (AD) process. Since within the region of Salland (intensive) livestock farming is practised, manure is assumed to be abundantly present. Hence, the utilisation of manure for the production of green gas by means of the aforementioned AD process should have considerable potential. Within the AD process microorganisms break down biodegradable material (e.g. manure) in the absence of oxygen. The resulting products are biogas and digestate. Digestate can be used as a fertiliser equal to manure if at least 50% of the input stream is composed of manure. The technology for AD is mature and facilities are available at different scales, ranging from small farm-scale to large-scale applications used in industry.

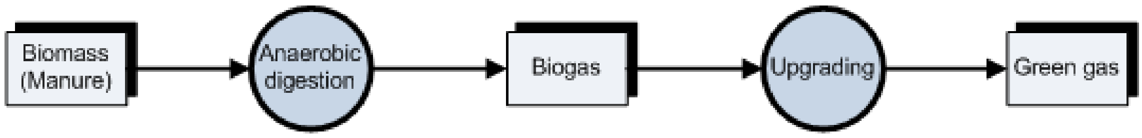

Figure 1.2: Production of green gas from manure

Within the envisioned biogas infrastructure small-scale biogas producers are connected to a (local) biogas distribution network that collects the biogas and upgrades it subsequently to green gas. A biogas infrastructure or a *green gas hub* aims at an efficient match between biogas production and utilisation sites, hence increasing the cost-effectiveness of renewable energy production. We consider a biogas infrastructure a new concept within the Netherlands and many challenges are faced with respect to its development. We emphasise that the local circumstances are highly influential for its development and that the cooperation of many different actors is imperative.

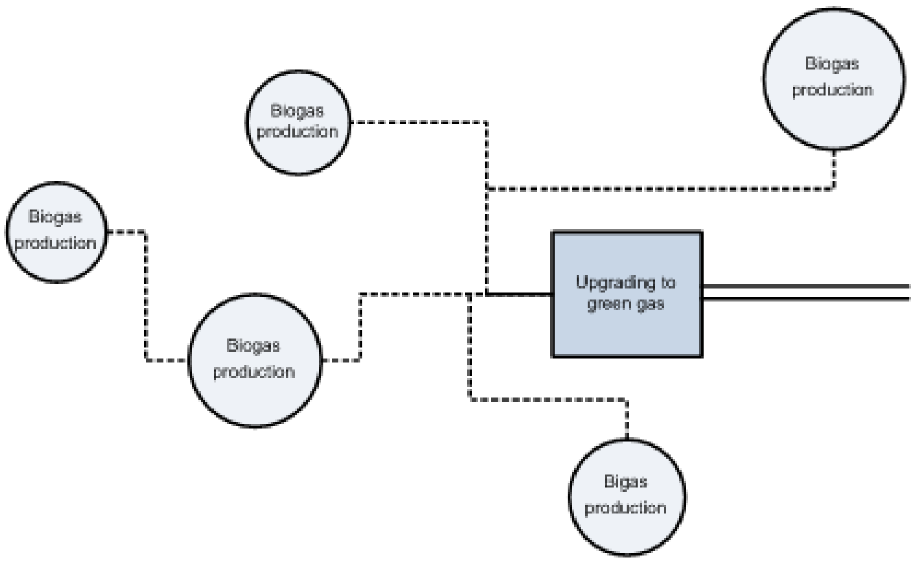

Figure 1.3: Concept biogas infrastructure

1.1.1 Challenges

Challenges are for instance present in the sense that the *Dutch Gas Act* does not apply to a biogas network since biogas does not have the same quality compared to natural gas. As a consequence, operating the network does not fall automatically under the responsibility of the (local) distribution network operator, leaving uncertainties with respect to its governance (Damste, 2011).

Since the production costs for renewable energy are considered rather high, production of green gas is estimated not economically feasible without the *SDE+*[1] subsidy. The SDE+ is an exploitation subsidy to stimulate the production of renewable energy. *Agency NL*, a governmental organisation which falls under the Dutch Ministry of Economic Affairs, Agriculture and Innovation, decides which renewable energy projects will be granted subsidy. As many projects might be taken into consideration and only a few will be selected, it remains uncertain whether this subsidy eventually will be granted. The SDE+ regulation is a rather complex piece of legislation. Moreover, it has been subject to change causing additional uncertainties.

Biogas producers are vital to the development of a biogas infrastructure. Since it is expected that the utilisation of manure for renewable energy production will contribute to the stated sustainability goals, local farmers are confronted with the decision to produce manure-based energy.

Due to the innovative character of this concept, it is unclear what the prospects are for local green gas production. Farmers are not naturally involved in energy production: they are mainly concerned with livestock farming. It may therefore not come as a surprise that these actors hesitate to participate in local renewable energy production.

The fact that the participation of local farmers is considered vital for the production of renewable energy adds an extra dimension to the development of a biogas infrastructure. Technologies that facilitate the production of renewable energy maybe mature and available, the fact that local farmers are doubtful towards the production of manure-based energy is considered a serious problem. In order to solve this problem, it is expected that a farmer's decision to invest in manure-based energy can possibly be influenced by economic factors like the amount of subsidy available and the transparency of the specific costs of technology.

As aforementioned, manure is considered to be abundantly present within the region of Salland due to (intensive) livestock farming. To comprehend whether the manure can become available for energy production, it is necessary to learn how manure is currently used and valued by the local farmers. The following section describes how the abundance of manure gives rise to a manure distribution system.

1.2 Manure distribution system

Manure is currently used as a fertiliser. However, due to intensive livestock farming the (continuous) manure production exceeds the local demand for manure-based fertilisers. To protect the environment from the detrimental consequences of excessive manuring, the fertiliser law puts restrictions to the amount of (manure-based) fertilisers used. As a result, a large volume of manure cannot be used within the direct surroundings and farmers are obliged to distribute the manure to places elsewhere, this against high costs.

It should be emphasised that the local accumulation of minerals is by no means sustainable. The scale and the intensification at which livestock farming occurs as well as the current fertilising strategies have led to a mineral unbalance. Minerals are currently not reused and the impact is

[1] Stimulering Duurzame Energieproductie 2011

experienced on a local level. As farmers bear the distribution costs, manure is frequently valued as waste.

Within the agricultural sector farmers are influenced by many policies that try to control their farming activities. For instance, the fertiliser law together with the *animal production rights* and *EU milk quota regime* (which both control (in)directly the livestock population), are all part of the manure policy. Currently, many of these policies are subject to change and uncertainties are created as the impact of these changes is not (yet) known. Due to the amendment of policies, circumstances within the manure distribution system may change.

1.3 Research question

Based on the subjects described in the forgoing sections, we formulate the following research question and sub-questions:

Research question: Considering the evolving manure distribution system in Salland, what is the potential for manure-based energy production?

Sub-question 1: What factors influence the adoption of manure-based energy production?

Sub-question 2: How can the production of manure-based energy be beneficial for the manure distribution system in Salland in the long run?

In the following section the research approach to find answers to these questions is further outlined.

1.4 Research approach

The evolving manure distribution system is complex as changes in the institutions result in many different behaviours by the farmers. In addition, the introduction of manure-based energy production will further complicate this evolving social system.

The system under study comprises many actors situated within a dynamic institutional environment. These individuals are considered autonomous and unique with respect to their own *micro-level behaviour*. Within their decision making they are influenced by many different factors and since they have different ways of interacting with each other, it will become clear that - due to these local interactions - the system can emerge in many possible ways, giving rise to a wide variety of possible system behaviours or patterns (Epstein, 2006). It is emphasised that this *macro-level behaviour* arises bottom-up.

Since an agent-based model (ABM) allows a complex system to emerge from bottom-up by local interactions of individuals who are captured as agents, the development of an ABM is proposed as this enables the exploration of different system behaviours: ABM can be used to increase the capability to grasp micro-level behaviour and to relate this behaviour to macro-level outcome (North and Macal, 2007).

Within an ABM, agents act according to simple local rules, but generate - due to interaction - some kind of coherent, systematic behaviour involving multiple agents (Epstein and Axtell, 1996). The fact that simple rules give rise to a collective structure emphasises the notion of complexity, namely that the whole is greater than the sum of its constituent parts. As a result, within this approach the system is viewed as '*collections of interacting parts* (North and Macal, 2007).

1.4.1 Agent-based social simulation

Considering the emergence of complex behaviour from relatively simple activities, these social systems are mostly non-linear. As a consequence, it is suggested to *simulate* these social systems in stead of using conventional statistic methods as the latter apply an analytical approach and analytical solutions to agent interactions are often impossible (Nikolic et al., 2009; Gilbert and Troitzsch, 2005).

Within the agent-based modelling approach, the assumption is that agent behaviours or environmental responses are not known with complete certainty, so these factors are characterised by a ranges of possible values, means, variances and other statistical measures (North and Macal, 2007). As a consequence, simulations will generate different outputs given the same inputs. For that reason these models should be executed many times to produce valid general results. Nevertheless, the execution of one run[2] can already help to understand how individual agent interactions can contribute to system behaviour, because '*each run can present a different possible historical trace or future path given a particular set of assumptions* (North and Macal, 2007)'.

The fact that a model can be simulated many times provides a clear benefit: settings can be varied to explore the effects of different variables. When a good understanding of the micro-level behaviour exists, possible outcomes can be related to their underlying causes and thereby enhance the '*discovery of innovative answers to outstanding questions*': an agent-based model can be used to expand the scope of future possibilities considered in decision-making (North and Macal, 2007).

1.4.2 Methodology

To develop an ABM for social simulation, relevant system components should be defined and captured. We consider the MAIA framework appropriate for conceptualising the manure distribution system for agent-based social simulation, especially when one considers the existence of many institutions being part of the system. The MAIA framework constitutes a meta-model for *M*odelling *A*gent systems based on *I*nstitutional *A*nalysis and is based on the *Institutional Analysis Development* (IAD) framework, which applies an institutional perspective on social system concepts (Ostrom, 2005).

To develop a agent-based model by means of MAIA, a good understanding of the micro-level behaviour is required. To obtain relevant information and data - especially with respect to the Salland region - interviews are held with local actors and this information is combined with additional data from a literature review.

1.5 Reading guide

Chapter 2 is subdivided in three main sections. The first of these sections explains the issues with respect to the abundance of manure in regions with (intensive) livestock farming as well as the aspects regarding the manure distribution system. In the second section, it is explained how manure can be utilised for the production of energy. The final section explains what the decision to produce manure-based energy entails from a farmer's point of view. In chapter 3, we present the methodology applied in this research. This chapter describes how data is collected and how the MAIA framework can be used to conceptualise the system for an ABM. Chapter 4 gives a description of the modelling process that is carried out to build the actual model. In chapter 5 we present the model outcome. Furthermore, in chapter 6, we will discuss this model outcome. Finally, in chapter 7 we present our

[2] A *run* might be referred to as a narrative or possible sequence of events.

conclusions and recommendations with respect to the insights we have obtained. Additional data as well as the tables that accompany the MAIA framework can be found in the appendices.

Chapter 2

Case description

2.1 Introduction

Due to (intensive) livestock farming the manure production exceeds the local demand for manure-based fertilisers. As a result, manure is distributed within a manure distribution system. This chapter is composed of three main sections in which the first section describes the current issues related to the abundance of manure. Subsequently, in order to understand *how* manure can be used for the production of energy, section 2.3 introduces the manure-based energy (ME) system, provides a description of the AD process and presents the institutional aspects with respect to ME production. Since we are especially interested in the decision making of local farmers (in Salland) being confronted with the decision to produce ME, section 2.4 describes this investment decision, placed in appropriate context of current trends observed in the livestock farming sector. An overview of the structure applied in this chapter with respect to three main sections is provided in figure 2.1.

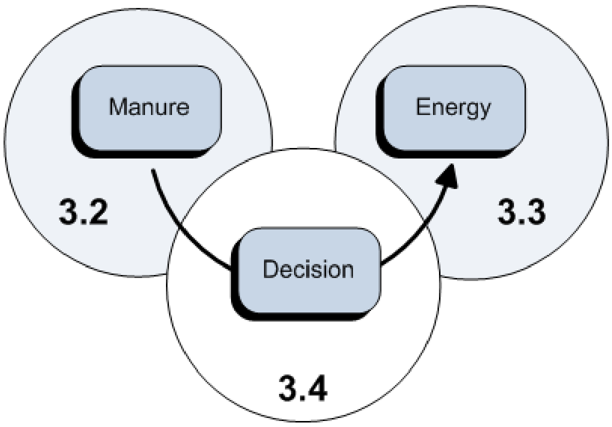

Figure 2.1: Structure of chapter

2.2 The 'problem' with manure

To understand the current issues related to manure, a good understanding of the functioning of the livestock farming sector is necessary.

Manure production is a natural consequence of livestock farming. Manure is an organic compound that is valued for its mineral content and as a result mainly used as a fertiliser within arable farming. The valuable components are minerals: N (Nitrogen), P_2O_5 (Phosphorus (pentoxide)) and K_2O (Potassium (oxide)).

In regions with (intensive) livestock farming, a manure 'surplus' is present as the amount of manure that is produced exceeds the local need for manure-based fertilisers.

As presented in following figure 2.2, the in- and outgoing flow of farm products can be presented as an in- and outgoing stream of minerals. To prevent the accumulation of minerals (e.g. manure surplus), a mineral balance should be maintained.

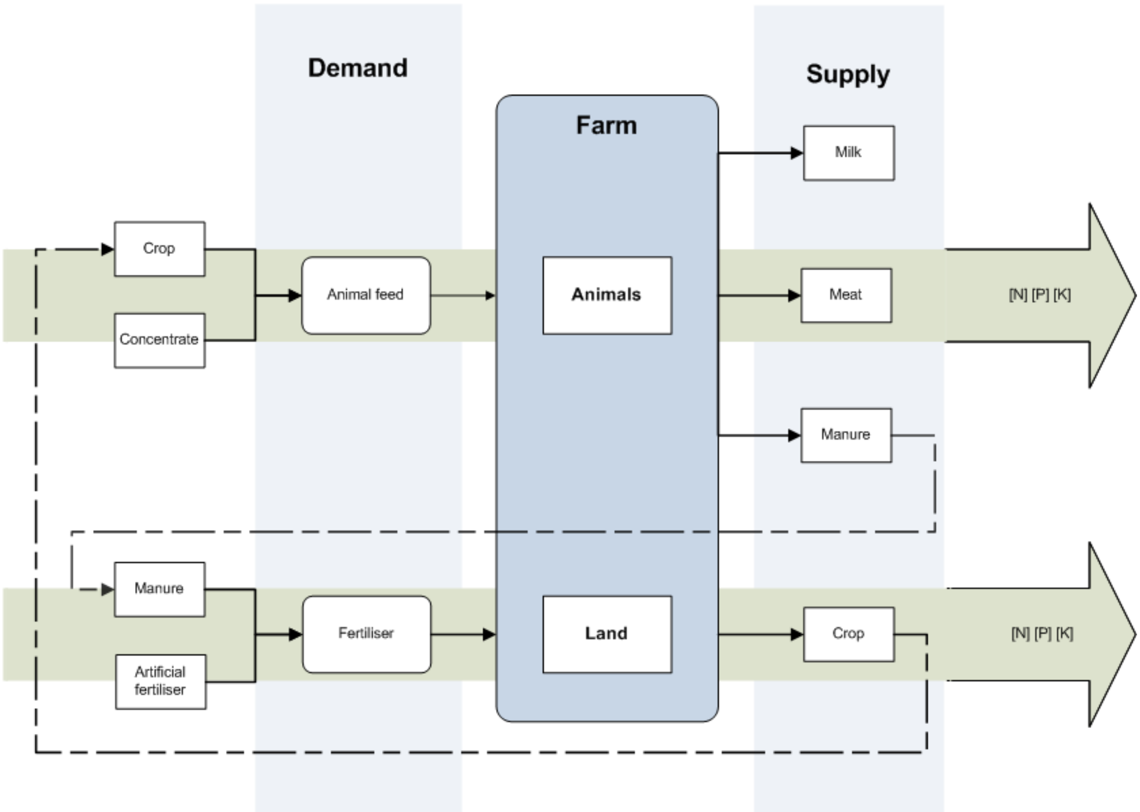

Figure 2.2: The in- and outgoing flow of farm products presented as an in- and outgoing stream of minerals.

We identified two main causes for the accumulation of minerals:

- The current fertilising and animal feeding strategies. As shown in 2.2, the usage of artificial fertilisers (and animal feed concentrate) constitutes an external inflow of minerals into the system.
- The scale and intensification at which livestock farming currently occurs.

To maintain a mineral balance the ingoing streams should equal the outgoing streams. The importance of recycling organic manure to maintain crop production has been recognised by farmers for thousands of years. Nevertheless, due to the availability of artificial fertilisers, the reuse of minerals became no longer a necessity. As a result, the agriculture production was increased, indirectly allowing the human population to grow. In spite of the benefits, the introduction of artificial fertilisers comes at a cost.

On an annually basis about 450 million tonnes of N fertiliser is produced by the *Haber-Bosch process*[1]. This amounts approximately 50% of all N that is taken up by the agriculture worldwide. The production requires an enormous amount of energy and consumes about 1% of the annual energy supply worldwide. (Knip, 2011)

P fertilisers are derived from *phosphate rock (concentrates)* that has preferably levels of 30% phosphorus pentoxide (P_2O_5), amounts of calcium carbonate (5%) and less than 4% combined iron and aluminium oxides. Agriculture alone results in the depletion of approximately 19 Mt of P annually worldwide from phosphate rock, from which one-fifth reaches eventually the food eaten by the global population (Schroder et al., 2011). Under current utilisation levels, high grade phosphate rock reserves are likely to be depleted within 50-150 years (Schroder et al., 2011). Furthermore, the European Union (EU) is almost completely dependent on P imports which account for approximately 10% of the world production (de Haes et al., 2009). This shows that the EU is not self-reliant in food production, emphasising the far reaching consequences of current management.

Based in the aforementioned issues, it becomes clear that the accumulation of minerals should not be considered as just a local problem, although the impact is experienced on a local level. In the following section it is described how the manure policy is concerned with the environmental impact of local farming activities and especially the usage of (manure-based) fertilisers. These policies influence the way manure is used and distributed.

2.2.1 The Dutch manure policy

The Dutch agriculture accounts for 10% of the total greenhouse gas emissions within the Netherlands, in which dairy farming takes the biggest share (NL, 2011b). The emission of **methane** (CH_4) is caused by the digestion of cattle-fodder (mainly depending on the cellulose content) and by the storage of manure in which natural AD takes place. Besides methane, **ammonia** (NH_3) and other nitrogen compounds (di-Nitric oxide (laughing gas) (N_2O), nitrogen (N_2) and Nitric oxide (NO)) are emitted (CBS, 2011b).

The most important greenhouse gas is *laughing gas*. This compound is formed by the denitrification process which takes place in the soil (after land treatment) or in the solid residue of the manure. In addition, a part of the nitrogen added to the soil might be converted to nitrate (NO_3^-) in presence of water and oxygen. The risk of ground-water contamination by nitrate depends both on the nitrogen input to the land surface and the degree to which an aquifer is vulnerable to nitrate leaching and accumulation. Also, nitrate can be released into the air as laughing gas when reaching the water surface. Furthermore, due to energy usage the release of carbon dioxide (CO_2) accounts for approximately 10% of the total emitted greenhouse gases (NL, 2011b).

Besides nitrate, *phophate* (*phosphorus pentoxide*, P_2O_5) which is present in manure and other fertilisers, might be harmful to the environment. In contrast to nitrate, phosphate will not directly flush to surface- or groundwater. Instead, this will happen after the soil has been saturated. High concentrations of phosphates may lead to significant ecological consequences, e.g. *eutrophication*.

The manure policy is based on the *European Nitrates Directive* (91/676/EEC) and is concerned with the protection of waters against pollution by nitrates from agricultural sources. Each Member State is obliged to put in place a *Nitrate Action Programme* and to review, and if necessary revise their action programme, at least every four years. In the Netherlands the *Nitrate Directive* is

[1]In the Haber-Bosch process the reaction between nitrogen gas (N_2) and hydrogen gas (H_2) is catalysed by iron or potassium result in ammonia (NH_3) as a product. The major source of hydrogen is methane from natural gas. The reaction takes place at elevated temperatures (300 till 550 degree Celsius) and pressures (150 till 250 bar) (Knip, 2011)

implemented by means of:

- *Meststoffenwet* (Fertiliser law)
- *Wet bodembescherming (Wbb)* (Law concerning the conservation of the soil)
- *Wet herstructurering varkenshouderij* (Law concerning the reorganisation of pig keeping)

These laws are mainly directed towards the usage of manure. In addition, the *Action Programme Ammonia* has been implemented. This action programme is concerned with the reduction of ammonia emissions from animal housing systems at farms. More information about this programme can be found in appendix A.

An extensive legal framework in the form of a fertiliser law applies to the distribution and usage of manure. Furthermore, the amount of manure produced in a particular region is (indirectly) controlled by the **animal production rights** and the **EU milk quota regime**. These regulations are concerned with the number of animals a farmer is allowed to keep. In the following paragraphs, details concerning latter three regulations are further outlined.

Fertiliser law

The fertiliser law states how much kilogrammes of manure-based nitrogen a farmer is permitted to use for manuring. For nitrogen this amounts 170 kilogrammes per hectare land or 250 kilogrammes per hectare land in case *derogation*[2] can be applied.

How much kilogrammes of nitrogen a farmer is allowed to use in total for manuring depends on the number of hectares, the soil characteristics (clay, sand, peat or loess) and the cultivation. Different tables exist that provide guidance in how to determine this amount (DR-Loket, 2011). Equivalent legislation applies to the amount of phosphate (in kilogrammes) a farmer is allowed to use and this amount depends mainly on the phosphate condition of the soil. A distinction is made with respect to grassland and cropland. Furthermore, for cropland with a high phosphate condition, the amount of phosphate a farmer is allowed to use decreases from 70 kilogrammes per hectare in 2011 to 55 kilogrammes per hectare in 2013.

For not obeying the fertiliser law a fine is paid per kilogramme mineral that exceeds the stated threshold.

In general, manuring is restricted to seven months per year (from February to September), but this depends mainly on the manure type, soil characteristics and type of land. Furthermore farmers should possess enough storage capacity for the period of the first of September to the first of March. Only a qualified shipping-agent - an intermediary - is allowed to transport manure from one place to another. In addition, since the first of October 2011 farmers are allowed to transport manure through a pipeline in stead of trucks, from the location of one particular farm to an intermediary firm (DR-Loket, 2011). Furthermore, it is allowed to export manure to another Member State or another country outside Europe on the condition that the exporter will be registered by the *Voedsel en Waren Autoriteit (VWA)* (Food and Consumer Product Safety Authority).

[2] In 2005, the European Commission granted the Netherlands the right to derogate from this obligation on several conditions. Farmers are only allowed to use manure from grazing animals (in particular cattle) and they should possess at least 70% grassland. Furthermore this land is cultivated for animal feeding purposes and a rate should be paid of ∼€5.45 per hectare (DR-Loket, 2011). Furthermore, farmers are obliged to participate in a monitoring network (*Landelijk Meetnet effecten Mestbeleid (LMM)* (National Programme for Monitoring the Effectiveness of the Manure Policy) (RIVM, 2011). The results of this network should be reported to the European Commission.

In order to transport the manure, the manure should be weighted, sampled and analysed. This is the responsibility of the intermediary. Exemption from weighting, sampling and analyses is allowed, provided that:

- the manure is distributed within a radius of 10 kilometres where it is generated;
- at least 80% of the manure can be used for manuring at location where it is generated;
- the manure will be transported directly to the receiving party without disposal;
- both companies are farms.

This exemption is referred to as *farmer-farmer transport* regulation. In addition, exemption is also allowed when land that belongs to a farmer is temporarily (less than a year) handed over to someone else (DR-Loket, 2011).

A farmer calculates (each year) how much manure he should distribute away from his farm (mineral mass balance) and information should be obtained with respect to:

- How much manure is produced by animals (a distinction is made between grazing animals and 'stable animals').
- How much fertiliser is present at stock at the beginning of the year (1st of January) and at the end of the year (31st of December).
- How much fertiliser is taken and discharged in one year.

This is a challenging exercise as a farmer should collect data about the flow of minerals within animal feed, animals and products from animals (eggs). This is referred to as the 'stable balance' for 'stable animals'. Furthermore, within this calculation there should be a correction for the gaseous nitrogen losses. For grazing animals, tables exist in which different norms are specified concerning the production of nitrogen and phosphate per animal. The norms for cows depend on the milk production and urea-content. Furthermore, different norms apply with respect to the applied animal housing system.

As it is a challenging exercise to obtain the required data with respect to the mineral flows at a farm, several tables are provided by the Dutch *DR-Loket*[3] which can be used to obtain data. Cattle farmers are provided with an opportunity if they wish to deviate from the data presented in these tables. They are allowed to calculate the *specific excretion* at their farm by means of a calculation tool (*Excretiewijzer*).

Animal production rights

As explained, farmers are restricted in how much manure-based minerals they are allowed to use. This can be considered as output monitoring. To control the livestock population and indirectly the (national) manure production, *animal production rights* are granted to farmers. In these rights it is stated how many animals (pigs or poultry) a farmer is allowed to possess. It is possible to hand over the production rights to another farm under the condition that the rights are not transferred between or to 'concentration areas' (areas - within the Netherlands - where already much intensive livestock farming exists). According to the fertiliser law, the production rights system will expire per the first of January 2015.

[3] Dienst Regelingen, Ministerie van Economische Zaken, Landbouw en Innovatie

EU milk quota regime

Although no animal production rights are formulated for dairy farmers, these farmers have to obey the *EU milk quota regime*. Every dairy farmer possesses a milk quota which defines how much milk (in kilogrammes) he is allowed to produce. If he wishes to increase this amount he should rent or purchase new quota from another dairy farmer. If a dairy farmer produces more than the quota, he will be charged with a 'superfee'[4]. By putting restrictions to the amount of milk that a farmer is permitted to produce, this regime indirectly controls the number of animals at a farm.

This EU milk quota regime is introduced in 1984, in order to limit public expenditure on the sector, to control milk production and to stabilise milk prices (and the agricultural income of milk producers). Since then, this policy is subject to change and has increasingly encouraged producers to be more market-oriented. The milk quota regime will finally end in (April) 2015. Until that time the quota is increased by 1% annually from 2009 to 2013 (Eur, 2009).

Future developments

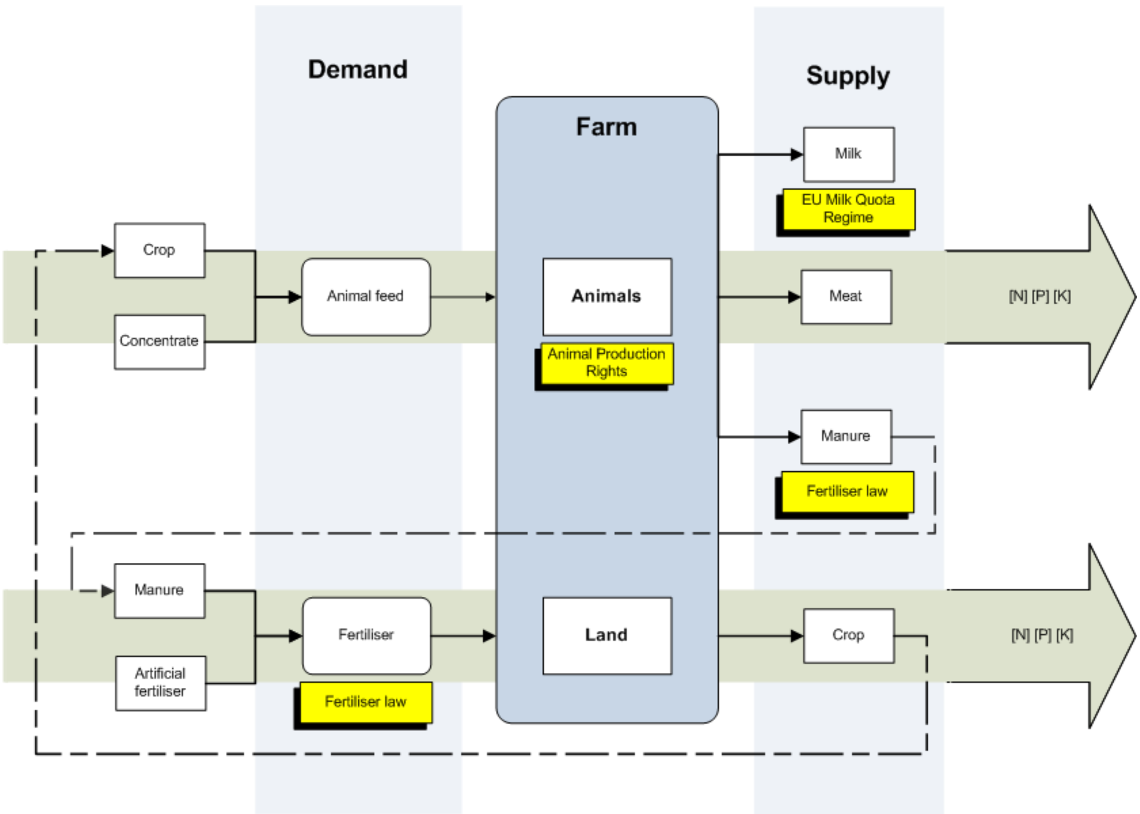

Figure 2.3: Regulations that control the production and usage of manure.

As stated in section 2.2.1, the amount of manure-based nitrogen is restricted and possible shortages should be filled up with (artificial) nitrogen fertilisers. Furthermore, limits are set to the use of phosphates as well. Depending on the mineral content of the animal feed and the type of animal (and its metabolism), manure comprises a specific ratio of N and P per volume. In general, the

[4]This amounts €27.83 per 100 kilogrammes of milk that is produced above quota (Pro, 2011)

phosphate limits determine mainly the amount of manure that can be used for manuring. Since cattle manure is perceived to have a better mineral composition (more organic as well) compared to pig manure (see also appendix C), it is higher valued. In addition, since *derogation* applies in most cases, cattle manure is favoured above pig manure. Within the coming years, the usage of phosphates will be further restricted. This has consequences for the amount of manure that can be used for manuring within a particular region. As a consequence, it is expected that the competition between cattle and pig manure will increase even further.

Both the animal production rights as well as the EU milk quota regime are ultimately considered for abolition. This has consequences for the amount of manure that is produced within a region. At first glance, it is expected that the number of animals will increase, but these developments should be understood within a broader (economic) context. Subsequently, it remains unclear if a new equivalent control system will be introduced after abolition.

Within this subsection it is described how different rules and regulations try to control the amount of manure that is produced as well as its usage. The fact that these rules and regulations are currently subject to change leads to uncertainties since the impact of the change is not known. The local abundance of manure gives rise to the manure distribution system. The following subsection introduces this manure distribution system.

2.2.2 The local distribution of manure

Within regions of (intensive) livestock farming, manure exceeds the local need for manure-based fertilisers. As a result, manure should be processed or distributed to places elsewhere where it still can be used as a fertiliser.

A farmer might have several options concerning the distribution of manure available to him:

- Usage of manure for own land. Within this option the fertiliser law should be reviewed.
- Transportation of manure to other farmers or agrarians within the surroundings of the farm. In case the conditions are satisfied, the farmer-farmer transport regulation might be applied.
- Transportation of manure to a contractor or an intermediary. An intermediary is permitted to collect and distribute the manure. In addition, he might take care of the manure storage facilities as well.
- Transportation of manure to a manure processing company (This applies mainly to manure of poultry).

What option to choose is determined by:

- The volume and mineral content of the manure.
- The presence of land at a farm. Subsequently, the number of hectares, soil characteristics and cultivation with respect to this land.
- The location of the farm within the region.

The particular local circumstances determine what manure distribution strategy a farmer applies. Each year he will evaluate the available options. As costs are associated with the distribution of manure, the general objective is to minimise these costs.

Manure distribution costs

As indicated in paragraph 2.2.1, manure has to be weighted, sampled and analysed. These activities are carried out by the intermediary. The intermediary collects manure and distributes manure to agrarians. Within Salland, approximately ten intermediaries are concerned with these activities. They transport the manure to the northern parts of the province of *Overijssel* and the provinces *Drenthe* and *Groningen*. In case the surplus increases, the manure should be distributed to places further away (at increased transportation costs) and additional costs might have to be paid to get the manure accepted by the agrarians. A farmer - especially a pig farmer - should possess enough storage capacity (for the time periods in which the manuring is not permitted). This storage capacity might also be present at the agrarian.

In table C.7, the manure distribution costs are presented.

Table 2.1: Distribution costs (€/m^3)

	Transportation of pig manure to intermediary	Transportation of cattle manure to intermediary	Transportation of cattle manure to neighbour	Usage of manure for own land treatment
Transport	8	8	4	-
Acceptance	4	1	1	-
Storage	3	0	0	-
Analysis	1	1	0	-
Labour costs	-	-	-	3
Total	16	10	5	3

As presented in table C.7 the total costs may add up to €16 per m^3, in winter time this might be €25 per m^3. Furthermore, additional information with respect to the manure distribution costs is presented in appendix A.

Manure distribution system

Within the region of Salland, most cattle farmers possess land and almost all satisfy the conditions for *derogation*. This in contrast to pig farmers, who in general don't have land. As a result, about 90% of the pig farmers distribute the manure to an intermediary. Furthermore, cattle manure is preferred above pig manure as a fertiliser. As a result, pig farmers are confronted with higher manure distribution costs compared to cattle farmers.

Approximately 60-70% of the animal farmers has a fixed relationship with a particular intermediary. This is preferred within the intensive livestock farming sector where continuity is highly valued. Most contracts are yearly contracts and prices are based on the amount of manure an intermediary collects. Seasonal contracts might be possible too. Since manuring is restricted to seven months a year, prices in summer differ much from the ones offered in winter.

Since cattle manure differs in composition from pig manure, an intermediary will keep them separate. Within the storage facility the manure is stirred, which results in a more homogenous mixture. The intermediary transports the manure to an agrarian, where a contractor is hired for manuring. An intermediary will try to optimise his logistical costs. Manure that contains a high concentration of minerals is transported further away compared to manure that contains relatively more water.

We define the manure distribution system as a local system in which farmers are concerned with the objective to minimise costs associated with the distribution of manure. An overview of the actors that are considered to be part of the manure distribution system is presented in figure 2.4.

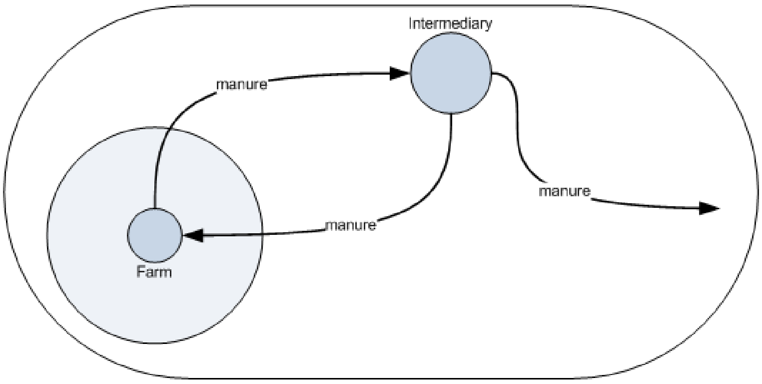

Figure 2.4: Actors that are involved in the manure distribution system.

Although manure is comprised of valuable minerals, manure is currently considered as a waste product due to high distribution costs. Furthermore, additional costs might have to be paid for artificial fertilisers[5]. It is suggested to improve this situation by means of manure processing (Biogreen, 2010; Min, 2008). Manure processing produces *mineral concentrate* which might satisfy demand in better ways as it might be able to replace artificial fertilisers. In the following paragraph, we introduce the technique of manure processing.

Manure processing

It is possible to separate manure in a thick and a thin fraction in order to satisfy demand in better ways (Verloop and Hilhorst, 2009). This separation technique might alter the composition of minerals as it divides manure into two separate streams, both composed of different mineral ratios. However, this is not perceived as beneficial since it is hardly applied within the region of Salland.

Within manure processing, manure is first separated in a thick and thin fraction, in which the thick fraction composes an organic and phosphate rich material. Secondly, the thin fraction is purified - by means of ultra filtration - and the minerals are obtained by reverse osmosis. The amount of water that is obtained after this process equals almost half of the (semi-liquid) manure used within the input stream (Vfo, 2009; Schoumans et al., 2010; Biogreen, 2010). An overview of this process is presented in figure 2.5.

[5] A pig farm that owns 3000 pigs might pay approximately €60,000 for the distribution of manure on a yearly basis. In addition - if land is present - extra costs should be added for artificial fertilisers (for example €1,400 for phosphate fertilisers)

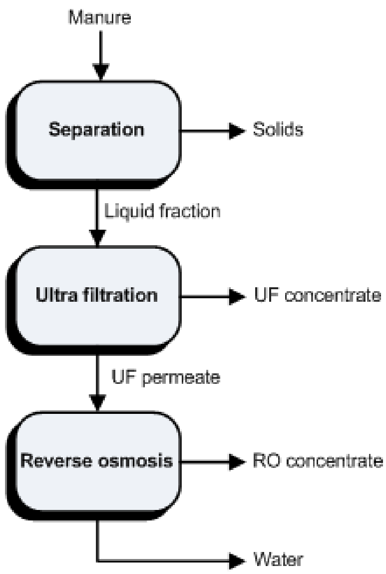

Figure 2.5: Production of mineral concentrate

Furthermore, *manure refinery* is suggested in which the production of bio-methane is combined with the processing of mineral concentrate (van Zessen, 2010). Although this technology is considered promising, it is not mature and available on the market.

Considering the technique for mineral concentrate production, the separation of minerals from the organic matter is causing most of the problems. Reverse osmosis requires a lot of energy and constitutes a relatively expensive technology. Furthermore, a rather small, farm-scale application is preferred which adds complexity to the design.

The economic feasibility of these technologies is very important for their adaption in society. Currently, the market always catches up: in case the production costs are higher compared to the costs for manure distribution, the technology is no longer supported.

Furthermore, a supportive legal framework is required. Whether mineral concentrate will be able to replace artificial fertilisers depends mainly on (European) legislation. Currently, no clear legal framework regarding the usage of mineral concentrate is present.

2.3 Production of manure-based energy

As described in chapter 1, it is expected that the utilisation of manure for energy production can contribute to achieving the sustainability goals, especially since manure is abundantly present and technologies that facilitate this conversion are mature and available on market. Within this context manure is no longer considered as a fertiliser, but as a source of energy.

Manure can be used for the production of biogas by means of the AD process. Biogas mainly comprises methane (CH_4, 50-60%), carbon dioxide (CO_2, 35-40%) and it may contain small amounts of hydrogen sulphide (H_2S), nitrogen (N_2), oxygen (O_2), moisture and siloxanes (Verbeek and Werktuigbouw, 2011; Welink et al., 2007). Besides the production of biogas, digestate is generated. Digestate is considered as a collective term to specify the material in the output stream. Its characteristics depend mainly on the composition of the input stream.

The AD process requires biomass. If the input stream is only composed of manure the process is referred to as *mono-digestion*. In the case of *co-digestion*, additional *co-substrates* (e.g. maize, corn, fats, grain or grass) are used. This is mainly done to increase the biogas yield, because manure has a low organic content due to a high concentration of water (Veefkind, 2009). Digestate can be used as a fertiliser equal to manure if at least 50% of the input stream is composed of manure (Morgenstern and de Groot, 2010).

Biogas is most often locally used for the production of combined heat and power. The produced power is used for local energy purposes or injected into the electricity grid. Although the generated heat can be used for heating the biogas production facility, it is frequently regarded as waste heat since the amount of heat often exceeds the local demand (Veefkind, 2009). In addition, it is stated that the inefficiency of this process amounts almost 60% (Dumont, 2010a). This in sharp contrast to the production of green gas, which results in very low methane losses ($\leq$3%) (Dumont, 2010b). Green gas is produced by upgrading biogas[6] to the desired (natural) gas quality. Green gas can be injected into the Dutch pipeline system.

A biogas production facility is most often comprised of an AD facility in combination with a combined heat and power (CHP) facility (HoS, 2010). An animal farmer might take care of the operations himself or may put them out under contract. A more centralised system might be another option, in which manure is collected from different participating animal farmers and centrally utilised for the production of biogas. A centralised system has advantages, since the overall costs will be reduced due to economy of scale. But it may have some disadvantages as well since market dependencies are created and additional transportation costs might be present[7].

2.3.1 Manure-based energy system

As described in the introduction, the development of a biogas infrastructure allows for an efficient match between biogas production and utilisation sites. As stated earlier, a ME system is defined as a system in which manure is used for the production of bioenergy by means of the AD process. Depending on the local circumstances within a particular region, different requirements can be formulated for the design of a local ME system. The system can either be centrally organised or based upon a decentralised organisation, the latter allowing for multiple biogas production sites that are part of a biogas infrastructure. Figure 2.6 provides a schematic overview of possible system design options.

[6] Several upgrading technologies are available like (Vacuum) Pressure Swing Absorption (PSA), Membrane Gas Adsorption (MGA), Cryogene Separation, Chemical Absorption (CA), Pressurised Water Scrubbing (PWS) (Welink et al., 2007).

[7] We obtained from interviews that these costs might be acceptable within a radius of 2 kilometres.

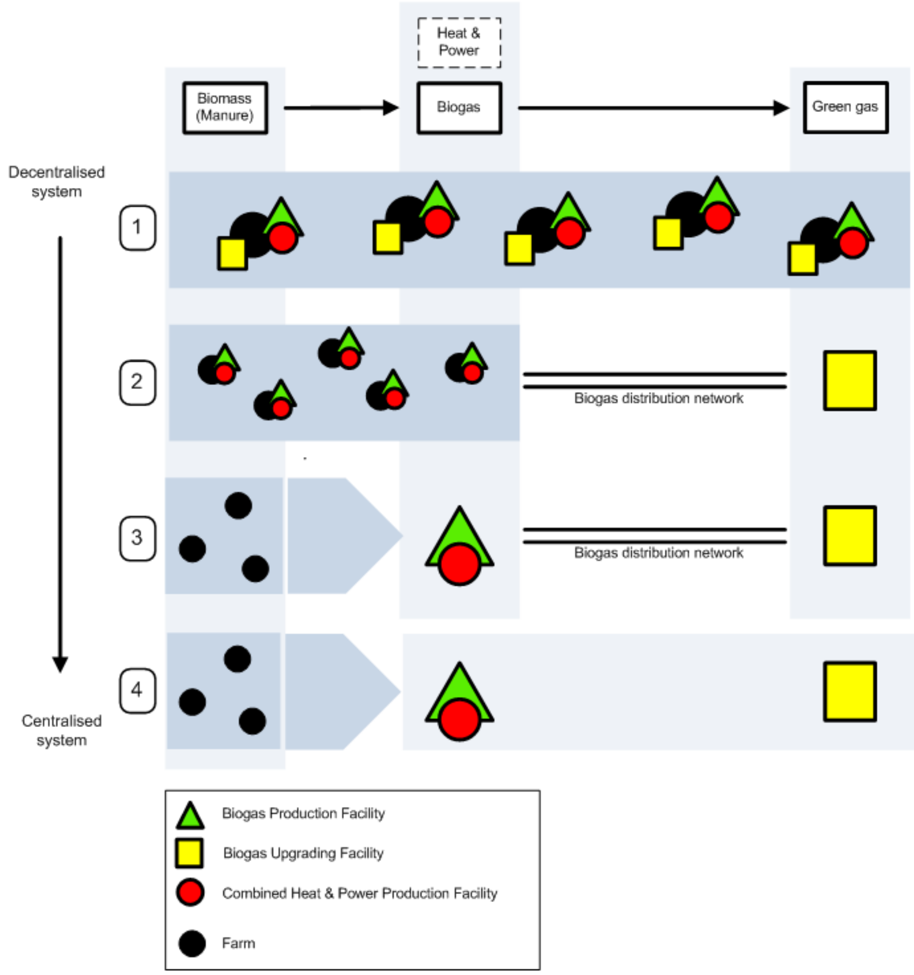

Figure 2.6: System design options

As shown in figure 2.6, design 1 shows a decentralised system in which the production of biogas as well as the upgrading to green gas (and its possible injection in the gas distribution network) occur all at one specific location (a farm). In design 2, biogas is locally produced at a farm and these farm-scale biogas production sites are part of a biogas infrastructure since they are connected to a biogas distribution network. Design 3 shows a more centrally organised system. Manure from different farms is collected and centrally utilised for the production of biogas. The facility is connected to a biogas distribution network. In design 4 finally, manure is collected and centrally utilised for the production of green gas without the presence of a biogas distribution network.

Within a particular region different combinations of the stated designs are possible. For example between design 2 and 3. Furthermore, depending on the current energy infrastructure, green gas can be injected in the gas distribution network at the location where it is generated.

In the Netherlands, around 180 firms (waste water treatment plants not included) have a permit to produce biogas (Morgenstern and de Groot, 2010), and about 100 agricultural AD facilities are put into service (Hagen et al., 2010). These facilities are available at different scales. In general a production facility ranges from 500 to 1500 kWh (Hagen et al., 2010) (a production of 1000 kWh matches 500-600 Nm^3 biogas (Welink et al., 2007))[8]. The interest in rather small-scale production

[8]The calorific value of natural gas comprises 32 MJ/Nm^3 and for biogas this comprises 20 MJ/Nm^3. It is

facilities (volume of 120 m^3) that process only manure (a capacity of 4000-5000 Nm^3 manure on a yearly basis) is emerging (HoS, 2010). These small-scale facilities have an advantage above the larger facilities (in which most often co-digestion take place) since no additional supply of co-substrates is required (Hagen et al., 2010). On the other hand, it is also stated that among others the recent usage of co-digestion has lead to a significant increase in the scale of production facilities(Morgenstern and de Groot, 2010).

2.3.2 The anaerobic digestion process

During the end of the seventies and the beginning of the eighties of the 20th century, a few ten AD facilities that processed manure were put into service. The incentives were the oil crisis and the reduction of odour. Due to technological immaturity, AD of manure was considered not to be economically feasible, and many quit at an early stage. This in contrast to Germany and Denmark, where initiators kept on developing. The interest in AD of manure is renewed due to the improved technology for biogas cleaning, the opportunities for co-digestion and the initiatives for stimulating renewable energy production (NL, 2005).

Within the Netherlands, the technique of AD is frequently used for sewage treatment in waste water treatment plants and for the processing of (mainly cattle and pig) manure (Morgenstern and de Groot, 2010). The first step within the AD process comprises bacterial hydrolysis. In the second step *acidogenic bacteria* convert sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Thirdly, *acetogenic bacteria* convert the resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally methanogens convert these products to methane and carbon dioxide (Kool et al., 2005). Since the input stream is most often pumpable, the AD process concerns in general a continuous process (Veefkind, 2009).

Biogas production yield

Depending on the input products and local process circumstances, the production of biogas amounts approximately 20 m^3 per tons of manure. This is rather low when compared to the utilisation of maize, which yields approximately 200 m^3 per tons of product, and glycerine, which yields approximately 600 m^3 per tons of product (Jansen, 2011; Morgenstern and de Groot, 2010). In general, the use of fatty products result in a higher biogas yield compared to the utilisation of products composed of carbohydrates (Kool et al., 2005). How much of the organic matter in the input is converted to biogas depends highly on the type of input products, to what extent they are made accessible for biological breakdown and on the process conditions[9]. Within this respect, the percentage that is converted varies from a few percent to 80% (WUR, 2010; Veefkind, 2009; Morgenstern and de Groot, 2010).

Digestate

Besides the production of biogas, digestate is generated. In general, digestate has a lower viscosity compared to the products in the input stream, but it has a similar nutritious composition since no nutrients are removed in the AD process (Velghe and Mattheeuws, 2007). In addition, no heavy

estimated that 1 kWh equals 2.6 MJ. As a result it is estimated that 8.88 kWh equals 1 Nm^3 for natural gas and 5.55 kWh equals 1 Nm^3 for biogas. In order to calculate the accurate power production, the efficiency of the gas engine has to be taken into account. Depending on the scale and status of technology, this might be 38%. More details are stated in appendix A

[9]It is recommended to process the manure as soon as possible to prevent *spontaneous* gas emissions.

metals are removed either and their concentration might even increase due to the reduction of organic content (Morgenstern and de Groot, 2010). In the co-digestion facility, mineralisation takes place which results in organic nitrogen fixation (causing an increase in ammonia) (Velghe and Mattheeuws, 2007). Although it is assumed that the volume and composition of the ingoing manure and produced digestate are more or less equal (WUR, 2010), digestate is perceived to be more homogeneous and the nutrients present (nitrogen (N), phosphorus (P) and potassium (K)) are better accessible for take up by the plant (Jansen, 2011; Koppejan and Annevelink, 2011). Digestate can be used as a fertiliser equal to manure if at least 50% of the input stream is composed of manure.

2.3.3 Rules and regulations

Several laws and regulations are concerned with the production of biogas by means of AD:

- The co-products that can be processed together with manure. The *Dutch Ministry of Economic Affairs, Agriculture and Innovation* approved a *Positive List* of co-products that are allowed to be utilised for the production of biogas in combination with manure (Morgenstern and de Groot, 2010). It is possible to request for exemption, the product will then be evaluated by the *RIKILT*[10].
- From a legal perspective digestate is considered as a fertiliser in case at least 50% of the input stream is composed of manure. There is one exception: the AD of only maize. If less than 50% manure is present in the input stream, digestate is considered as a waste product. It is possible to spread this product on own farmland if a request for exemption is granted. If no manure is present in the input stream (viz. only other biodegradable material), digestate might be considered as compost if the definition of compost applies.
- A building permit and a permit for processing should be obtained. More information with respect to these aspects can be found in the appendix A.

Subsidy for renewable energy production

Depending on the type and capacity of the facility, the investment costs might be €0.5M for a farm-scale application and the yearly operational costs are estimated €80,000 (HoS, 2010).

To stimulate the production of renewable energy in the Netherlands, the **SDE+**[11] subsidy, an important policy instrument of NL Agency[12] is established. The SDE+ is a exploitation subsidy which means that producers receive financial compensation (subsidy) for the actual production of renewable energy and not for the capital investment required to start producing renewable energy. The SDE+ compensates for the difference in cost-price of grey energy and sustainable energy (the unproductive top) within a duration of 12-15 years. Within the SDE+ subsidy regulation, the price of renewable energy is defined as the *basic amount* and the price of grey energy as the *corrective amount*. Since it is expected that the price of grey energy is lower compared to the price of sustainable energy (due to higher production costs of renewable energy), the SDE+ subsidy adds to the corrective amount to equal the basic amount. The maximum basic amount is set to €0.15 per kWh or €1.04 per Nm^3. It is expected that several technologies will be able to produce renewable energy within this limit.

In 2011 it became possible to obtain SDE+ subsidy for a *green gas hub*. Within this legal context, a green gas hub is defined as a collection of AD facilities that share provisions to upgrade the biogas

[10] Institute of Food Safety, www.rikilt.wur.nl
[11] *Stimulering Duurzame Energieproductie 2011*
[12] Ministry of Economic Affairs

and the additional injection of this green gas in the gas pipeline system. Individual facilities being part of a green gas hub can be grouped together and one request for subsidy can be submitted. Within this request, results of a feasibility study, the price indication of the (local) network operator and the obtained permit for putting the production facilities into service should be enclosed (Age, 2011). Agency NL decides eventually what renewable energy projects will obtain subsidy.

The production of biogas without this subsidy is currently not economically feasible (Hagen et al., 2010; HoS, 2010).

The decision to start with biogas production entails an investment. Capital is required to start operating an AD production facility. The capacity and type of biomass (manure) available determine how much biogas can be produced. Furthermore, as explained in section 2.3, the design of a ME system influences the business case to a great extent.

2.4 A farmer's decision to invest in manure-based energy

As shown in figure 2.6, a system according to design 2 and 3 requires the development of a biogas distribution network to distribute the produced biogas to several utilisation sites. As a consequence, it is stated that the development of a biogas distribution network is crucial for production to start (Saxion, 2010). Furthermore, as shown in design 2, a farmer can become an individual producer. In design 3, a more centralised system is presented in which manure is collected and centrally utilised for the production of biogas. This latter design requires the collaboration of different farmers.

2.4.1 Costs and benefits of manure-based energy production

As indicated in section 2.3, the production of biogas is a continuous process and a continuous input stream is required. As a consequence, co-digestion will make the logistics more complex since it requires the supply of co-substrates. Although the yield is increased when co-digestion is applied, mono-digestion is preferred by farmers as obtaining these co-substrates is perceived as a logistic burden. In many situations these products have to be bought[13] and prices fluctuate throughout the season. Furthermore, co-substrates are acknowledged as animal feed and should (principally) not be used for energy production. Furthermore, the production capacity and how the process is monitored also influences the costs for system operations. Since the AD process is a biological process, optimal process condition should be explored.

Besides operational costs, costs are associated with the distribution of the output product digestate. As explained in subsection 2.3.2, digestate is considered equal to manure in case at least 50% of the manure is used within the input stream. If this condition is satisfied, digestate can be distributed within the manure distribution system.

As a result, the benefits should mainly come from the supply of energy (green gas). As described in section 2.3.3, ME production is currently not feasible without subsidy. The design of the system and the available capacity determine the production scale. Eventually, the production costs and the availability of subsidy will influence what benefits can be obtained.

2.4.2 The willingness to invest in manure-based energy production

Although we consider the financial situation of a farmer important with respect to the decision to produce ME, the *willingness* to invest determines mainly whether an investment will actually be carried out.

[13] Depending on the type of products the price can amount €40 per tonne.

When confronted with a decision to invest in ME production, a farmer will consider the implications for his farm. A farmer is mainly concerned with his farming activities (e.g. the production of meat and milk) as these activities generate income[14]. As a result, the vision a farmer applies to his farm will influence how ME production is perceived.

Financial situation of farmers

A farm is (often) a family-owned company with only one labour unit who runs the company according to his own views. Furthermore, a farm is located within a specific region and depends on this location. Within this respect, we consider a farm a rather unique company. The fact that a farm is run by one person, who is very specialised, emphasises the importance of a successor who is able to take over when this becomes necessary. Farms can be quite different from each other depending on the personal views of the farmer who runs it.

A farmer is influenced by an extensive institutional framework. As explained in section 2.2.1, the manure policy should be evaluated in a broader legal context with respect to the environmental protection. Besides measures against environmental pollution, farmers should obey the animal welfare norms. These norms concern the animal housing system and animal transport. They are specific for the type of animal (NL, 2011c). It is stated that an animal housing system should be comprised of enough space, group housing and an appropriate floor grill (Baltussen et al., 2010). In 2013 the government will amplify these animal welfare norms. An overview of the different regulations that control farming activities is provided in figure 2.7.

[14] The production of manure is considered a byproduct of farming.

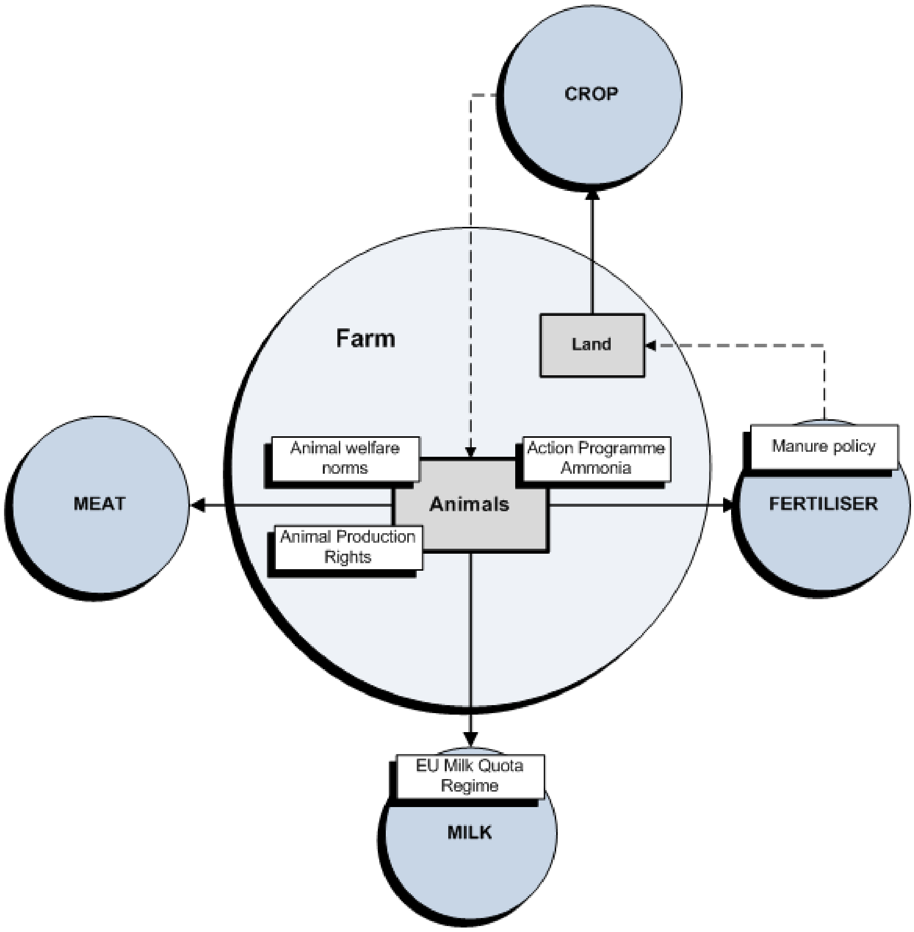

Figure 2.7: Farming activities are controlled by regulations

These rules and regulations clearly have an impact on farming activities. The fact that they are currently subject to change creates many uncertainties. The impact of these rules and regulations becomes clear when considering the financial situation of farmers.

Based on literature, the average income is considered low with respect to the (intensive) livestock farming sector (de Bont et al., 2010). As a result, the amount of capital that might be available for investments is modest. The poor financial situation is expressed in the sense that additional tasks - besides the main farming activities - are explored to improve the financial situation.

Due to the amplified regulations concerning the *animal welfare norms* and the *ammonia action programme*, farmers are confronted with investments concerning their animal housing system since many of them do not comply with the stated qualifications. If the required investment cannot be carry out (within the time period set), a future may no longer be envisioned in farming. As a consequence, a farmer may abandon his farm. From interviews it became clear that many farms - especially pig farms - may abandon before 2013. This percentage might exceed 40%. In addition, the percentage of cattle farms that may abandon each year is estimated 4 or 5% (LTO, 2011).

Within the livestock farming sector a tendency towards up scaling is observed. As stated in a study by LEI[15] large scale farms realise better economic results, but due to current organisation and the status of technology, these advantages are smoothed when the scale is even further increased

[15]The LEI Wageningen UR study is concerned with the process of up scaling in the agriculture sector.

(van der Meulen et al., 2011). Within this study it is stated that[16]:

- large-scale farms realise a higher labour productivity, have more often a successor, are more modern and run a higher risk compared to small-scale farms.
- large-scale farms are more intensive compared to small-scale farms. Although intensification may lead to a higher environmental impact, large-scale farms are better fit to carry out investments against the possible detrimental consequences caused by farming.

It is very important to realise that up scaling is an important strategy to secure a long-term continuity of the farm. As explained in (van der Meulen et al., 2011), up scaling leaves room for adjusting the production in a desired direction (e.g. to comply with animal welfare norms) as expanding the production can justify investments. As a result, up scaling could be a way to innovate and to become more sustainable.

Considering the above, it is expected that small-scale farms might be more vulnerable to abandonment compared to (relatively) large-scale farms. As a result, it is expected that the number of animals within a particular region may remain steady over time as farms expand and some other farms abandon.

2.5 Conclusion

As described in chapter 1, local initiatives are undertaken to explore new ways to produce renewable energy. In this light, the production of ME energy is introduced which constitutes the utilisation of manure for the production of biogas by means of the AD process and subsequently its upgrading to green gas. Since the collaboration of local farmers is desired for the development of a ME system, these farmers are confronted with the decision to produce ME energy.

Within this chapter we described the issues inherently related to the abundance of manure and how they give rise to a manure distribution system in which manure is distributed against high costs. Furthermore, the farmers situated within this manure distribution system are influenced by many policies that are currently subject to change. As a result, many uncertainties are present and it maybe therefore a valid and even challenging question whether ME has potential. Furthermore, with respect to the current issues related to the accumulation of valuable minerals, the question whether ME production can be beneficial for the manure distribution system in the long run.

The system under study is comprised of many individuals who are influenced by different factors. To explore the many possibilities that can emerge from the system, we proposed the development of an ABM as this *tool* allows a complex system to emerge from bottom-up. In chapter 3 we introduce the MAIA framework, which we used to develop the ABM.

[16] These statements are supported by findings from interviews.

Chapter 3

Methodology

3.1 Introduction

In this chapter we present the research methodology. In chapter 1, we proposed the development of an ABM for social simulation to obtain insights with respect to the formulated research questions. To develop an ABM we decided to use the MAIA[1] framework as this methodology allows for the decomposition and conceptualisation of the system for agent-based social simulation. *'To understand and explain individual behaviour, which is often extremely complex, institutions can provide a major structure for conceptualising these social systems'* (Ghorbani et al., 2012). As a result, we consider this methodology appropriate since this research is centred around local farmers and their decision making behaviour within a dynamic institutional context. Section 3.3 describes how the MAIA framework, which is organised in five structures, allows for the capturing of relevant system components. We used the resulting MAIA documentation to translate the system into computer code.

Conceptualisation by means of the MAIA framework requires a good understanding of the different system aspects and the components it is composed of. In chapter 2 we provide a description of the different aspects regarding the system placed within their appropriate context. As explained in chapter 1, we held interviews and made a literature review to obtain the relevant information and data. Subsequently, we applied an integrated system perspective with respect to the performed analysis. As a result, we were able to relate the different system aspects to the different concepts of the MAIA framework. An overview of this approach is presented in figure 3.1.

[1]MAIA constitutes a meta-model for *M*odellig *A*gent systems based on *I*nstitutional *A*nalaysis.

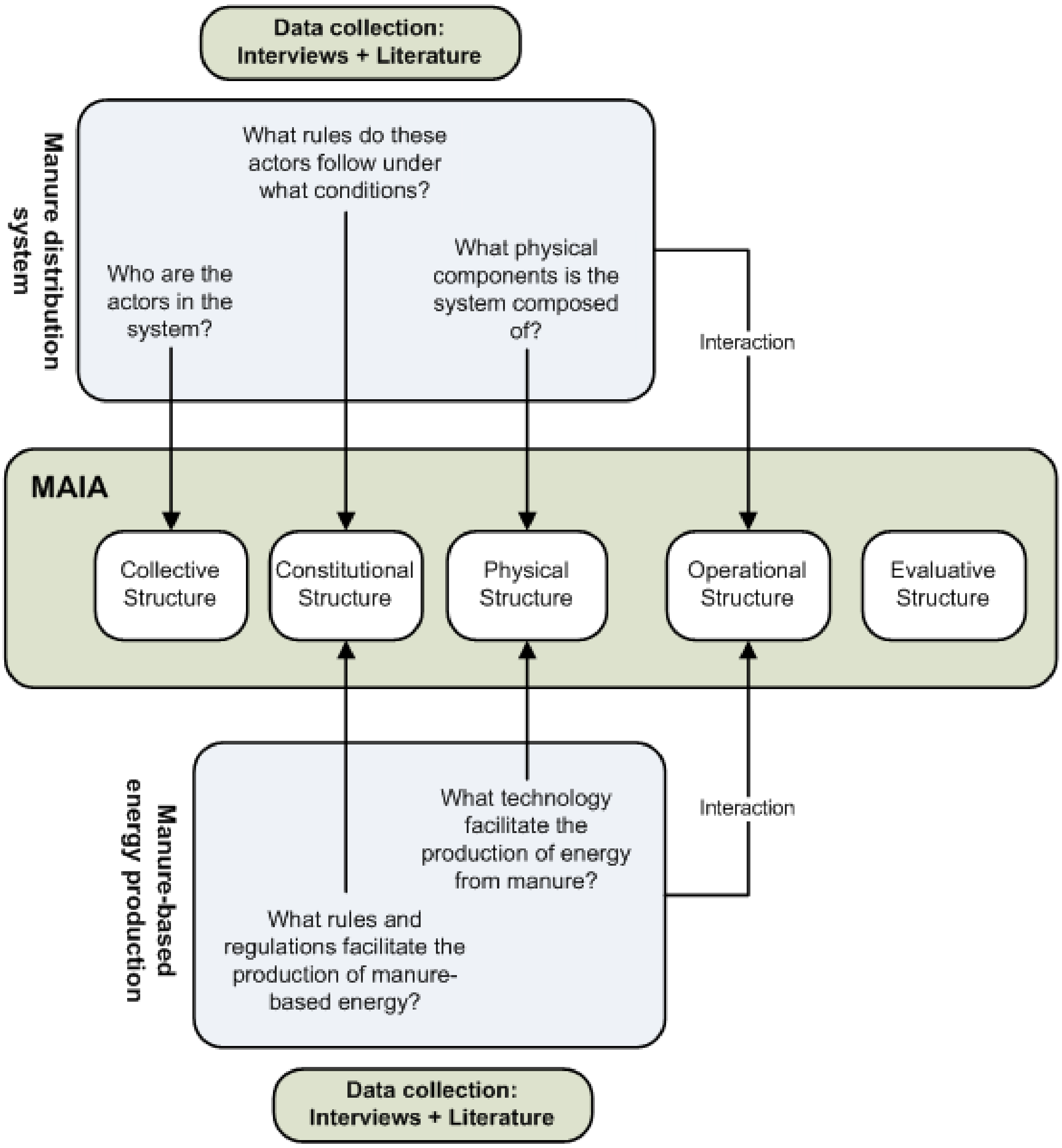

Figure 3.1: Approach to conceptualise system by means of MAIA for agent-based social simulation.

With respect to figure 3.1 we provide the following description:

- We stated (many) questions - in this figure we only present the most *fundamental* questions - with respect to the different system aspects as answering these questions would help to fill in the different MAIA concepts.
- Within the *collective structure* actors and their attributes are captured.
- The *constitutional structure* captures the institutional statements and defines what roles different actors are allowed to take.
- The *physical structure* captures the physical components (e.g. animals, manure, technology) of the system.

- The *operational structure* defines the conditions that allow for the interactions of different system components like for instance the agents that are capable of specific actions under specified conditions.
- We used the *evaluative structure* for the validation and verification of the modelled system.
- Conceptualisation by means of the MAIA framework resulted in an enhanced documentation that is used to translate the system into computer code.

This chapter is divided in three main sections. The first section 3.2 describes how relevant data and information are collected. Section 3.3 introduces the MAIA framework and how this methodology can be used to conceptualise the system for agent-based social simulation. We implemented the model in *Java*, then simulated it and we analysed the data output by means of *R*, a programming language and software environment for statistical computing and graphics. Section 3.4 describes the different steps we took regarding model simulation and data analysis to generate the modelling outcome.

3.2 Data collection

As introduced in chapter 1, the GGS project group has the objective to explore the opportunities of green gas production through a biogas infrastructure within the region of Salland. Considering this objective the collaboration of local farmers is considered vital as it is assumed that the production of ME has a considerable potential.

The objective of this research is concerned with the potential for ME production within Salland. As a consequence, this research is centred around the manure distribution system, the technology that facilitates the production of ME and the decision making of farmers with respect to ME production.

To obtain relevant information and data with respect to the stated research objective, we held interviews with actors within Salland and mainly based on these obtained insights we gathered additional data from literature.

A schematic overview of the approach applied for data collection is provided in figure 3.2. In this figure, we relate the information obtained from different actors[2] to the research content described in chapters 1 and 2.

[2] A list of respondents is presented in appendix A.

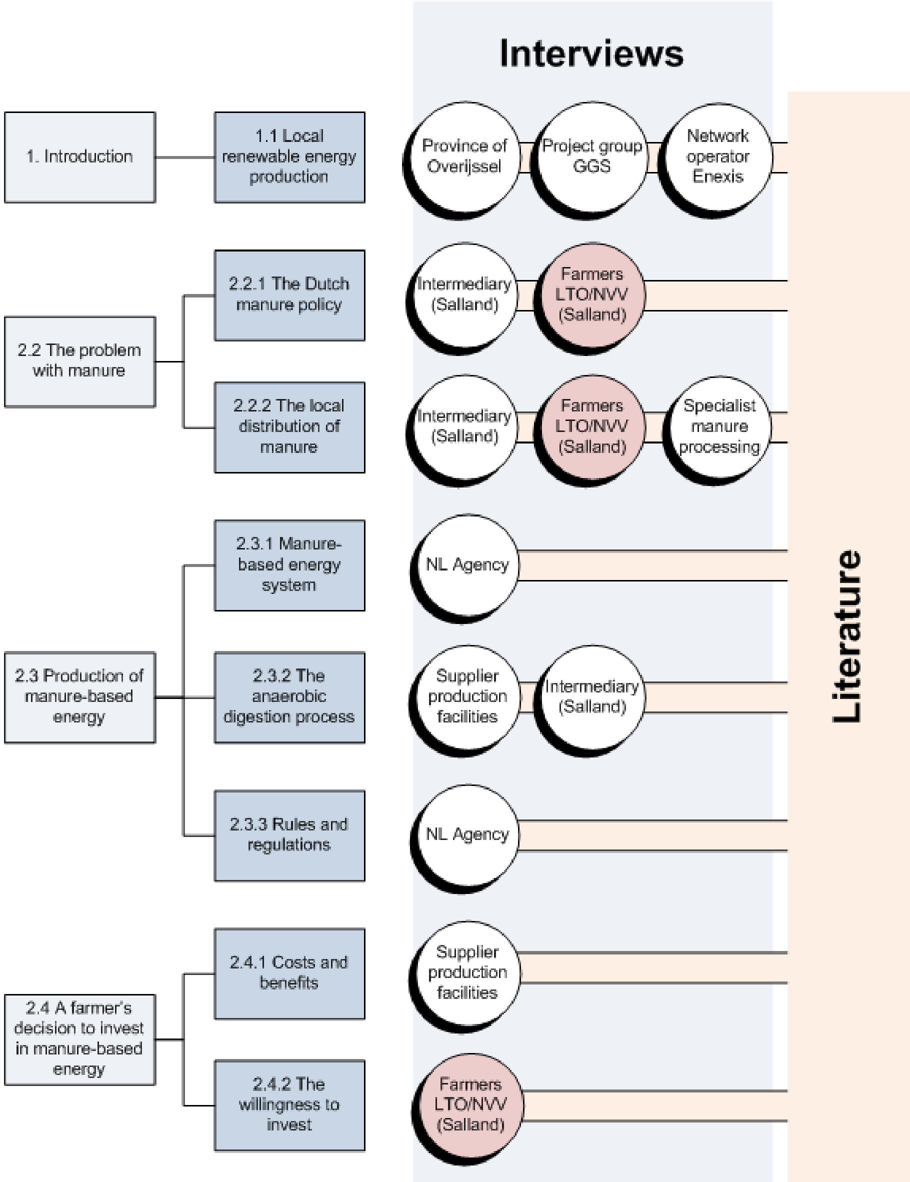

Figure 3.2: Data collection process

Interviews

We consider interviewing as an important way for collecting relevant data, especially since we are concerned with the local circumstances within the region of Salland and the perceptions of different actors towards the rather new concept of ME.

When considering the objective of the GGS project group, by means of attending project meetings we obtained relevant information with respect to the formulated objectives and we learnt what main challenges are faced regarding the (local) production of renewable energy. Furthermore, we obtained insights concerning the perspectives of different actors towards ME production as well as their possible roles within the development of a ME system.

At the start of the project, the project group GGS is composed of the following parties:

- Saxion, University of Applied Science
- Province of Overijssel
- Municipality of Olst-Wijhe
- Municipality of Deventer
- Municipality of Raalte
- ROVA, waste treatment plant that extends the activities of municipalities in the middle and eastern regions of the Netherlands.
- Enexis, distribution network operator
- LTO Noord Overijssel

We acquired an understanding of the manure distribution system by carrying out interviews with (cattle and pig) farmers[3] and an intermediary, all of them situated within Salland. With respect to the possibilities for manure processing, we interviewed a researcher from WUR (Wagening UR). Since this research is centred around the decision making of farmers, we consider their perception towards ME very important. On the other hand, since the production of ME is considered a rather new concept from a farmer's point of view, we consider their knowledge regarding the technological and institutional aspects of this subject rather poor.

Although information with respect to the technological aspects of ME production is made available by a supplier of production facilities and by an intermediary who owns a production facility, we obtained most of the information concerning these aspects from literature. As far as the institutional aspects of ME production are concerned, we gathered information by means of an interview with NL Agency and additional information from literature.

In order to develop a model a lot of quantitative (empirical) data is required. This data concerns for instance the number of actors that are modelled as agents in the system as well as the manure production figures. In appendix C we present an overview of the quantitative data used for modelling.

3.3 MAIA

The MAIA framework is designed by Amineh Ghorbani and supports the use of institutions as a major structure for conceptualising social systems (Ghorbani et al., 2012). The MAIA framework extends and formalises the components of the IAD[4] to present a meta-model for conceptualising social systems for agent-based simulation (Ghorbani et al., 2012).

An institution is defined by Ostrom as "the set of rules actually used by a set of individuals to organise repetitive activities that produce outcome affecting those individuals and potentially affecting others" (Ostrom, 2005). An ABM uses a bottom-up perspective. Individual agents act and react to each other, following their internal rules (Nikolic et al., 2009). The (local) interactions within a system lead to patterns that can be evaluated by the analyst. The MAIA methodology views actors as institutional-driven entities.

Agents form the key concepts of the modelled system and they are placed within a context comprised of physical and social[5] components. Agents should be viewed as intelligent entities with capabilities defined in an operational environment.

[3] In general, pig farmers are mainly associated in NVV (*Nederlandse Vakbond Varkenshouders*) and cattle farmers are associated in LTO (*Land- en Tuinbouw Organisatie Noord*.

[4] An institutional framework that provides a collection of concepts present in a social system with an institutional perspective (Ostrom, 2005).

[5] For example the social networks in which agents are embedded.

As described in the introduction of this chapter, the concepts in the MAIA meta-model are used to conceptualise and decompose a system for agent-based modelling. As described in (Ghorbani et al., 2012), the concepts within the MAIA framework are organised in five structures. An overview of these structures is presented in figure 3.3.

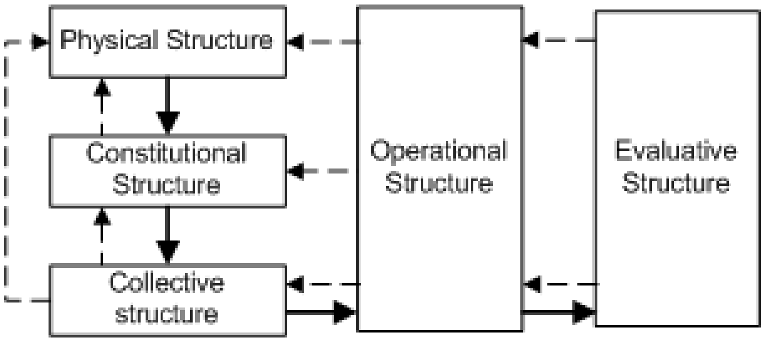

Figure 3.3: The MAIA meta-model is organised into five structures.

Within the structures relevant information is captured that can be used to translate the system into computer code.

3.3.1 Collective structure

The collective structure is concerned with the actors and their attributes. As explained, the system is considered as a social system and the different actors are referred to as agents. Agents could present both individual actors and composite actors (a group or a party).

Agents have a name, for example an *Animal Farmer Agent*. They possess certain properties (e.g. a location or a successor) and they own physical components (e.g. animals or fertiliser). Furthermore, they have personal values that influence the way how they perceive the choices available to them. Agents know things (they possess information) and they have intrinsic capabilities that are defined as behaviours specific for the particular agent. An intrinsic capability of an animal farmer might be carrying out an investment in green gas production. These capabilities are defined as intrinsic since they do not depend on the roles an agent can take within the system. Agents make decisions concerning the tasks they perform (Ghorbani et al., 2012).

3.3.2 Constitutional structure

The constitutional structure is comprised of three main concepts:

- Roles
- Institutional statements
- Dependency

As stated, agents can take different roles. Roles are enacted to reach social objectives (Ghorbani et al., 2012). These activities take place according to some rules. Agents are allowed to take a role if they meet the entry conditions specified for that particular role. For example, an animal farmer is allowed to take the *Landowner* role if he possesses *land*. As a Landowner he is able to fulfil his social objective which is manuring his land. When enacting a role, additional capabilities come available: a Landowner is capable of calculating how much fertiliser he needs for manuring his land. We define that a particular agent can take many different roles and that one particular role can be enacted by many different agents, simultaneously and sequentially (Ghorbani et al., 2012).

Within the system, **rules** are defined that govern agent behaviour. Besides rules, **norms** and **shared strategies** are defined which are all institutional statements. An institutional statement is comprised of the *ADICO*:

- **A**ttributes; the designated roles.
- **D**eontic; the statement can be of the type *prohibition*, *obligation* or *permission*.
- a**I**m; the action taken by an agent defined as a capability of the roles that the statement is part of.
- **C**ondition; indicates when or where the aim should take place.
- **O**r else; indicates what sanction might apply when the statement is not fulfilled.

Rules are comprised of all items of the ADICO. A statement without an explicit sanction is called a norm. Subsequently, a statement without a deontic can be a shared strategy among roles (Ghorbani et al., 2012).

Table 3.1 provides an example of a norm defined according the ADICO.

Table 3.1: Institutional statement: Norm

Name	Derogation
Attributes	Landowner
Deontic	Permitted
aIm	Using a maximum of 250 kg N manure-based fertiliser per hectare (instead of 170 kg N) for land treatment.
Condition	The manure is produced by cattle and the animal farmer agent possesses at least 70% grass land.
Or else	-

We emphasise that agents do not follow the rules associated with their roles in an automatic sense. Within their decision making process, agents are influenced by their properties, personal values or by the states of other agents as well as the state of the system. As a result, they can decide not to follow a particular rule.

3.3.3 Physical structure

Within the physical structure, physical components are defined. These components can be used or operated by agents. For example, *fertilisers* are used to manure *land* and a *technology* is applied to produce *green gas* and *digestate*. Furthermore, physical components may have behaviours. Within the system cattle and pigs are defined as physical components and their behaviour comprises the production of manure.

In addition to the physical components, the *physical composition* or the *physical connection* might be relevant. The physical composition captures the composition relation between components. The physical connection shows which physical components are connected to each other.

3.3.4 Operational structure

As described in (Ghorbani et al., 2012), '*the operational structure describes the conditions in which agents use their capabilities to act and react, and the changes in the status of the system*'.

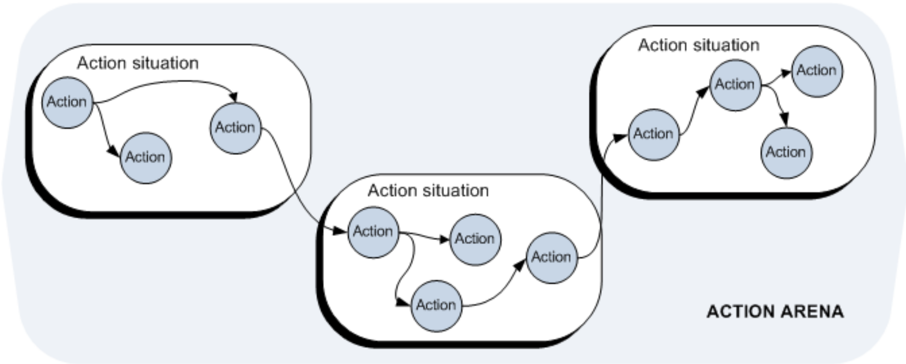

Figure 3.4: Action arena

Agents perform actions. Within the MAIA framework, actions are defined as '*an operationalised description of the capabilities of roles or the behaviours of agents and physical components specifying the pre and post conditions for a capability/behaviour to trigger, the role, agent or physical component that will be performing that action and the institutions that are involved (if any)*' (Ghorbani et al., 2012).

As shown in figure 3.4 these *actions* are defined in *action situations* which are part of an *action arena*. The *action sequence* defines the order in which the actions take place. In addition, for each action it is defined which roles should be taken by which agents.

For example, within the action situation *Bio-production* several actions can be defined, such as the production of manure by animals, the decision to invest in biogas production and the production of biogas (and digestate). It should be clear that 'the postcondition of the first action changes the status of the system which is a precondition for the consequent action to take place' (Ghorbani et al., 2012), e.g. biogas production does not occur without investments.

3.3.5 Evaluative structure

The evaluative structure is concerned with two questions:

- *Did we build the right model?*
- *Does the model answer our questions?*

To answer the first question, variables should be identified that allow the model to be validated. Direct and indirect relationships between these validation variables are captured in a *validation matrix*.

To answer the second question, variables should be identified that can provide answers to problem domain questions. These problem domain variables should provide insight regarding the model dynamics, e.g. the number and type of green gas producers within the system. Similar to the validation variables, direct and indirect relationships between these variables are captured in a *scope matrix*.

3.4 Model simulation and data analysis

We decided to build the model in the object-oriented programming language **Java** with means of the open-source IDE[6] software *Eclipse*. After the implementation we simulated the model and preformed the data analysis by means of **R**, a programming language and software environment for statistical computing and graphics. In carrying out the data analysis the IDE for R, *RStudio* is used.

An schematic overview of the performed steps regarding model simulation and data analysis is presented in figure 3.5.

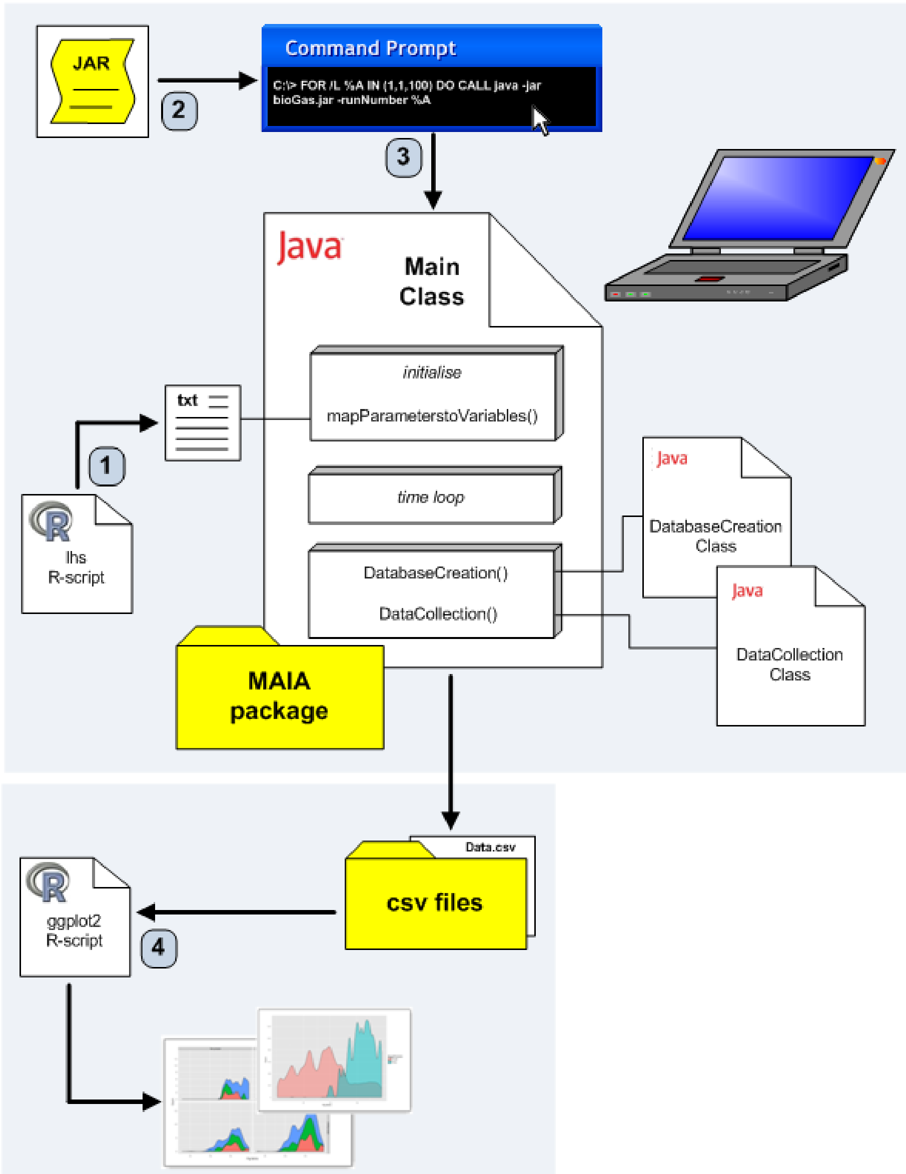

Figure 3.5: Schematic overview of performed steps regarding model simulation and data analysis

The following sections describe the different steps that we performed to come to the desired model output.

[6] integrated development environment

3.4.1 Model simulation

Since the MAIA framework allows for the conceptualisation in relational tables they can be easily coded with object-oriented programming languages (Ghorbani et al., 2012). The structures in MAIA can be defined as packages that consist of a number of abstract classes which have default fields and methods. The advantage of an object-oriented programming language like Java is the fact that domain specific classes are able to override the methods within each abstract class with their own specifications. As explained in (Ghorbani et al., 2012), the main class consist of three parts: the *initialise method*, the *time loop* where the action arena is located and the *data methods*. The model is simulated on a laptop[7].

Step 1

By means of the Latin Hypercube Sample (LHS) package of R, we wrote a R-script that produces a text file. The LHS is a statistical method for generating a distribution of plausible collections of parameter values from a multidimensional distribution. As explained in (Nikolic et al., 2009), LHS is used to guarantee a more uniform distribution across the parameter range.

The generated text file comprises a data table in which different values are assigned to parameters that are selected for the data input design. The *mapParameterstoVariables()* method within the main simulation class receives the text file as an input and maps after each run new values to the parameters in the model.

Step 2

We built a JAR[8] file by means of the *Fat Jar Eclipse Plug-In Deployment-Tool*, which deploys an Eclipse java-project into one executable jar. The resulting jar contains all needed classes and can be executed directly with "java -jar", no classpath has to be set and no additional jars have to be deployed.

Step 3

We used the text-mode command prompt window to call the generated jar file in order to execute the java-project. This is done by means of a FOR loop that repeats the command for each particular run number. As a result, the model is simulated for 50[9] runs.

After each run, we collected the data by means of the *DataCollection()* method from the DataCollection class and stored the data in a csv (comma-separated values) file format by means of the *DatabaseCreation()* method from the DatabaseCreation class.

3.4.2 Data analysis

The model comprises in total 1039 agents[10]. We collected data concerning the actions of these agents over time. The run time amounts 26 years and at every tick (a year), the situation of each

[7] Intel(R) Core(TM)2 Duo CPU T9600 @ 2.80GHz

[8] JAR (Java ARchive) is an archive file format typically used to aggregate many Java class files and associated metadata and resources into one file.

[9] Depending on the type of experiments, the model can be simulated as many times as desired, e.g. 500 times would have been possible as well.

[10] As stated in appendix C: 843 cattle farmer agents and 196 pig farmer agents.

unique agent is saved[11]. We run the model repeatedly 50 times, generating a large amount of data.

As stated in section 3.4, we carried out the data analysis by means of the programming language *R* that allows for data manipulation, calculation and graphical display. Especially since the amount of data is large, *R* is considered an effective data handling and storage facility. Furthermore, *R* provides a wide variety of statistical and graphical techniques, and is highly extensible.

Step 4

We wrote a R-script to make the generated data files in csv format accessible for analysis. Several packages can be used for data manipulation. To create the graphics we used mainly the *ggplot2*[12] package[13].

3.5 Conclusion

In this chapter we described how we performed the data collection and how MAIA can be used to conceptualise the system for agent-based social simulation. Within the data collection process, we consider especially interviewing quite helpful to obtain relevant information. Conceptualisation by means of the MAIA framework resulted in an enhanced documentation that we used for translating the system into a computer code. We simulated the model to obtain the required data output. By means of the programming language *R* we were able to analyse the data and interpret the model outcome.

In this chapter we introduced the MAIA framework. In chapter 4, we will describe explicitly the identification and capturing of different system components as well as the modelling choices and assumptions made with respect to modelled system.

[11]Since the *DataCollection()* method is executed within the *time loop*, this becomes possible.

[12]Mostly the functions *facet-grid*, *facet-wrap* and *stat-density*.

[13]The R-scripts can be found at https://svn.eeni.tbm.tudelft.nl/FemkeDeKorte/Rscripts.

Chapter 4

Modelling a manure distribution system

4.1 Introduction

Within this chapter, it is described how the manure distribution system is modelled. As described in chapter 3, the MAIA framework allows for the conceptualisation, design and implementation of an ABM. In addition, based on the analysis in chapter 2, relevant system components are identified and captured for an ABM. This chapter starts with a description of the model in which the model narrative as well as the modelling choices and assumptions are presented. Section 4.3 explains the performed conceptualisation by means of the MAIA framework. This section is followed by a section in which details with respect to the model design are described. Finally, a description of the performed verification and validation is presented.

4.2 Model description

4.2.1 Model narrative

In this section the model narrative is presented describing a sequence of events which can be thought of as a *story line*.

The model concept comprises a manure distribution system in which farmers are confronted with decisions with respect to their farming activities. Within this modelled system, farmers are introduced to ME production. As a result, they can start producing ME next to their farming activities. An overview of what part of the system has been conceptualised for modelling is indicated in figure 4.1.

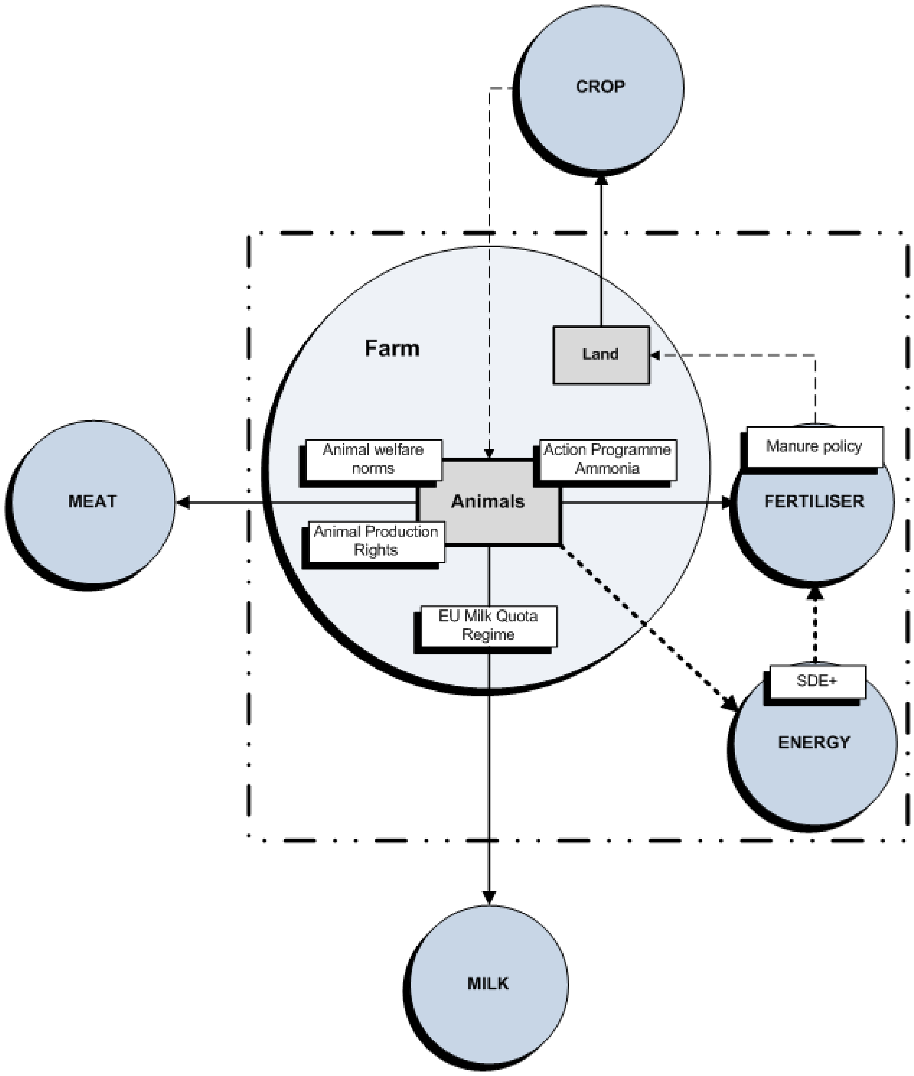

Figure 4.1: Part of system that is conceptualised for modelling

Manure distribution system

We defined cattle and pig farmer agents within the manure distribution system and we identified several properties for these agents:

- Animals: All farmer agents possess a specific amount of animals.
- Land: Only cattle farmer agents are defined to own crop and grass land.
- Location: Within the system, three locations are defined: *Raalte*, *Olst-Wijhe* and *Deventer*.
- Successor: Both cattle and pig farmer agents may have a successor.
- Capital: Both cattle and pig farmer agents possess a small, medium or large amount of investment capital.

All animals produce manure, this is a continuous process. The manure contains minerals: phosphates (P) and nitrogen (N). All farmer agents are obliged to obey the *fertiliser law*. As a result, each year they make a decision concerning the distribution of manure. Depending on their individual circumstances (e.g. the volume of manure produced, the mineral content of the manure, their location and the availability of land) they use the manure for manuring their own land, distribute the manure to a neighbour or leave the distribution to an intermediary.

Manure that is collected by the intermediary is distributed again within the system in case a need for manure-based fertilisers is still present. Since the use of *manure-based* fertilisers is restricted, some farmer agents will pay for *artificial* fertilisers.

The distribution of manure is associated with costs. These costs are comprised of four components: transportation, analysis, storage and acceptance costs (details are provided in appendix C). Furthermore, labour costs are paid for manuring. Each year, the intermediary will calculate these costs based on the amount of manure he collects and will distribute again. Manure that cannot be used within the system is considered as abundant.

Due to the introduction of the *action programme ammonia* and the amplified animal welfare norms, farmer agents may, depending on their individual circumstances, decide to abandon their farm. On the other hand, some farmers may decide to expand their farm. Each year, all agents are confronted again with these choices.

Production of manure-based energy

All farmer agents are on a annual basis confronted with the decision to produce ME. The production of ME comprises the adoption of a technology that allows for the production of *green gas* and *digestate* from manure. Digestate is considered to have similar qualities compared to manure and will be distributed in the manure distribution system. Annual technology costs have to be paid for operating the technology and revenue is obtained by the supply of green gas. It is presumed that permits and subsidy (by means of the SDE+ regulation) are granted.

The decision to produce ME (or green gas) is based on the following factors:

- Gains: The benefits that can be obtained from ME production.
- Neighbours: The actions of neighbouring agents concerning ME production.
- Capital: Both cattle and pig farmer agents possess a small, medium or large amount of investment capital.
- Character: The personal strategy a farmer applies to his farm.

Furthermore, it is incorporated that farmer agents can cooperate with each other. Farmer agents that decide to cooperate will form a group and will operate a technology together.

It is defined that time starts running in 2011 and stops in 2026. Considering the time required for design and implementation of a ME production system, it is decided that production may start from 2014.

4.2.2 Modelling choices and assumptions

The objective of this research is to explore the potential for ME production within an evolving manure distribution system and to investigate to what extent this can be beneficial for this system in the long run. The system is explored by means of agent-based social simulation.

As described in chapter 1, possibilities for the production of green gas are currently explored within the region of Salland. As a natural consequence, the defined manure distribution system is based on the local circumstances with respect to Salland and relevant data for modelling is collected from this region.

In the development of every model, modelling choices and assumptions are made. In the following paragraphs we describe what choices and assumptions are made with respect to the capturing of different system components.

Manure distribution system

In general, we observed that only cattle and pig manure is considered for the production of renewable energy. Considering this fact, we chose to capture only the cattle and pig farms within model. Based on the empirical data available from the region of Salland combined with data from literature, a farmer agent distribution is made in which the number of agents present in the system and the specific agent properties are defined (see appendix C).

Based on literature and interviews, we assumed that only cattle farmer agents own land. Based on statistics with respect to the number of hectares agricultural land within Salland, crop- and grassland is distributed among these cattle farmer agents in proportion to the size of their farm.

Cattle manure does differ from pig manure with respect to the volume produced and its mineral composition. Based on figures from literature, an estimation is made regarding the mineral composition and the annual production (see appendix C).

Although we explained in chapter 2 that approximately 10 intermediaries are present within the region of Salland, we decided to capture just only one intermediary agent as we only consider the *function* he carries out important: Farmers may have several manure distribution options in which the distribution of manure to an intermediary is considered the most expensive. Since manure is abundantly present and farmers are forced to distribute the excess. They have no other choice but to give the manure to an intermediary against the price set by this intermediary. As a result, there exists no *actual trade* between an intermediary and a farmer agent.

Rules and regulations

As described in chapter 2, many rules and regulations are stated from which we consider to have an impact on the decision making of farmers (see figure 4.1).

Within the manure distribution system all farmer agents obey the fertiliser law which states how much of the minerals can be used for manuring. Furthermore, farmers are made aware of the policy adjustments with respect to the *animal welfare norms* and *action programme ammonia*. Based on the expected impact of these regulations[1], farmers may decide to abandon their farm. In addition, a tendency of up scaling is observed as this might secure a long term continuity of the farm in times of economic uncertainty[2]. To capture the possibility of up scaling, farmers are provided with the opportunity to expand their farm. The decision to abandon or to expand is considered each year.

Farmers and their decision making behaviour

We characterise agents as entities of bounded rationality as their rationality is limited by the information they have, their cognitive capabilities and time. As outlined in section 4.2.1, the decision making of farmer agents to produce ME is based on four factors: *gains*, *neighbours*, *capital* and *character*.

We decided to capture the agent's decision making process within a *Multi Criteria Decision Analysis* (MCDA) concept. This concept is not static as the value of different factors is influenced by changes in the internal state of the agents and state of the system. The implemented MCDA comprises an abstract an simplified presentation of a decision making process as different weights[3]

[1] As described in chapter 2, it is expected that a considerable percentage will quit farming as they consider themselves no longer capable of carrying out the required investments.

[2] Especially the possible abolition of the *animal production rights* and the *EU milk quota regime* is expected to create a push towards up scaling.

[3] As explained in chapter 4, these weights are set based on information obtained from interviews.

are used to calculate a *decision value* which on its turn is compared to a *decision threshold*. The functioning to the MCDA is further explained in section 4.4.

We make clear that assumptions are made especially with respect to the personal attitude of farmers towards ME production. In addition, general concepts are at the basis of the stated factors. Considering the number of agents and the level of detail applied, we decide to provide all agents with the same decision making procedure, which might not be true in reality as factors might be valued differently.

Production of manure-based energy

When a decision is made to produce ME, a farmer agent starts operating a technology and pays annual technology costs. The investment capital required for operating a production facility is captured within the (MCDA) factor *capital*. The annual technology costs are assumed to be influenced by the dynamics of energy prices (electricity and gas prices). Furthermore, we made the decision to allow for *cooperation*. In case a group of agents is formed, they share a technology. Each of them obtain revenue based on the volume of manure he makes available and pays annual technology costs. Based on the number of agents that cooperate, it is assumed that annual technology costs will decrease as soon as a certain production capacity is reached.

The technology converts manure directly to *green gas* in a fixed ratio, hence *no* biogas is produced. Furthermore, it is assumed that subsidy and permits are granted as soon as the decision to start production is made. Farmer agents who produce green gas will obtain revenue from their supply as they receive a specific *basic amount* for every m^3 of gas produced. This *basic amount* will be referred to as *revenue*.

We assumed that production can take place somewhere within the surroundings of a farm as the physical space is not defined. Furthermore, a biogas distribution network is not captured as a physical component. Furthermore, local possibilities for gas injection into the natural gas distribution network are not considered as the current energy infrastructure is not taken into account. As a consequence, no implications can be made with respect to the actual production locations. Within this context, we decided to allow only for the production of green gas as the final end product for which revenue can be obtained.

4.3 Conceptualisation

Within the process of system conceptualisation, design and implementation the MAIA framework is used. In the following sections the conceptualisation process is described. The MAIA documentation which is composed of tables and diagrams that accompany the different concepts can be found in appendix B.

4.3.1 Collective structure

Within the collective structure the agents are defined as the nodes of the collective (Ghorbani et al., 2012).

Agents

In the model three different agents are defined: the *Animal Farmer Agent*, the *Intermediary Agent* and the *Artificial Fertiliser Supplier Agent*. Since the later two are defined as **external**, only the

Animal Farmer Agent is allowed to take roles and follows institutions. Two different types of Animal Farmer Agents are defined: *cattle farmer agents* and *pig farmer agents*. Details with respect to the agent distribution can be found in appendix C.

- **Intermediary Agent**: The Intermediary Agent is an intermediary operating in the system. He collects manure or digestate from the region and distributes these products according to the mineral need within the region. He has knowledge about which Animal Farmer Agents have manure or digestate available and which agents are in need of minerals. He receives money for his activities from Animal Farmer Agents who need to distribute the manure or digestate.
- **Artificial Fertiliser Supplier Agent**: The Artificial Fertiliser Supplier Agent is a company that sells artificial fertiliser to any Animal Farmer Agent who is in need of minerals from artificial fertilisers.
- **Animal Farmer Agent**: This agent owns cattle or pigs. He follows institutions and is allowed to perform actions. All agents will make decisions with respect to the distribution of manure (or digestate), the investment in ME production and the abandonment as well as the expansion of the farm.

4.3.2 Constitutional structure

Roles

Only the Animal Farmer Agent is allowed to take roles. Depending on the situation, this agent might take one of the following roles that are defined:

- **Landowner**: The Landowner owns crop- and grassland. Since crop- and grassland should be manured, the Landowner is capable of calculating each year how much nitrogen and phosphate he needs for manuring.
- **Producer**: The Producer is capable of green gas production from manure and obtains revenue from the supply of green gas.

Since pig farmer agents do not own any land, they are not allowed to take the role of Landowner. Both agent types are can take the role of a Producer.

Institutions

Each year the Animal Farmer Agent is confronted with many decisions and within his decision making he is affected by several institutions. The following institutions form the basis for the rules that influence the behaviour of the agents:

- **Manure policy**: The manure policy constitutes the *fertiliser law*, the *animal production rights* and *EU milk quota regime*. The fertiliser law indicates how much nitrogen and phosphate an agent is permitted to use for manuring. Based on type of land and the number of hectares, agents calculate the amount of nitrogen and phosphate they need for manuring. We assumed that all cattle farmer agents apply *derogation*, they are allowed to use more kilogrammes of nitrogen per hectare. However, this is only permitted if the nitrogen originates from cattle manure.
- **Farmer-farmer transport**: On the condition that cattle farmer agents use 80% of their phosphates for manuring of own land, they are permitted to apply *Farmer-farmer transport*. This institution permits a cattle farmer agent to transport the manure to neighbouring agents (within the same location) against reduced costs.

- **Subsidy**: An agent who takes the role of a Producer is allowed to obtain a specific *basic amount* (revenue) granted by subsidy for his supply of green gas.
- **Abandonment and expansion of a farm**: Agents are confronted with policies such as the *ammonia action programme* and the *animal welfare norms*. As pig farmer agents own housing systems, these policies mainly affect pig farmer agents. As described in chapter 2, it is expected that a considerable percentage of the farmers may abandon their farm by 2013. Furthermore, a tendency towards up scaling is observed for both cattle and pig farms. Depending on the individual circumstance (e.g. scale of the farm and presence of a successor), an agent might decide to abandon or expand. Since it is expected that each year a few percent may abandon, this trend is captured in the model. In case an agent decides to expand, he is allowed to increase the number of animals and hectares[4]. An agent is permitted to expand only twice within on simulation.

The MAIA table 4.1 provides insight in the capturing of these institutions for the translation into an executable computer code.

[4] An agent is only allowed to increase the number of hectares if land is made available to him by an abandoning neighbour within the same location.

Table 4.1: MAIA constitutional structure: institutions

Institution	Manure policy (including *derogation*)	Farmer-farmer transport	Subsidy	Abandon of farm	Expansion of farm
Deontic type	Prohibition	Permission	Permission	Obligation	Permission
Type	Formal institution	Formal institution	Formal institution	Informal institution	Informal institution
Subject	Landowner	Animal (Cattle) Farmer Agent	Producer	Animal (Cattle and Pig) Farmer Agent	Animal (Cattle and Pig) Farmer Agent
Content	Agents that take the role of *Landowner* are allowed to manure their land. Depending on the number of hectares, type of soil, and cultivation the amount of nitrogen and phosphate are set. The usage of more then 170 kilogrammes of nitrogen per hectare is prohibited. Furthermore, in case *derogation* applies this amount is increased to 250 kilogrammes of nitrogen. The amount of phosphate is set to 90 kilogrammes for grassland and 65 kilogrammes for cropland.	Agents that have cattle and are able to use more then 80% of the phosphate for manuring of own land, are permitted to transport their excess to neighbouring (cattle) farmer agents within the same location. This against reduced *transport costs* and no *analysis costs*.	Agents that take the role of *Producer* are permitted to obtain a *basic amount* granted by subsidy for the production of green gas.	Farmers are obliged to meet the requirements stated in the *ammonia action programme* to reduce the ammonia emissions from animal housing systems at farms by 2013. In addition, in 2013 the government will amplify the *animal welfare norms*. Since the adjustments to the animal housing systems require investments, a financial burden is placed upon especially pig farmers. Considered the financial situation within this sector, it is expected that a substantial part of these agents will abandon their farm in 2013. Furthermore, a tendency is observed in which farms expand and relatively small-scale farms abandon. To capture this trend, farms that are considered to be more vulnerable for the possible impact might abandon. It is captured that a few percent of both cattle and pig farmer agents will abandon each year.	Agents are permitted to expand their farms. It is implemented that they can expand their farms only two times during a simulation, depending on their local circumstances.

4.3.3 Physical structure

Within the physical structure relevant components that have a physical representation in the system are captured.

Physical components

The following physical components are captured:

- **Animals**: Animal Farmer Agents own cattle or pigs. These animals produce manure. Details about the number of animals as well as the volume of manure and mineral composition can be found in appendix C.
- **Land**: Only cattle farmer agents own crop- and grassland. These agents possess a specific amount of hectare based on statistics of the Salland region C.
- **Manure**: All animals produce manure. Depending on the type of the animal an estimation is made of the annual production and mineral composition.
- **Digestate**: Besides the production of green gas, digestate is produced. We assumed digestate to be similar to manure. Since manure from cattle differs in composition compared to manure from pigs, digestate from cattle also differs from pig digestate.
- **Artificial fertiliser**: The fertiliser law puts limits to the excessive usage of minerals from manure. Since the agents that own land might still be in need for minerals, they are permitted to use artificial fertilisers. The artificial fertiliser is priced according to the quantities of nitrogen (kg) and phosphate (kg) it contains.
- **Green gas**: Green gas is produced from manure by means of technology. The volume (m^3) of green gas that is produced depends on the volume of manure that is utilised.
- **Technology**: The technology used for the production of green gas and digestate can be considered as a *conversion unit* which requires manure as an input and produces green gas and digestate at the output. For operating a technology, agents pay annual technology costs.
- **Money**: Every agent has to pay money (€) for the distribution of manure (or digestate), for the possible labour costs with respect to manuring and for the annual technology costs. Likewise, they receive money when they accept manure from a neighbour or Intermediary Agent. Furthermore, they obtain revenue from the supply of green gas.

4.3.4 Operational structure

Within the operational structure we capture the continuous activities of the system. In the following paragraphs we present the *action situation* and the *role enactment*. The action situation defines the overall operational procedure of the system as it is the place holder for a set of related events (Ghorbani et al., 2012). Within the role enactment the relationships between agents, roles and action situations are shown.

Action situation

We defined three main action situations:

- **Farming**: Within the *farming* action situation all farm-related activities are performed. These activities comprise manuring and the decision making with respect to the expansion and abandonment of the farm.

- **Manure distribution**: In the *manure distribution* action situation, all activities related to the distribution of manure and digestate as well as the buying of artificial fertilisers are performed.
- **Bio-production**: The *bio-production* action situation comprises the activities that are related to the production of manure, green gas and digestate. Within this action situation, the decision to produce green gas is made. Subsequently, annual technology costs will be paid and revenue from green gas will be obtained.

In figure 4.2, the action sequence is shown. This action sequence shows the overall operational procedure of the system as it defines the order in which the actions take place.

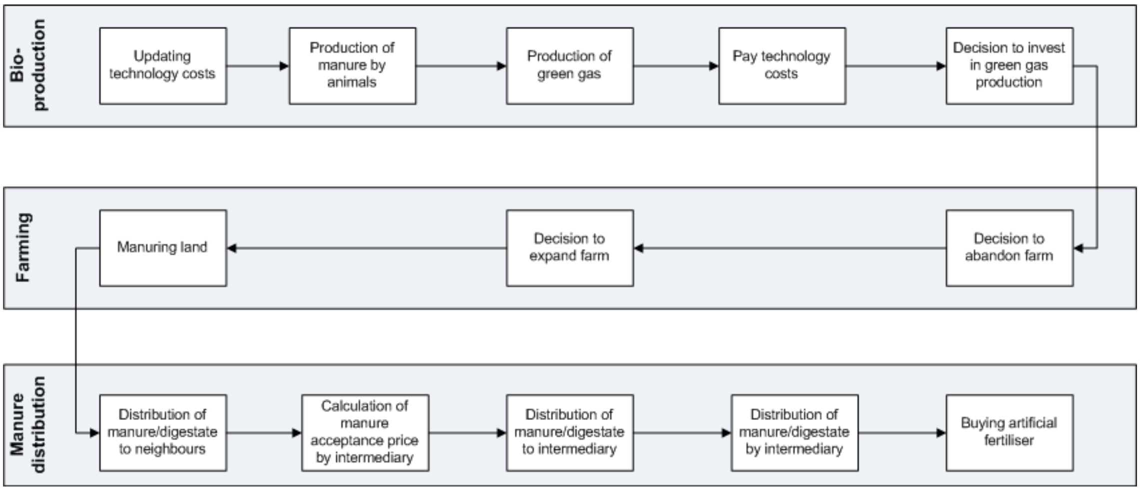

Figure 4.2: Action sequence

Role enactment

Table 4.2 shows what roles can be taken by which agents in a particular action situation.

Table 4.2: Role enactment

Agent	Action situation	Role
Animal Farmer Agent	Farming	Landowner
Animal Farmer Agent	Manure distribution	Landowner
Animal Farmer Agent	Bio-production	Producer

4.3.5 Evaluative structure

Within the evaluative structure two matrices are defined: the *scope matrix* (table 4.3) and the *validation matrix* (table 4.4). These matrices capture the relation of each variable with the actions performed in each action situation. This relation can be direct (d) or indirect (i).

Scope matrix

The problem domain variables are identified to make sure that the answers the model needs to give are covered. These variables provide insight with respect to the dynamics of the system. The values of these identified variables constitute the outcome of the model simulation and are realised during runs or even after. The problem domain variables are presented in table 4.3 and the relationship with each action is defined by a *d* for direct or an *i* for indirect.

Table 4.3: Scope matrix

	Update technology costs	Manure production	Green gas investment	Green gas production	Paying technology costs	Decision to abandon	Decision to expand	Manuring land	Distribute manure to neighbours	Calculation of manure acceptance price	Distribute manure to intermediary	Distribution of manure by intermediary	Buy artificial fertiliser
Manure (cattle or pig)	i	d	d	d	i	i	i	d	d	d	d	d	i
Acceptance price manure	i	i	d	i	i	i	i	i	d	d	d	d	i
Money of farmers	i	i	i	d	d	i	i	d	d	i	d	d	d
Number of farmers	i	i	i	i	i	d	i	i	i	i	i	i	i
Number of animals	i	i	i	i	i	i	d	i	i	i	i	i	i
Technology costs	d	i	i	i	d	i	i	i	i	i	i	i	i
Green gas volume	i	d	i	d	i	i	i	i	i	i	i	i	i
Number of producers	i	i	d	i	i	i	i	i	i	i	i	i	i
Number of groups	i	i	d	i	i	i	i	i	i	i	i	i	i
Size of groups	i	i	d	i	i	d	i	i	i	i	i	i	i
Composition of groups	i	i	d	i	i	i	i	i	i	i	i	i	i

From table 4.3 it is shown that many variables, for example the number of producers in the system and number of groups, are directly related to the *decision to invest*, indicating the magnitude of this action.

Validation matrix

The validation matrix identifies variables to validate and debug the system. The matrix is presented in table 4.4. Similar to the scope matrix, the relationship with each action is defined by a *d* for direct or an *i* for indirect.

Table 4.4: Validation matrix

	Update technology costs	Manure production	Green gas investment	Green gas production	Paying technology costs	Decision to abandon	Decision to expand	Manuring land	Distribute manure to neighbours	Calculation of manure acceptance price	Distribute manure to intermediary	Distribution of manure by intermediary	Buy artificial fertiliser
Manure (cattle or pig)	i	d	d	d	i	i	i	d	d	d	d	d	i
Green gas volume	i	i	i	d	i	i	i	i	i	i	i	i	i
Acceptance price manure	i	i	d	i	i	i	i	i	d	d	d	d	i
Money	i	i	i	d	d	i	i	d	d	i	d	d	d
Number of farmers	i	i	i	i	i	d	i	i	i	i	i	i	i
Number of animals	i	i	i	i	i	i	d	i	i	i	i	i	i
Technology costs	d	i	i	i	d	i	i	i	i	i	i	i	i

From table 4.4 it is shown that the number of farmers is directly related to the *decision to abandon*. As a consequence, a sudden (unexpected) increase in the *number of farmers* will indicate that there is something wrong with the *decision to abandon*.

4.4 Design

Based on concepts created by means of the MAIA framework we created a model design. Agents make decisions concerning the tasks they perform and a criterion is underlying each decision making behaviour. Within the detailed design these criteria are specified. In addition, some actions are concerned with the behaviour of physical components. Within this section, these behaviours are specified into more detail as they form the concept for an algorithm.

4.4.1 Decision to produce green gas

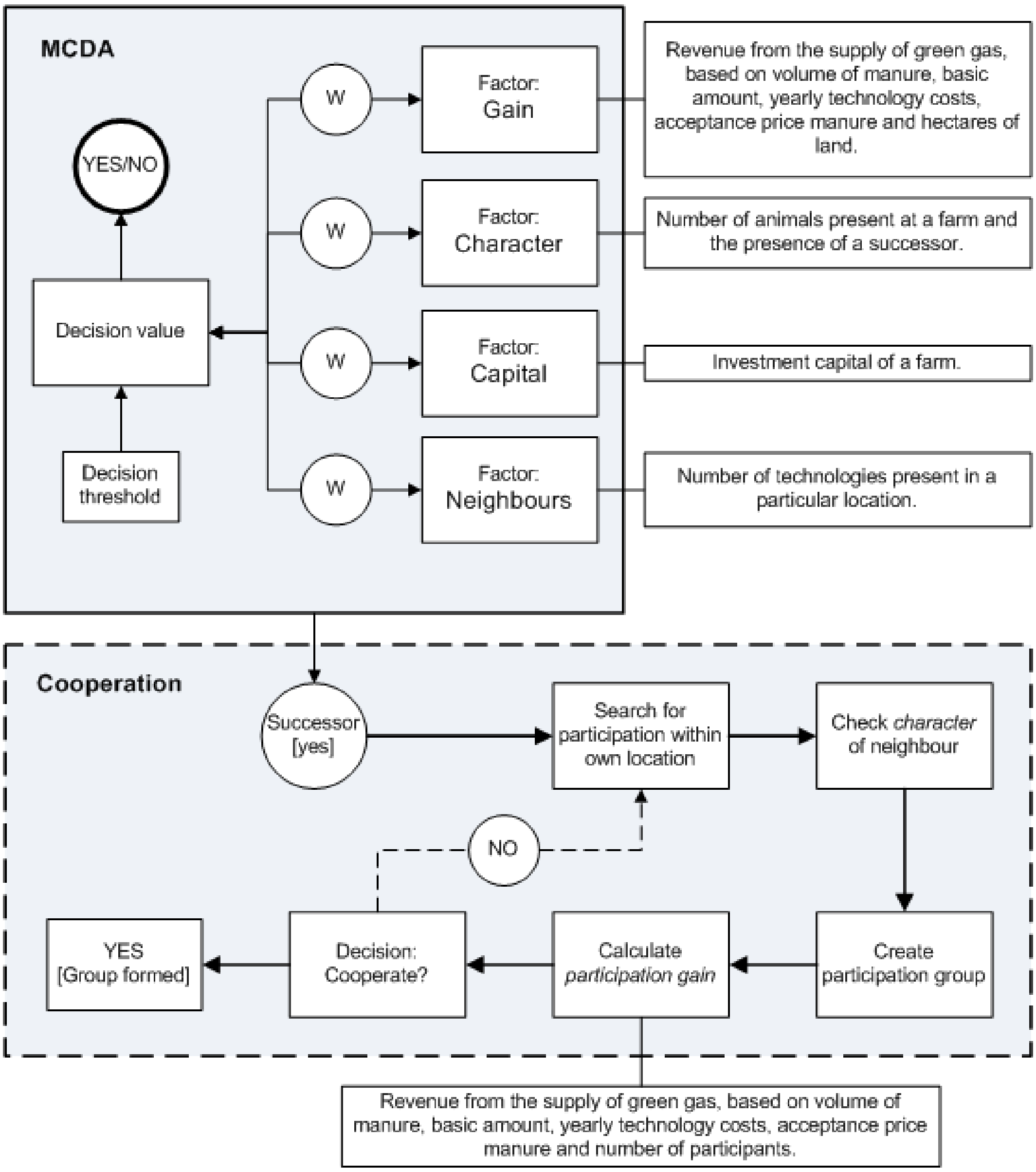

Figure 4.3: Decision to produce green gas

All Animal Farmer Agents have the opportunity to invest in green gas production. Since multiple criteria should be evaluated to make this decision, it is decided that the algorithm should comprise a MCDA. As shown in figure 4.3 the MCDA is constructed on the basis of four factors.

Different weights are assigned to the factors. The weights are multiplied by the values of the different factors. To increase the impact of a particular factor, the weight of this factor can be increased. The calculated decision value is compared to a threshold. The weights and decision threshold are variable and can be altered according to the views of the domain expert. Table 4.5 shows what values are applied to the weights and the decision threshold with respect to the default setting.

Table 4.5: MCDA factor design

Weight: Gain	[0.2-0.9]	Default: 0.8
Weight: Character	[0.3-0.6]	Default: 0.7
Weight: Capital	[0.01-0.8]	Default: 0.5
Weight: Neighbour	[0.1-0.4]	Default: 0.3
Decision Threshold	[0-7]	Default: 6

Based on the outcome of the MCDA, an Animal Farmer Agent might decide to invest in technology and become a producer. To explore the effect of cooperation, we decided to extend the decision making algorithm with an extensional feature that allows for cooperation as shown in figure 4.3.

Cooperation

We decided that all agents will first consider individual production before they would consider cooperation: in case the agent decides not to invest, he might seek for cooperation if the preconditions are met. Both cattle farmer agents and pig farmer agents can cooperate with each other as long as they are situated within same location. Possible gains are based on the overall volume of manure made available by *potential* group members. If they can make revenue, they decide to form a group.

We decide to incorporate the effect of 'economy of scale' as we made the annual technology costs depended on the particular production capacity. As a result, above a certain production capacity, these costs will become a function of the number of agents within the group. In addition, an agent that is in search for cooperation will evaluate all the agents within his particular location.

4.4.2 Annual technology costs and subsidy

Annual technology costs

The annual technology costs change according to electricity and gas prices. The initial value for the annual technology costs is an estimation and based on the costs for an AD facility and an additional green gas upgrading facility (HoS, 2010).

The capital investment costs are not explicitly defined as they are indirectly captured within the MCDA. The electricity and gas prices change over time and it is expected that these prices will increase in the future. The energy prices and default annual technology costs are set to:

- €0.12 per kWh for electricity.
- €0.61 per Nm^3 for gas.
- €$80,000$ per year for operating technology.

Subsidy

In order to explore the effect of subsidy on the decision to produce green gas, the basic amount is varied from €0.00 to €2.00 per Nm^3 of gas produced.

4.4.3 Green gas production

A fixed ratio exists between the manure input and the green gas output. It is estimated that the volume of green gas equals the volume of manure times 13.4[5]. The volume of digestate produced

[5] It is estimated that a volume of 1 m^3 manure results in 20 m^3 biogas and $(20 \cdot 0.67 =)$ 13.4 m^3 green gas.

equals the volume of manure in the input stream.

4.4.4 Calculation of manure acceptance price

The *manure acceptance price* is the price that should be paid by the farmer agent for the acceptance of cattle manure and pig manure by the agrarian. The Intermediary Agent is permitted to calculate this price. The calculation is based on the volume of manure (of current and previous year) that is abundant within the system. For the calculation the distribution costs are used as presented in appendix C.

4.5 Verification and validation

The verification and validation of the model is an important phase during the implementation process. Based on the scope and validation matrix defined in the evaluative structure of the MAIA framework, the model performance is explored by studying the values of different variables that are generated during runs or collected in the model output after a run.

Model debugging

We studied the system behaviour to make the model free from programming errors. We detected several bugs and solved them successively. A few of the most significant bugs are described below.

Land We encountered that farmland that belonged to cattle farmer agents who decided to quit, did not become automatically available to other agents who for instance wanted to expand their farm. We solved this by keeping track of the amount of available land within the system by means of a *list* and providing other agents access to this list.

Manure acceptance price We observed that the acceptance price of manure did not change according to the volume of manure collected by the Intermediary Agent. This error comprised a bug in the Java software, which we solved eventually.

Cooperation The code for cooperation comprises a complicated algorithm as many different agents simultaneously evaluate their neighbourhood in search for cooperation. Furthermore, before a group is actually formed a *potential* group is created, giving rise to a two-step procedure. Within this piece of code many links exist to other methods within program to obtain the necessary information. We detected two errors as only very large groups seemed to be possible and zero revenue was obtained from the green gas supply. This was solved when we recognised that agents were trapped in an endless loop. Furthermore, we found a subtraction mistake in the calculation of the gains from green gas production.

Action sequence The action sequence is representative for the overall operational procedure of the system. In other words, subsequent actions depend on each other for appropriate input[6]. Hence, it is very important that the order in which the actions take place is correct. We encountered that the action *decision to invest in green gas production* was stated above the action *manure production*. As a result, no proper investment decision could be made as the volume of manure was not 'known' by the agents. This was easily solved by adjusting the order of actions.

[6]The system status and internal states of the agents are continuously updated. Subsequently, many actions will only start when preconditions - that depend on these states - are met.

Model robustness

After studying the system behaviour, we explored the model for robustness by repetitive simulation with *real world data*. Based on the model output we found that the model is quite robust. This can also be observed from the figures 4.4 and 4.5, which both show the result of 50 repetitions.

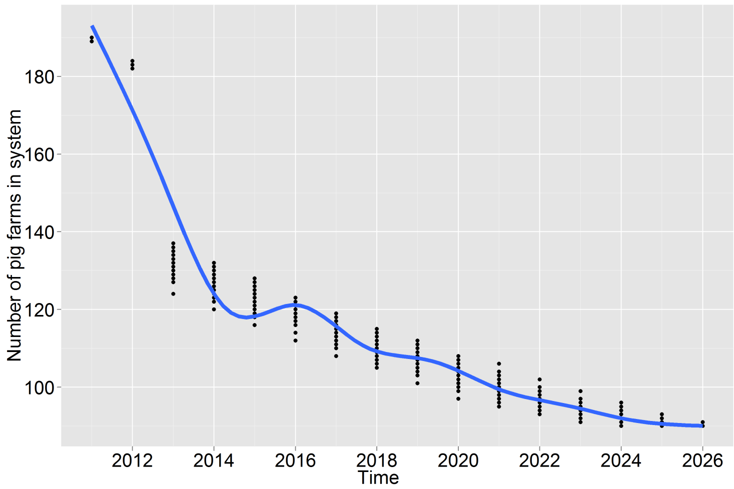

Figure 4.4: Presence of pig farms in the system over time

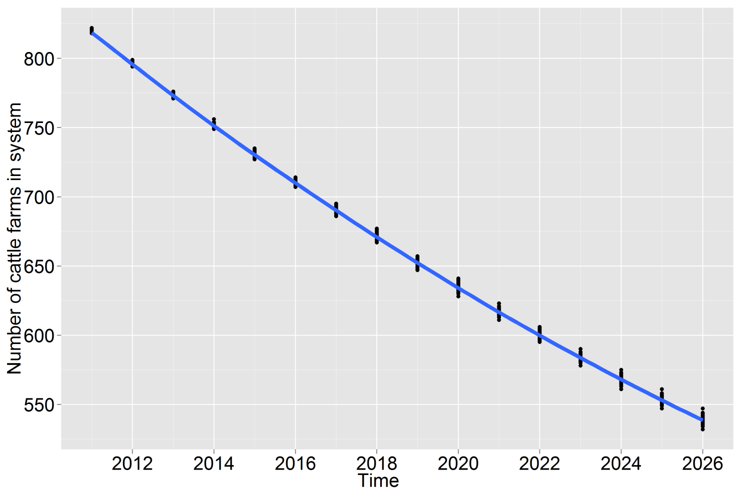

Figure 4.5: Presence of cattle farms in the system over time

Since we consider the model quite robust and we found the behaviour space rather small, there was no need to simulate the model on the 480 core high performance computer (HPC) and we decided to simulate the model on a laptop[7]. This went very well as also evidenced by the reasonably short processing time[8].

[7] Intel(R) Core(TM)2 Duo CPU T9600 @ 2.80GHz
[8] The processing time took about 5-10 minutes.

4.6 Experimental design

In the forgoing sections we explained how we modelled farmers and their decision making within the manure distribution system. These modelled farmer agents are influenced by an institutional framework which is part of the modelled system. We decided that the farmer agents in the system are capable of different actions when confronted with different (farming) decisions. As the objective of this research is to explore the potential for ME production by farmers situated within the manure distribution system, we are especially interested in the adoption of ME production by the farmer agents. Due to simulation we allowed the system to emerge from bottom-up to obtain an understanding of influential factors by relating the observed macro-level behaviour to its underlying causes.

Based on the objective of these research we made choices with respect to the experimental design. As a result, we decided to design three experiments. Table 4.6 provides a description of the experimental design.

Table 4.6: Experimental design

Experiment	Objective	Data input design and set-up
Experiment 1: Dynamics within manure distribution system	Since farmers are influenced by many institutions that are currently subject to change, we expect that circumstances within the manure distribution system may change. We designed this experiment to obtain an understanding of these dynamics over time, especially with respect to number of farms present in the system and the volume of manure produced. As a result, we simulated the system under different institutional settings to obtain insight with respect to the impact of these settings on the dynamics.	We decided to range the variable *Abandon percentage cattle farms* from 0 to 7, the variable *Abandon percentage pig farms* from 0 to 8 and the variable *Abandon 2013 percentage pig farms* from 10 to 60.
Experiment 2: Potential for manure-based energy production by individual farms	The production of ME is a new concept introduced next to the main farming activities of a farmer. To obtain a better understanding of the possible (economic) factors that may influence this potential we allowed the farmer agents - who are situated within a manure distribution system - to decide upon the production of ME.	We confronted farmer agent within the system with the decision to invest in ME and we simulated the system under different economic settings in which we varied the variables *annual technology costs* from 10000 to 100000 euro and the *basic amount* from 0 to 2 euro.
Experiment 3: Effect of cooperation on the potential for manure-based energy production	Farmers may decide to cooperate when confronted with the decision to produce ME. Cooperating can be an advantage as the costs might be reduced due to economy of scale. In order to explore the effect of cooperation (especially with respect to group formation) we decided to allow for cooperation in ME production between farmer agents.	Additional to experiment 2, we decided to allow for cooperation between farmer agents each time they were confronted with the decision to invest in ME. We simulated the system under the same economic settings compared to experiment 2.

4.6.1 Data output design

To study the model outcome, a broad variety of variables are selected for the data output design. We selected these variables based on table 4.3. After each run, we collected data and stored the data in a database. This database is comprised of two tables: a cattle farmer table and a pig farmer table.

Cattle farmer table

The data output table 4.7 is concerned with all variables related to cattle farmer agents.

Table 4.7: Data output: Cattle farmer table

Run number	The current run number.
Time	The run time is set from 2011 to 2026. The time indicates the year in which the data is collected.
Farmer ID	The individual identification number that is assigned to each particular cattle farmer agent.
Cattle	The number of cattle a particular cattle farmer agent owns.
Total farmers	The total number of cattle farmer agents present in the system.
Money	The money of a particular cattle farmer agent.
Cattle manure	The amount of cattle manure collected by the Intermediary Agent.
Cattle manure acceptance price	The acceptance price of cattle manure calculated by the Intermediary Agent.
Green gas	The amount of green gas a particular cattle farmer agents produces.
Technology costs	The annual costs of technology.
Group ID	The individual identification number that is assigned to each particular group of cattle (and pig) farmer agents that share a technology for green gas production.
Producer	Indicator (*boolean*: true or false) whether a cattle farmer agent takes the role of Producer.
Group member	Indicator (*boolean*: true or false) whether a cattle farmer agent cooperates within a group.
Subsidy	The basic amount a cattle farmer agent receives in case he takes the role of Producer.
Initial technology costs	The initial technology costs.
Decision threshold	The decision threshold.
Abandon percentage	The percentage of cattle farmer agents that abandon each year.

Pig farmer table

The data output table 4.8 is concerned with all variables related to pig farmer agents.

Table 4.8: Data output: Pig farmer table

Run number	The current run number.
Time	The run time is set from 2011 to 2026. The time indicates the year in which the data is collected.
Farmer ID	The individual identification number that is assigned to each particular pig farmer agent.
Pigs	The number of pigs a particular pig farmer agent owns.
Total farmers	The total number of pig farmer agents present in the system.
Money	The money of a particular pig farmer agent.
Pig manure	The amount of pig manure collected by the Intermediary Agent.
Pig manure acceptance price	The acceptance price of pig manure calculated by the Intermediary Agent.
Green gas	The amount of green gas a particular pig farmer agents produces.
Technology costs	The annual costs of technology.
Group ID	The individual identification number that is assigned to each particular group of pig (and cattle) farmer agents that share a technology for green gas production.
Producer	Indicator (*boolean*: true or false) whether a pig farmer agent takes the role of Producer.
Group member	Indicator (*boolean*: true or false) whether a pig farmer agent cooperates within a group.
Subsidy	The basic amount a pig farmer agent receives in case he takes the role of a Producer.
Initial technology costs	The initial technology costs.
Decision threshold	The decision threshold.
Abandon percentage	The percentage of pig farmer agents that abandon each year.

The values of the different variables collected in these tables are subject to data analysis with *R*, a programming language and software environment for statistical computing and graphics as explained in chapter 3.

4.7 Conclusion

Within this chapter we described how the performed conceptualisation by means of the MAIA framework resulted in a computer model that we were able to use for social simulation. In addition, during the verification and validation of the model we experienced that the model is quite robust. Based on our research objective, we designed three experiments and selected the data in- and output design. Based on the experimental design, we simulated the model and the model outcome is presented in chapter 5.

Chapter 5

Model outcome

5.1 Introduction

As described in chapter 2, local farmers are affected by many rules and regulations that influence their decision making behaviour with respect to their farming activities. It maybe therefore a valid and even challenging question whether ME has potential and to what extent this potential is influenced by economic factors.

Based on the research objective we designed three experiments as described in the experimental design of chapter 4. In addition, figure 5.1 shows a visual presentation of these three different experiments.

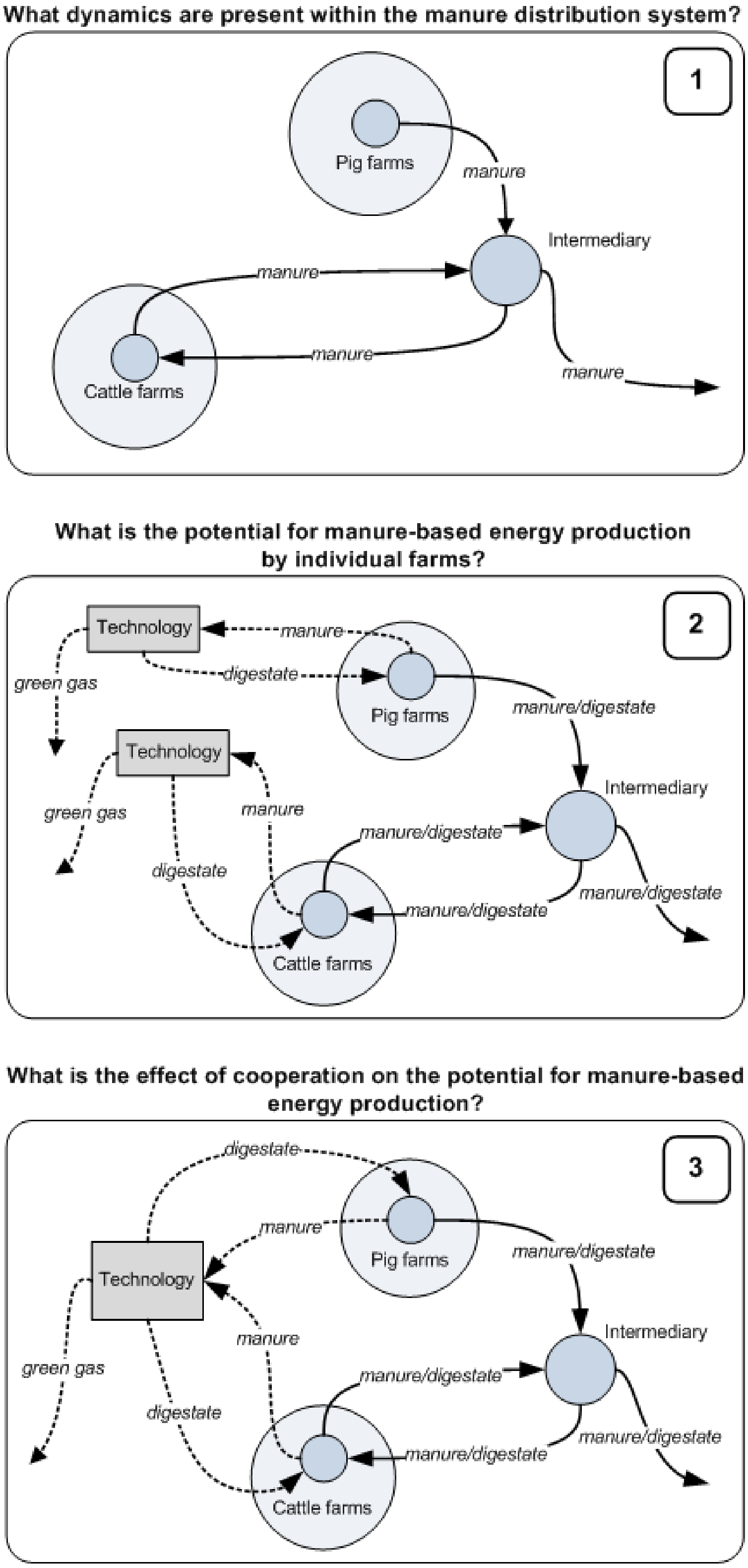

Figure 5.1: Three different experiments to obtain insights regarding the system behaviour.

Based on figure 5.1, we provide a description with respect to the experiments we performed:

Experiment 1: In this experiment we are interested in the dynamics within a manure distribution system. To obtain an understanding of the system behaviour, we allowed the system to emerge under different institutional settings and we explored the number of farms, the number of animals and the volume of manure produced over time.

Experiment 2: In this experiment all farmer agents were confronted with the decision to invest in ME production to obtain insight with respect to the potential of ME. We allowed the system to emerge under different economic settings to explore the effect of economic factors - like the *revenue*[1] and the annual technology costs - on the potential of ME production. As a result, we analysed the data output of different runs with respect to the presence of farmer agents that are involved in green gas (or ME) production, the characteristics of these particular farmer agents and the volume of green gas that is produced.

Experiment 3: In this experiment all farmer agents who were confronted with the decision to produce ME were provided with the opportunity to cooperate: we decided that they will first decide upon individual ME production and if this does not seem to be possible, then they will consider cooperation. Identical to experiment 2, we allowed the system to emerge under different economic settings. Furthermore, we analysed the data output with respect to the presence of farmer agents involved in green gas (or ME) production, the volume of green gas that is produced, the characteristics of these particular farmer agents and their group formation.

With respect to the performed experiments we decided to divide the chapter into three main sections. In each section we explain the model outcome with respect to the performed experiment.

Visualisation of the model outcome

As described in chapter 3, the data output from the model is analysed by means of the programming language *R*. We generated the different graphs with the *ggplot2* package. We simulated each experiment at least 50 times[2]. The data output with respect to experiment 1 is presented by plotting the values of different variables against time. In addition, the data is smoothed and the *loess line* is presented in blue. The data output with respect to experiment 2 and 3 are mainly visualised by position density plots in which geometries are positioned relative to each other by means of the position-identity function of the *ggplot2* graphics technique. In other words, as the outcome of different runs is accumulated, this technique counts how frequently a particular variable is present with respect to another variable under specified conditions (or defined boundaries).

5.2 Dynamics within manure distribution system

In this section we explored the dynamics of the manure distribution system under different institutional settings. As described in chapter 4, farmer agents make decisions with respect to the:

- expansion and abandonment of a farm;
- usage and distribution of manure.

[1]The *revenue* is composed of the *basic amount* that is made available by the SDE+ subsidy.

[2]Since we found the model quite robust, we decided to simulate the model 50 times.

As explained, we simulated the model for 50 runs. Each run starts in 2011 and ends in 2026. The outcome is plotted in one graph and we smoothed the data by applying a loess line in blue.

5.2.1 Number of farms over time

At the start of every run, the initial number of cattle farms amounts **843** and the number of pig farms amounts **196**.

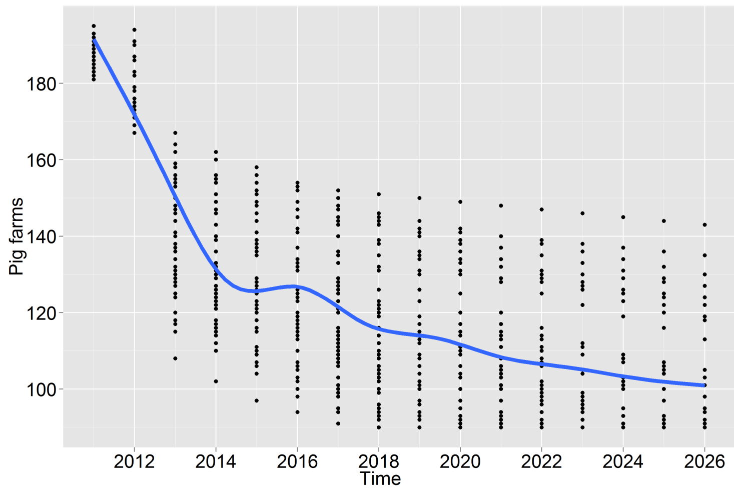

Figure 5.2: Number of pig farms in the system over time

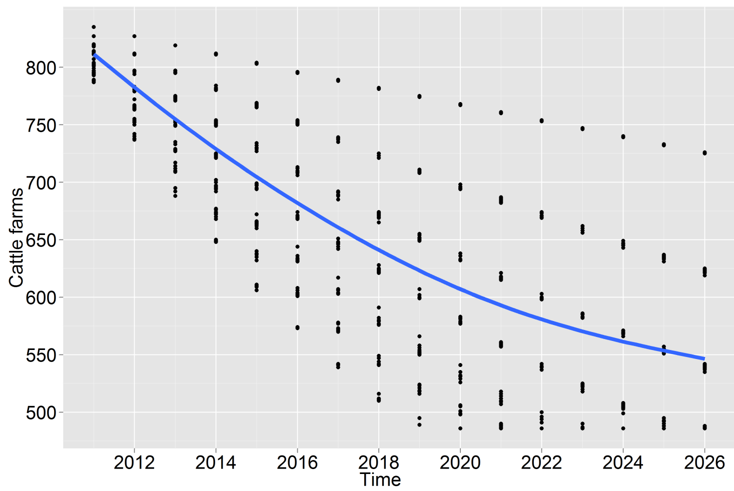

Figure 5.3: Number of cattle farms in the system over time

From the figures 5.2 and 5.3 we observe that:

- a large dispersion is present.
- in general both cattle and pig farms decrease in number over time.

- for the cattle farms the decrease seems to proceed in a gradual manner, whereas a more abrupt decrease in number can be observed for the pig farms. This becomes especially visible when we consider the first 5 years of the simulation.

In any case it can be seen that the number of both pig and cattle farms decrease over time. As described in chapter 2, the number of farms is expected to decrease due the amendment of policies, market developments within the livestock farming sector and the financial position of local farmers. This is considered especially true for the rather small-scale farms as they are expected to be more vulnerable to these changes. Furthermore, pig farmer agents react differently with respect to institutional changes when compared to cattle farmer agents. As described in chapter 2 we consider the pig farms more vulnerable to abandonment since the *animal welfare norms* and the *ammonia action programme* are especially directed to livestock farms that comprise an animal housing system.

5.2.2 Number of animals over time

Each black dot in the figures 5.4 and 5.5 presents the total number of animals that is present at a particular farm for that particular moment in time.

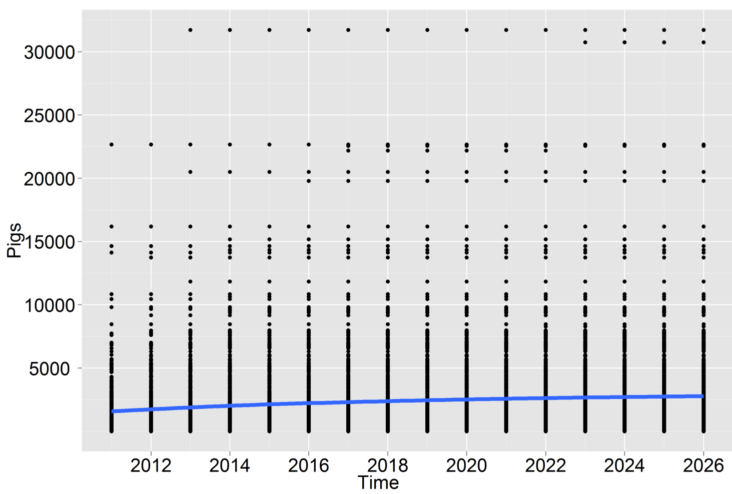

Figure 5.4: Number of pigs present at a farm over time

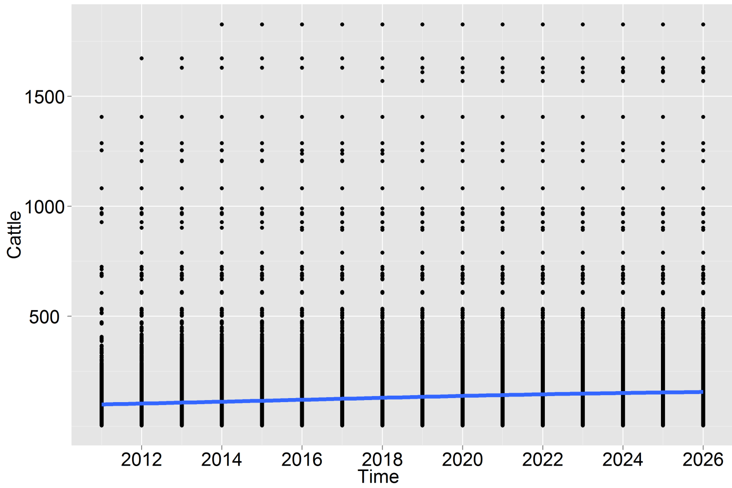

Figure 5.5: Number of cattle present at a farm over time

When a farmer agent decides to expand his farm, he is allowed to increase the number of animals that is present at his farm. Furthermore, as a farmer agent decides to abandon his farm, his animals can be taken over by another farmer agent who wishes to expand. As a result, we are able to see some variation within the spectrum of dots as for instance the occurrence of a dot at a particular moment in time shows the expansion of a particular farm. Considering these figures, we observe that the overall number of animals within the system remains stable.

As described in chapter 2, a tendency towards up scaling is observed as this might secure a long-term continuity. As a result, it is expected that some farms expand and increase their number of animals. Since some farms abandon and others expand, we were expecting some balance with respect to the number of animals in the system.

5.2.3 Manure production over time

Within the system, farmer agents decide upon the distribution of manure. As described in chapter 4, they will have several distribution options:

- Usage of manure for manuring of own land.
- Distribution to neighbours.
- Distribution to intermediary agent.

Each year the intermediary agent collects pig and cattle manure. He is able to redistribute this manure to farmer agents who might still be in need of manure-based fertilisers. Manure that cannot be distributed within the region, is placed outside the system.

Since the overall number of animals within the system stays stable over time, we expect that the total volume of manure collected by the intermediary over time will remain stable as well.

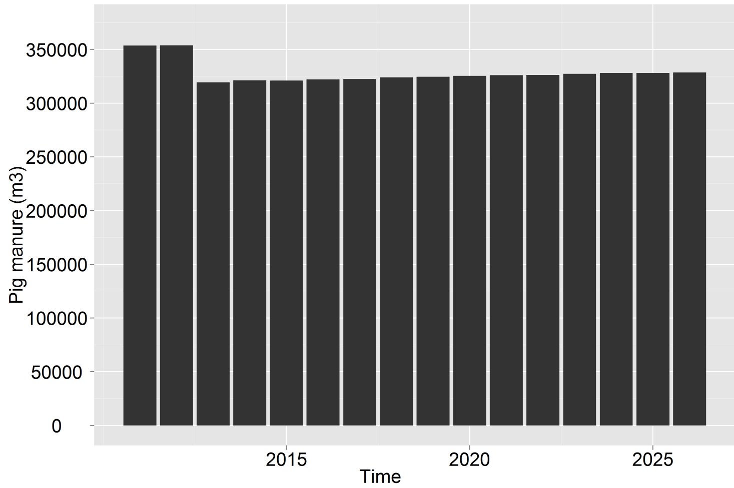

Figure 5.6: Pig manure collected by intermediary agent at the end of each year.

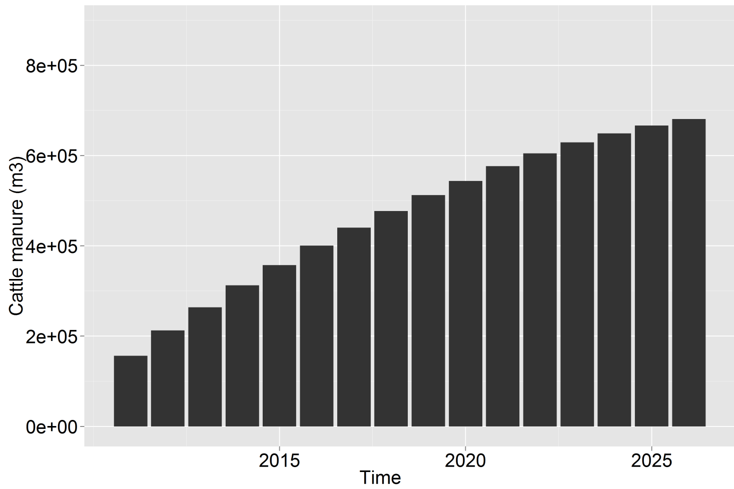

Figure 5.7: Cattle manure collected by intermediary agent at the end of each year.

As shown in figure 5.6, the volume of pig manure stays stable over time, although we observe a decline in volume around the year 2013. This decline is probably caused by the abrupt decrease in the number of pig farms shown in figure 5.2.

As described in chapter 4, since only cattle farmer agents own land. Subsequently, since cattle manure is preferred above pig manure, it is used first. As a consequence, pig manure is directly distributed to the intermediary agent.

In figure 5.7, the volume of cattle manure increases over time. Since cattle farmer agents own land, they have several distribution options available. Furthermore, if a cattle farmer agent expands his farm, he might increase the number of hectares he possesses as well in case land is made available to him within his location. Land is made available by a farmer agent who abandons his farm. However, if the land of an abandoned farm is not taken by another farmer agent, this land is not available for manuring. As we observe an increase in the volume of cattle manure that is collected by the intermediary over time, we indeed tend to believe there is a decline of land accessible for manuring.

5.3 Potential for manure-based energy production by individual farms

Within this experiment we allow farmer agents to invest in ME production. As described in chapter 4, farmer agents who invest in ME production:

- start operating a technology. As a result they pay annual technology costs.
- obtain revenue from the supply of green gas.
- bring the produced digestate in the manure distribution system in a similar way as they would have done with the manure.

Farmer agents that produce green gas (or ME) we refer to as *green gas producers* or just *producers*.

5.3.1 Presence of farmer agents involved in green gas production

Figures 5.8 and 5.9 present a position density plot in which the data is marked for producers (TRUE) and non-producers (FALSE). The x-axis presents the individual farmer agents. The y-axis presents the count, which indicates how frequently a farmer agent is present as a (non)-producer in the system with respect to the outcome of 50 runs[3].

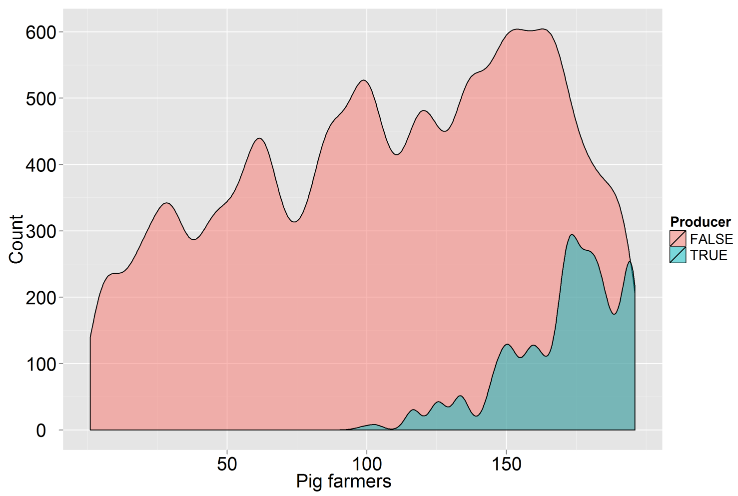

Figure 5.8: Presence of pig farmer agents involved in green gas production (TRUE or FALSE).

[3]We accumulated the output of 50 runs.

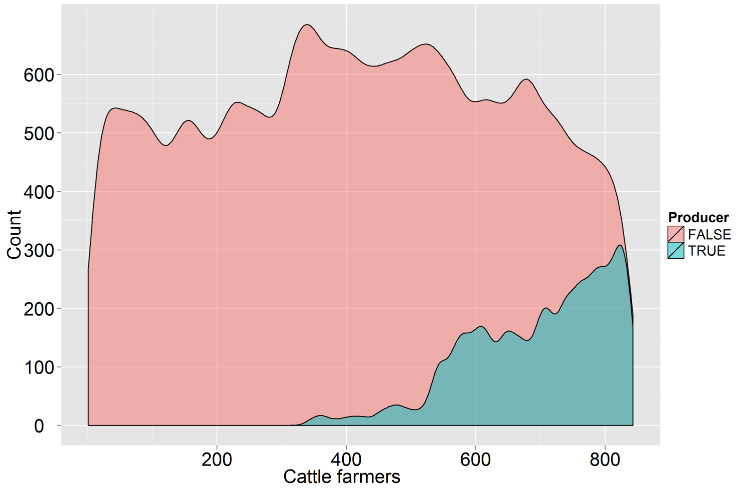

Figure 5.9: Presence of cattle farmer agents involved in green gas production (TRUE or FALSE).

Considering these figures, we observe that a minority of the farmer agents may invest in green gas production at a particular moment in time during a specific run. We found that approximately 12.0% of the total pig farmer agent population and approximately 12.2% of the cattle farmer agent population might be present as a producer within the system.

The fact that not all of them invest in green gas production might have several underlying causes[4]:

- The volume of manure produced at a farm is not sufficient to start a feasible production.
- The farmer agent has not enough investment capital to carry out production.
- There exists no long-term strategy with respect to the farm. As a result, green gas production is not considered to be an option.
- Farmer agents are reluctant towards green gas production.

5.3.2 Characteristics of green gas producers

The decision to invest in energy production is influenced by different factors:

- the gains from green gas production;
- the amount of investment capital;
- the individual strategy with respect to the farm;
- the decision of neighbouring agents concerning green gas production.

As described in the experimental design in chapter 4, we are interested in the effects of economic factors on the potential of ME. As a result we allowed the system to emerge under different economic settings in order to study macro-level behaviour and to obtain an understanding of the influence of these factors on the occurrence of green gas production.

We can characterise the farmer agents according to different aspects:

- **Successor:** A farmer agent may have a successor for his farm.

[4]We emphasise that these causes do not rule each other out.

- **Scale of the farm:** A farmer agent owns a number of animals. Based on the number of animals, his farm is small-scale (pig farms with less than 500 pigs and cattle farms with less than 50 cattle), middle-scale (pig farms with more than 499 pigs, but less than 3000 pigs and cattle farms with more than 49 cattle, but less than 150 cattle) or large-scale (pig farms with 3000 pigs or more and cattle farms with 150 cattle or more).
- **Capital:** A farmer agent possesses a specific amount of investment capital. He may own a large amount, average amount or a small amount of investment capital.

Based on the aforementioned characteristics we identified the characteristics of green gas producers. Furthermore, we present the outcome for different values of *annual technology costs* (€) and *revenue* (€/Nm^3) to obtain an understanding of the influence of these economic factors with respect to the type of farmer agents involved in green gas production.

Successor

Based on figures 5.10 and 5.11, we observe that all producers have a successor (as this is indicated with all being *TRUE*). As a result, we conclude that the presence of a successor - or someone who is able to take over the farm when this becomes a necessity - is beneficial for green gas production to occur. As described in chapter 2 farmers who apply a long-term strategy with respect to their farm more often have a successor.

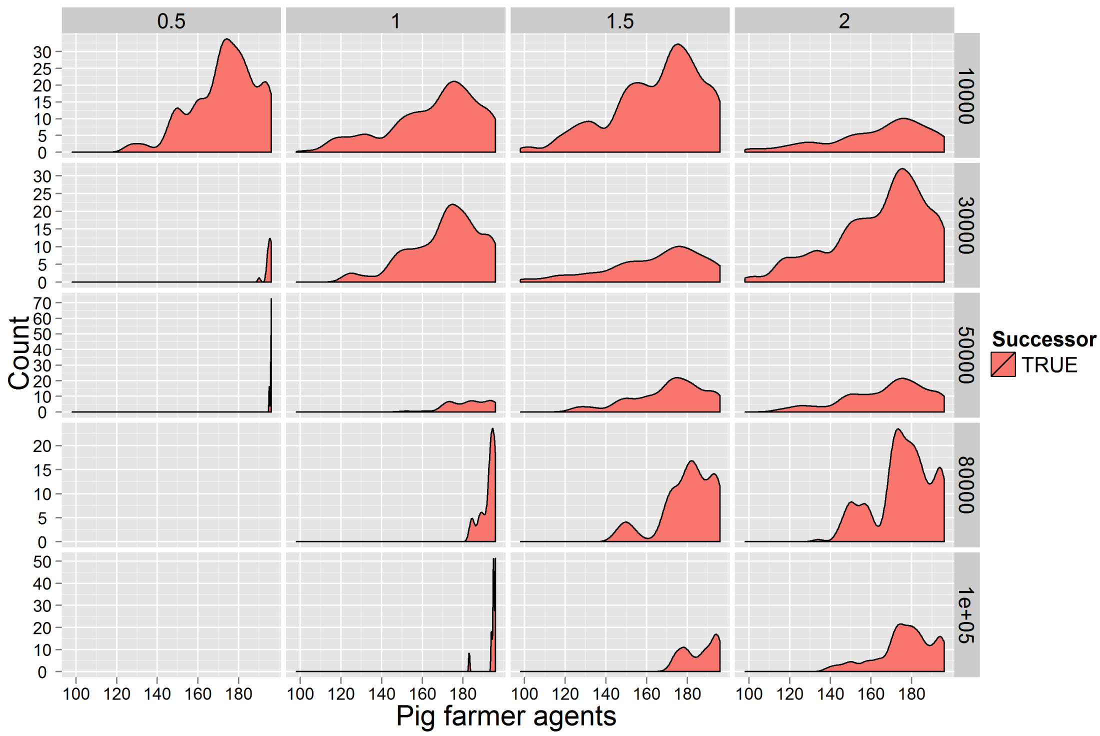

Figure 5.10: Pig farmer agents involved in green gas production marked for having a successor (indicated by TRUE or FALSE). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

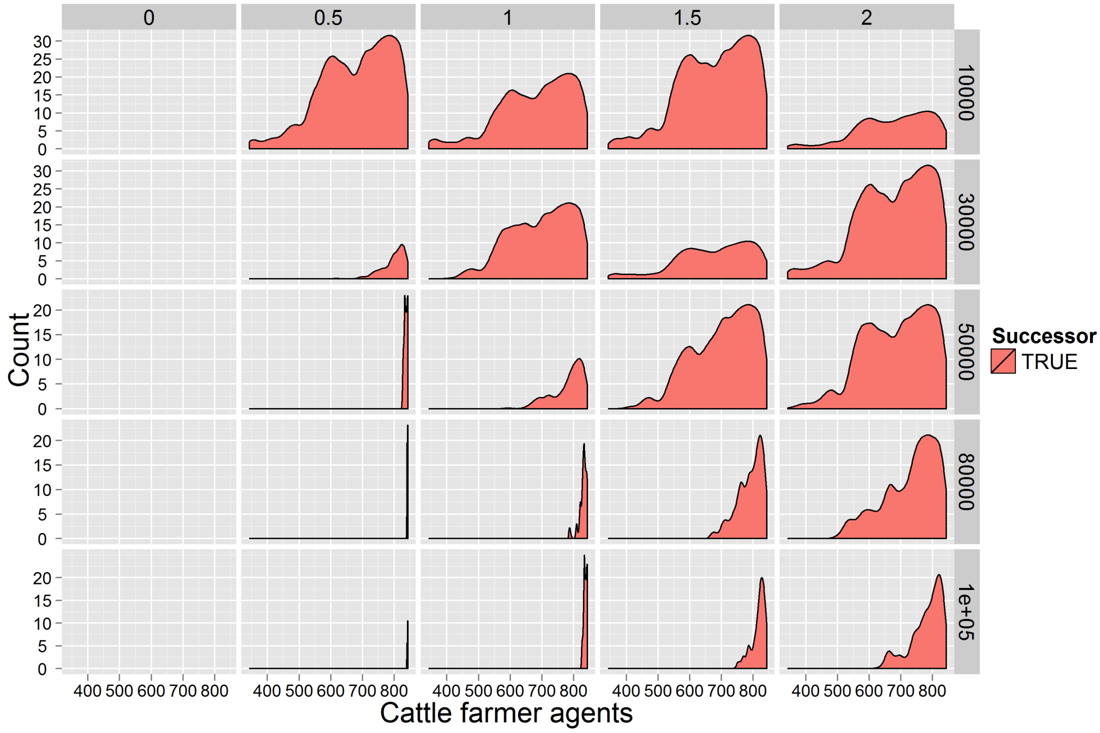

Figure 5.11: Cattle farmer agents involved in green gas production marked for having a successor (indicated by TRUE or FALSE). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

Scale of the farm

Based on the figures 5.12 and 5.13, we state the following observations:

- Mostly large-scale farms, some middle-scale farms and none of the small-scale farms are involved in green gas production.
- The annual technology costs influence at what scale and how frequently farms are involved in green gas production as the presence of (middle-scale) farms decreases at increased costs.
- A revenue is required for green gas production to occur. Furthermore, as technology costs increase, only at increased values for the revenue green gas production still occurs at the same level.
- Although we do not observe large differences between cattle and pig farms as both figures show quite similar patterns, we observe that cattle farmer agents may invest under slightly more stringent conditions when compared to pig farmer agents. With a relatively low revenue (0.5) and a high annual technology costs $(100,000)$, some very small percentage of the cattle farmer agents may still invest.

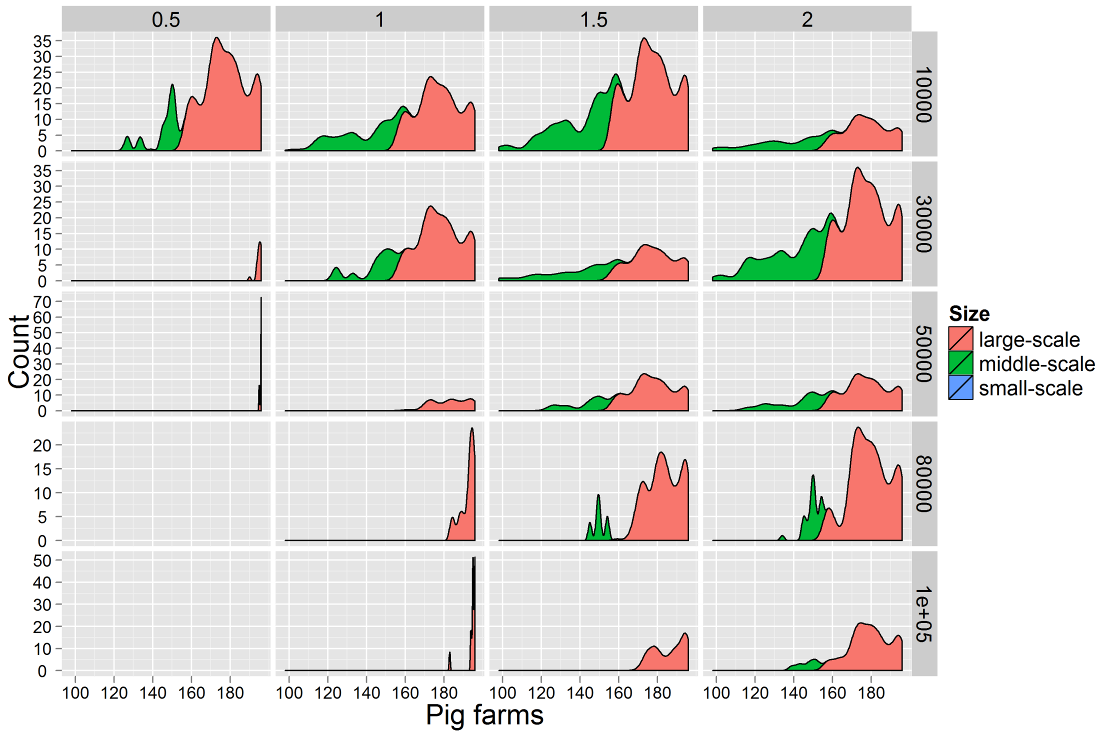

Figure 5.12: Pig farmer agents involved in green gas production marked for their farm-scale (indicated by *size*). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

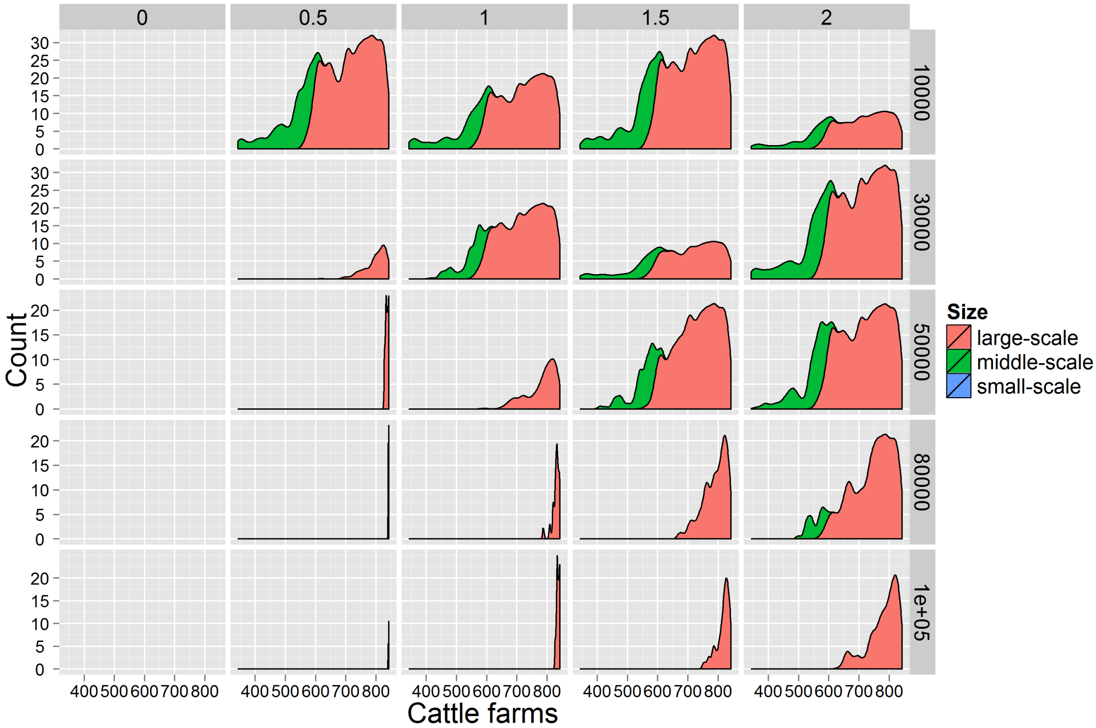

Figure 5.13: Cattle farmer agents involved in green gas production marked for their farm-scale (indicated by *size*). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

Capital

We made the following observations with respect to the figures 5.14 and 5.15:

- Mostly farmer agents that possess a large amount of investment capital, some farmer agents that possess a average amount of investment capital and none of the farmer agents that possess a small amount of investment capital are involved in green gas production.
- When the technology costs increase and the revenue remains relatively low, we observe only farmer agents that possess a large amount of investment capital.

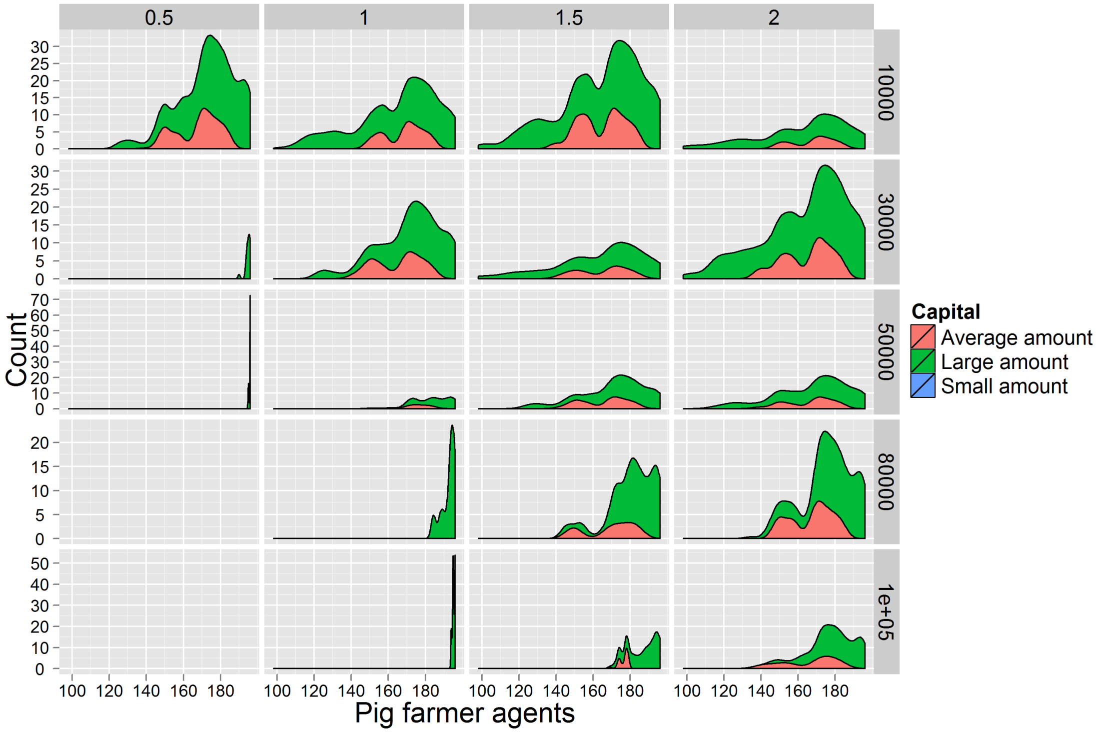

Figure 5.14: Pig farmer agents involved in green gas production marked for their investment capital. The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

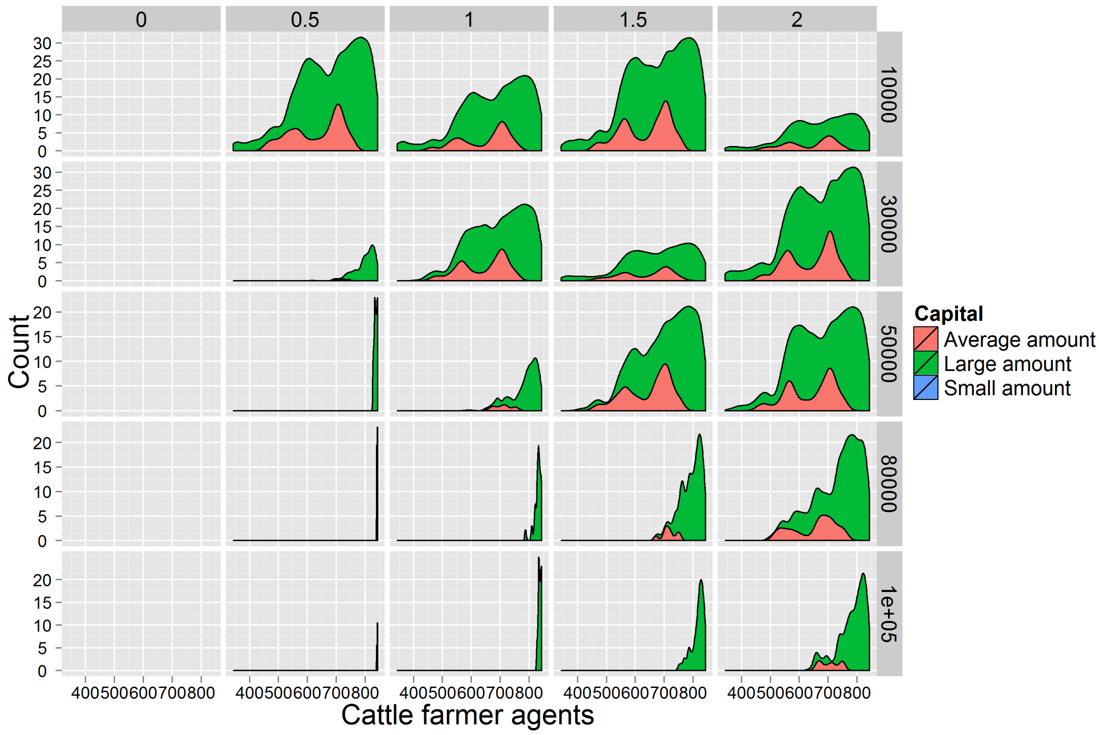

Figure 5.15: Cattle farmer agents involved in green gas production marked for their investment capital. The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

5.3.3 Green gas production

We observe that only a minority of the farmer agents might invest in green gas production.

In chapter 2 we described that the 'maximum revenue' that can possibly be granted amounts €1.04 per Nm^3. Furthermore, we estimated that the annual technology costs amount €80,000. As a consequence, only farmer agents who have a successor and possess both a large-scale farm and a maximum amount of investment capital potentially invest in production. If we look at the small minority that may invest in green gas production presented at the beginning of this section, we consider this potential low.

In the following figures 5.16 and 5.17 the green gas production is shown for different values of annual technology costs and revenue. Each dot in the plot presents the total volume of green gas that is produced at either all pig farms (figure 5.16) or at all cattle farms (figure 5.17) that are involved in green gas production with respect to one specific run.

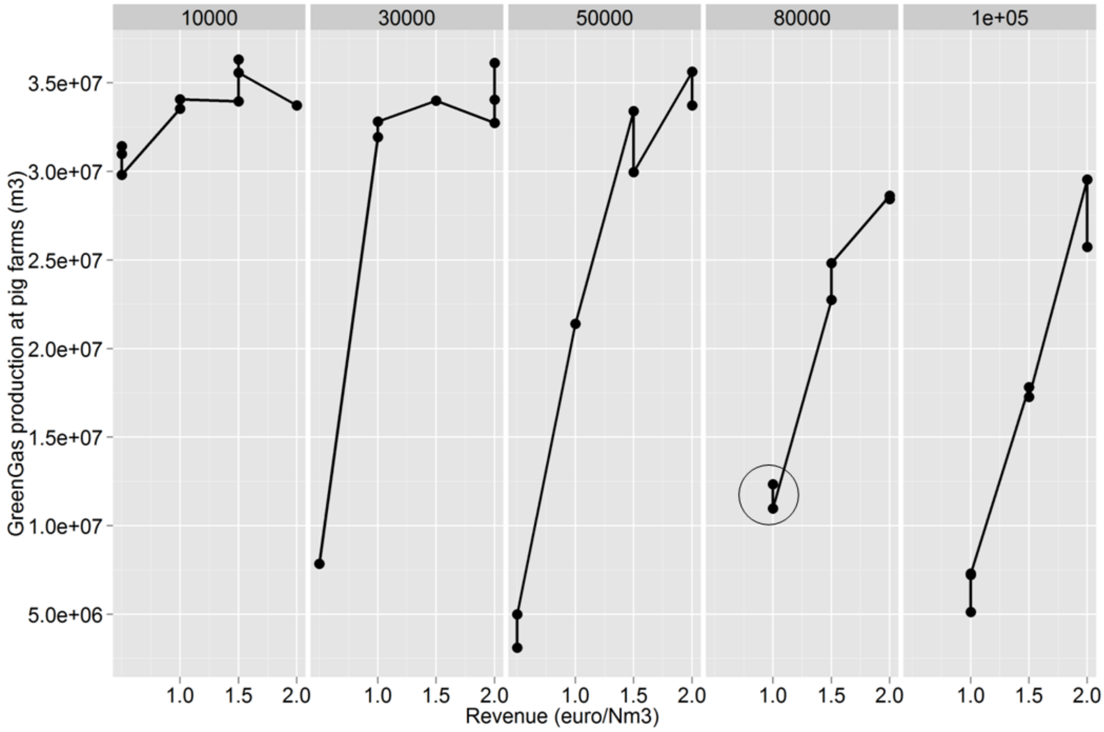

Figure 5.16: Green gas production at pig farms for different values of revenue (€/Nm^3) and annual technology costs (€). The circle indicates the volume produced for annual technology costs of €80,000 and a revenue of €1.04 per Nm^3 (in run X).

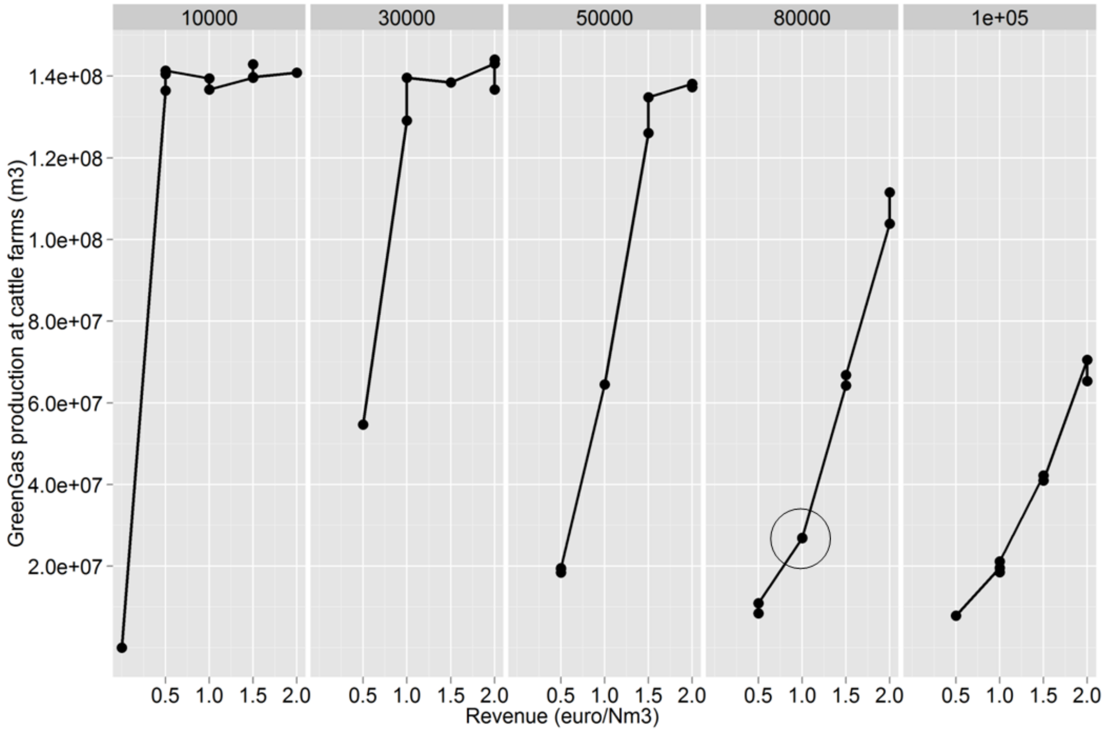

Figure 5.17: Green gas production at cattle farms for different values of revenue (€/Nm^3) and annual technology costs (€). The circle indicates the volume produced for an annual technology cost of €80,000 and a revenue of €1.04 per Nm^3 (in run X).

Considering these figures, we observe that:

- the green gas production at cattle farms results in a higher volume of green gas compared to the green gas production at pig farms. But here we like to emphasise that more cattle farms (843) are present in the system compared to pig farms (196).
- both annual technology costs and revenue influence the volume of green gas that can be produced. At relatively low technology costs, the amount of subsidy influences mainly the volume of green gas produced. Increasing the technology costs to €80,000 or €100,000, decreases the green gas production largely.
- as indicated with a circle in both figures, if the annual technology costs are set to €80,000 and the revenue is set to approximately €1 per Nm^3, the total volume of green gas that can be produced in the system amounts approximately $3.92 \cdot 10^7$ m^3 with respect to this particular run[5], which we call *run X*.

When considering the volume of green gas produced within the system with respect to run X, we present in figures 5.18 and 5.19 the number of producers involved in this green gas production over the years.

[5]The amount of $3.92 \cdot 10^7$ m^3 is composed of $1.23 \cdot 10^7$ m^3 at pig farms and $2.69 \cdot 10^7$ m^3 at cattle farms. If the amount of produced *biogas* is used for the production of power instead of green gas, this will amount by approximation $11.70 \cdot 10^7$ kWh.

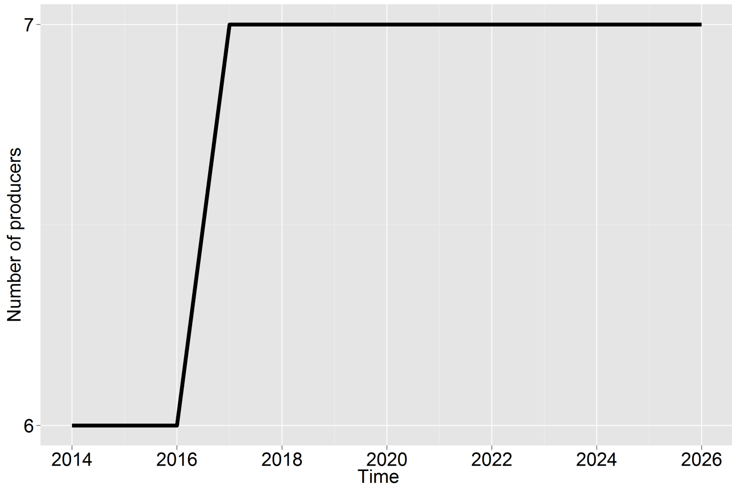

Figure 5.18: The number of pig farmer agents that are involved in green gas production over the years with respect to run X.

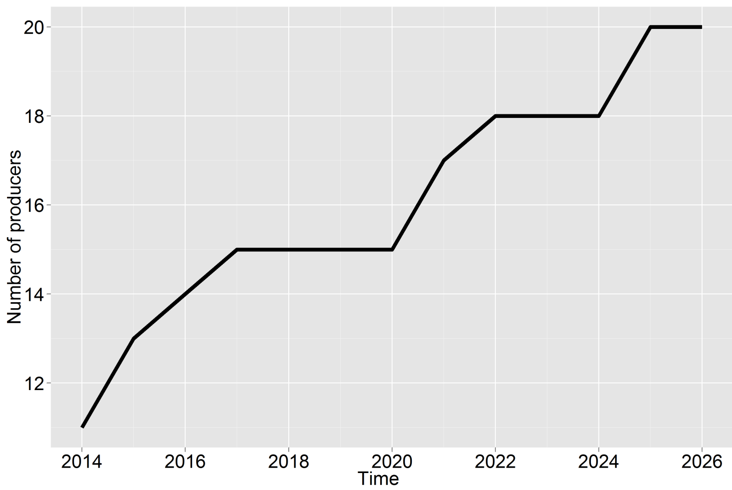

Figure 5.19: The number of cattle farmer agents that are involved in green gas production over the years with respect to run X.

Based on these figures, we observe that most farmer agents decide directly to start with production in the year 2014. The number of pig farmer agents remains stable after the year 2017 and the number of cattle farmer agents shows a gradual increase over the years. Furthermore, more cattle farmer agent are involved in green gas production compared to the number of pig farmer agents[6].

[6]But this might be caused by the fact that more cattle farms are present in the system with respect to pig farms.

5.4 Effect of cooperation on the potential for manure-based energy production

Within this section we explore the effect of cooperation on the potential of ME. We have chosen that farmer agent will decide first upon individual ME production before they decide upon cooperation.

When farmer agents decide to cooperate, they will:

- form a group which can be comprised of both cattle farmer agents and pig farmer agents.
- share one technology and the annual technology costs might be reduced depending on the production capacity.
- obtain revenue based on the volume of manure they make available for green gas production.

Farmer agents that cooperate in groups with respect to green gas production, we refer to as *green gas producers* or just *producers*.

5.4.1 Presence of farmer agents involved in green gas production

Figures 5.20 and 5.21 present a position density plot in which the data is marked for producers (TRUE) and non-producers (FALSE). The x-axis presents the individual farmer agents. The y-axis presents the count, which indicates how frequently a farmer agent is present as a (non)-producer in the system with respect to the outcome of 50 runs[7].

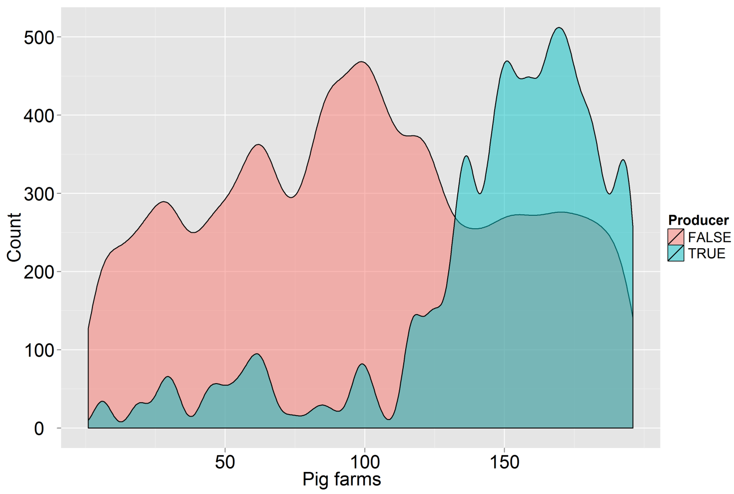

Figure 5.20: Presence of pig farmer agents involved in green gas production (TRUE or FALSE).

[7] We accumulated the output of 50 runs.

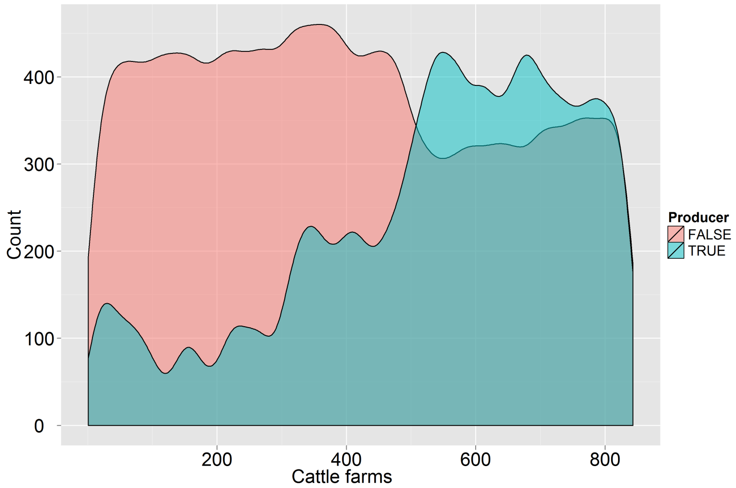

Figure 5.21: Presence of cattle farmer agents involved in green gas production (TRUE or FALSE).

With respect to these figures, we found that approximately 35.8% of the total pig farmer agent population and approximately 38.9% of the cattle farmer agent population cooperates in green gas production. Besides the production carried out by groups of farmer agents, individual production might still be carried out as well. We found that approximately 1.6% of the total cattle farmer population and approximately 0.0% of the total pig farmer population is involved in individual green gas production.

Based on these findings, we state the following:

- Cooperation is preferred above individual production.
- The opportunity to cooperate results in an increased green gas production potential when compared to the outcome of experiment 2.

5.4.2 Green gas production in case of cooperation

In the following figure 5.22 the green gas production is presented for different values of annual technology costs and revenue. Each dot in the plot presents the total volume of green gas produced by all producers in the system with respect to one specific run.

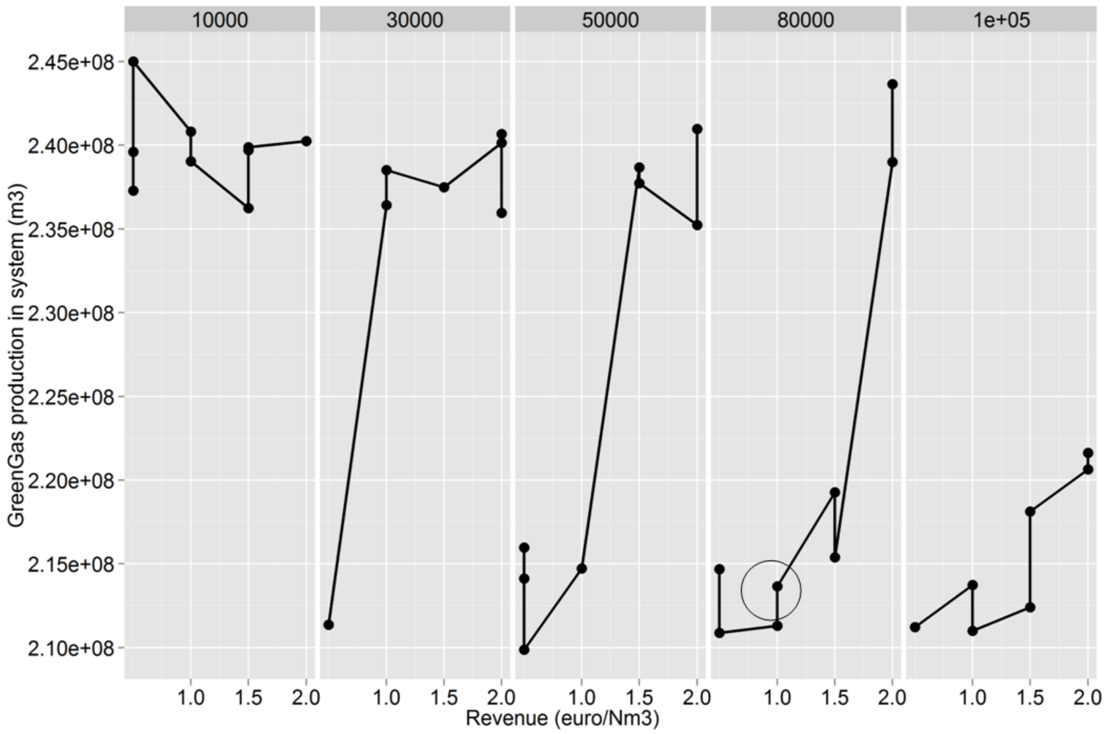

Figure 5.22: Green gas production by farmer agents that cooperate in groups for different values of revenue (€/Nm^3) and annual technology costs (€). The circle indicates the volume produced for an annual technology cost of €80, 000 and a revenue of €1.04 euro per Nm^3 (in run Y).

Considering this figure, we observe that:

- The volume of green gas that can be produced is clearly influenced by the annual technology costs and the revenue available. When technology costs increase, the revenue should increase as well to obtain a similar production volume.
- If the annual technology costs are set to €80, 000 and the revenue is set to approximately €1 euro per Nm^3, the total volume of green gas produced within the system amounts approximately $2.14 \cdot 10^8$ m^3 with respect to this particular run[8], which we call *run Y*. Subsequently, this volume equals almost 5.5 times the volume produced by individual production under the same economic conditions.

When considering the volume of green gas produced within the system with respect to run Y, we present the number of farmer agents that cooperate in green gas production over the years in figure 5.23.

[8] If the amount of produced *biogas* is used for the production of power instead of green gas, this will amount by approximation $6.39 \cdot 10^8$ kWh.

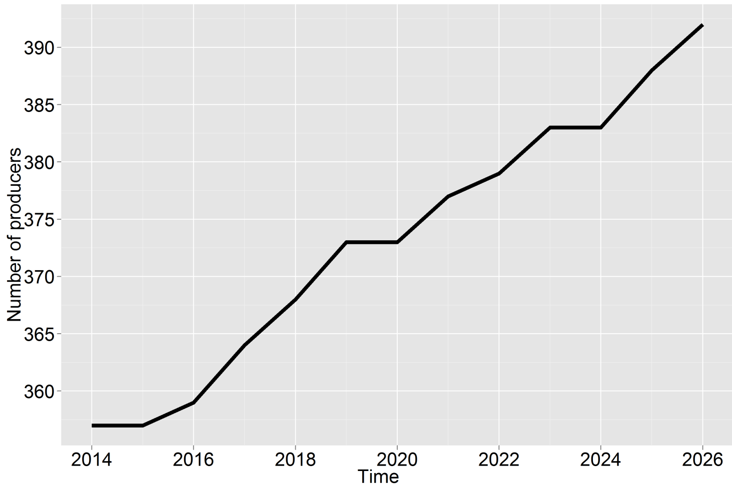

Figure 5.23: The number of farmer agents that cooperate in green gas production over the years with respect to run Y.

With respect to this figure, we observe again that a substantial part of the farmer agents decide to start with production in the year 2014. In addition, the number of farmer agents increases gradually over the years.

Since we found many of the producers cooperating in groups, within the following section we take a closer look at the characteristics of these producers.

5.4.3 Characteristics of green gas producers cooperating in groups

As described in section 5.3.2, we characterise the farmer agents with respect to 3 different aspects: a *successor*, the *scale of the farm* and the amount of investment *capital*.

Successor

Similar to individual production, it is found that all producers cooperating in groups have a successor as we can see from figures 5.24 and 5.25. As a result, we emphasise again that the presence of a successor is beneficial for green gas production to occur.

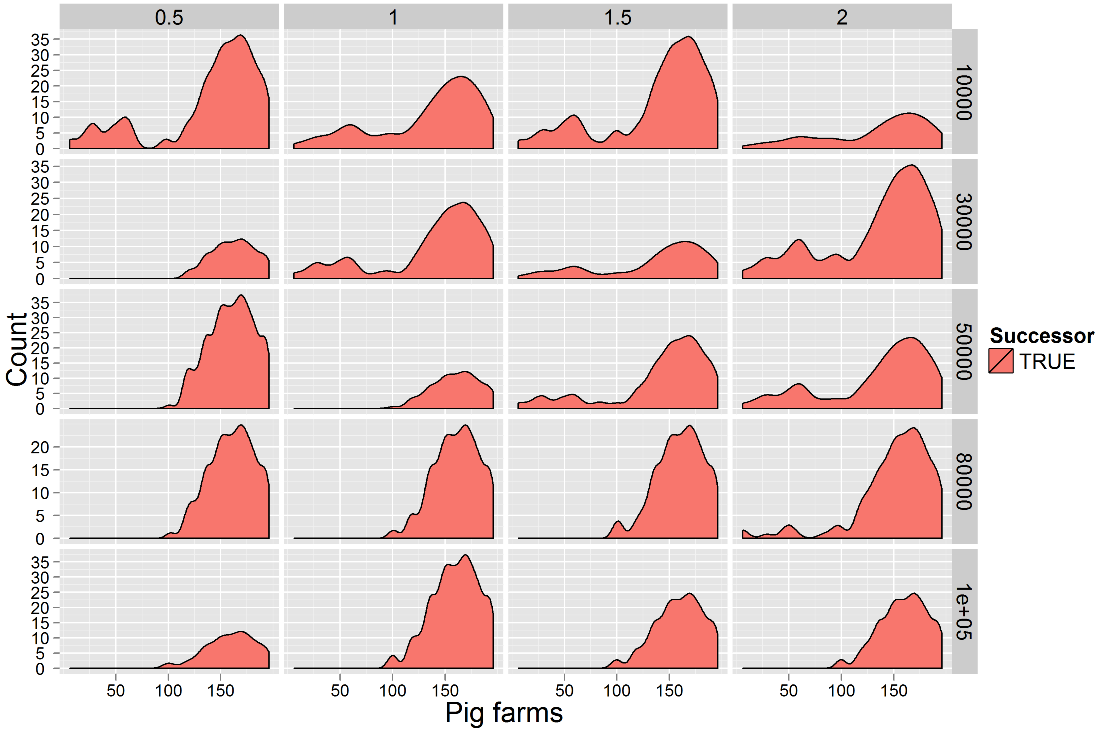

Figure 5.24: Pig farmer agents cooperating in green gas production marked for having a successor (indicated by TRUE or FALSE). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

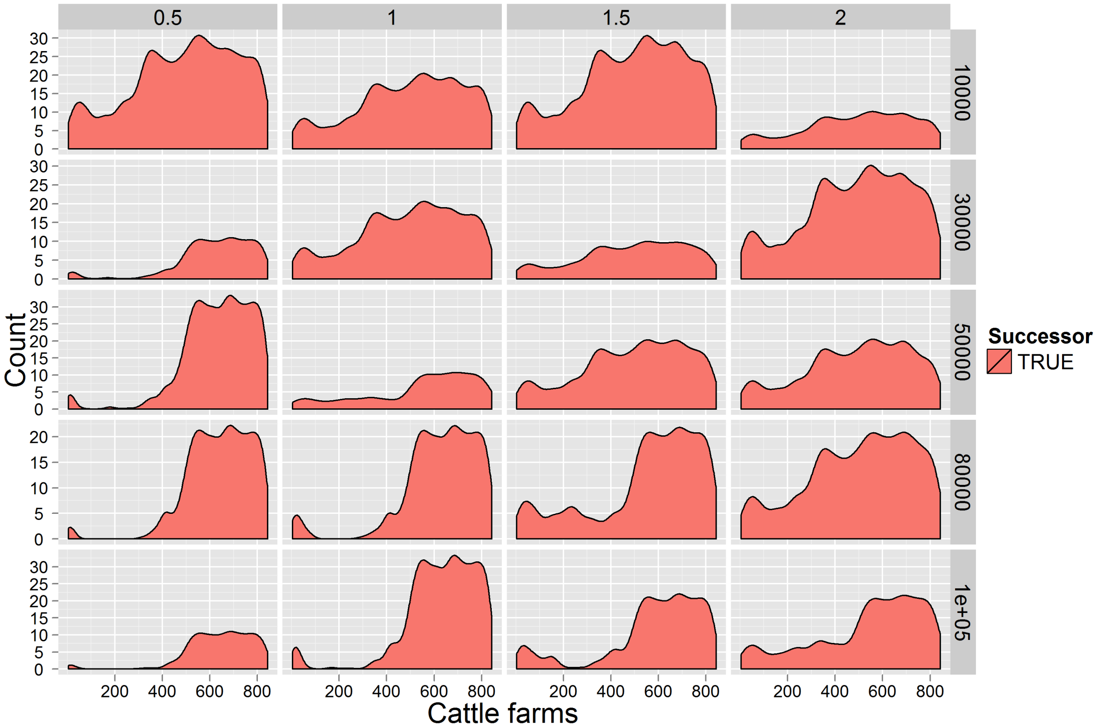

Figure 5.25: Cattle farmer agents cooperating in green gas production marked for having a successor (indicated by TRUE or FALSE). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

Scale of farm

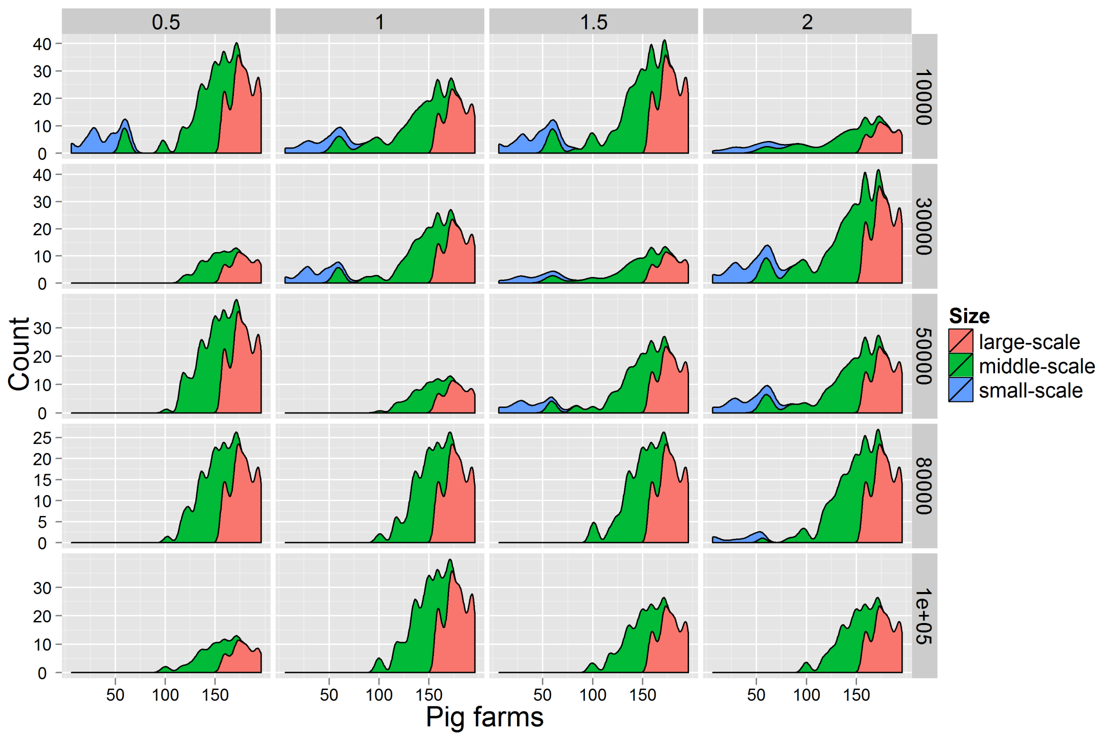

Figure 5.26: Pig farmer agents cooperating in green gas production marked for their farm-scale (indicated by *size*). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

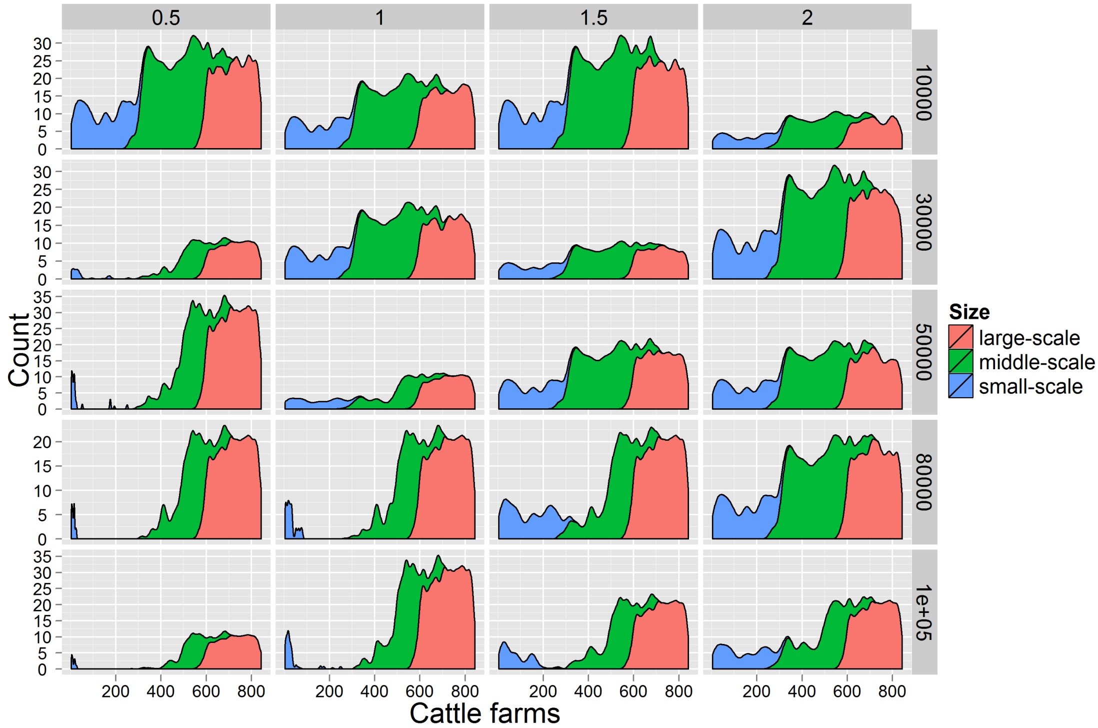

Figure 5.27: Cattle farmer agents cooperating in green gas production marked for their farm-scale (indicated by *size*). The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

Based on the figures 5.26 and 5.27, we state the following:

- Although less frequent compared to the middle- and large-scale farms, small-scale farms are involved in green gas production.
- although the annual technology costs influence at what scale and how frequently farms are involved in green gas production, we consider the farmer agents to be less influenced by this factor when compared to the outcome regarding individual production.
- A revenue is required for green gas production to occur. Furthermore, we observe that the amount of revenue seems to have an influence - although relatively small - on the occurrence of green gas production as we can see for example in figure 5.26 a decrease with respect to the small-scale pig farms at decreased revenue values.
- We observe a remarkable difference between pig and cattle farms: where the presence of small-scale pig farms decreases at increased technology costs and low values for revenue, we still observe the presence of small-scale cattle farms. Based on this observation and the outcome with respect to subsection 5.4.1, we tend to believe that the chances for cattle farmer agents to be involved in cooperation are higher as the system composes more cattle farms with respect to pig farms.

Capital

As we can observe from figures 5.28 and 5.29 - in contrast to the outcome of experiment 2 - a farmer agent's decision to produce green gas is hardly influenced by economic factors with respect to the amount of capital he might possess. This observation applies to both cattle an pig farmer agents.

We explained that cooperation results in reduced costs due to economy of scale. Furthermore, since responsibilities are shared with respect to the owned technology, (capital) risks might be reduced as well. As a consequence, we suggest that farmer agents might evaluate their individual circumstances (with respect to the specific amount of investment capital) to a lesser extent in case they are allowed to share responsibilities: the specific amount of investment capital a farmer agent possesses is of less 'importance' when considering cooperation, viz. a farmer agent should only be *willing* to provide this amount of capital.

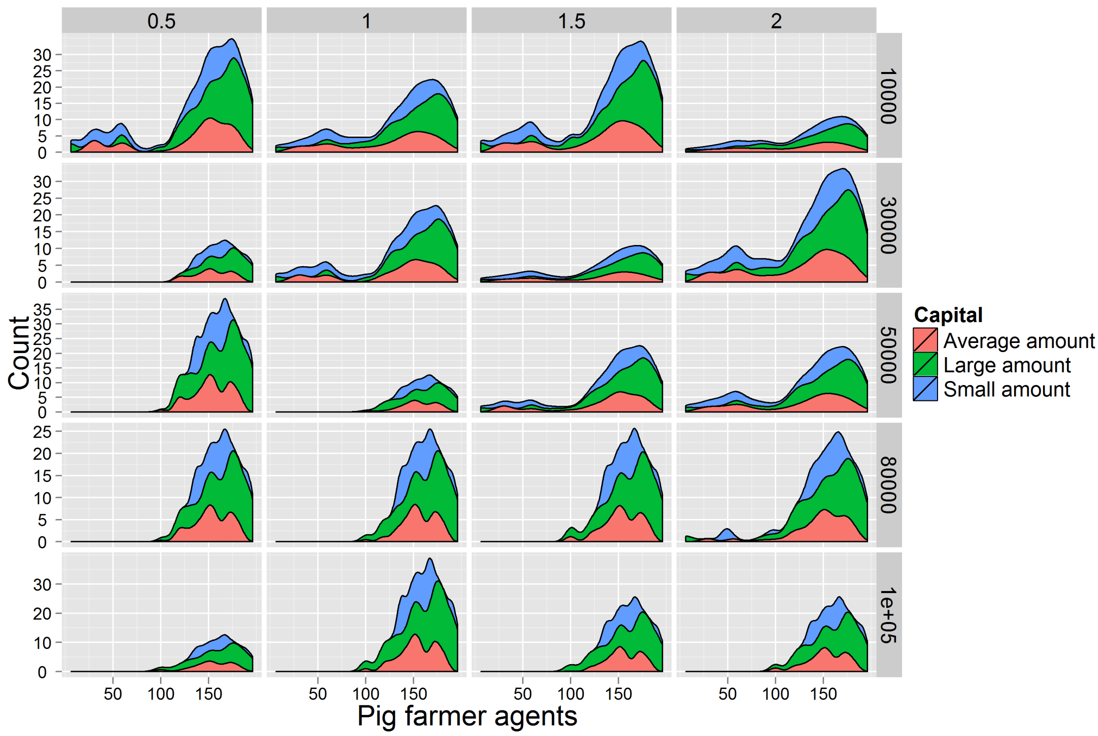

Figure 5.28: Pig farmer agents cooperating in green gas production marked for their investment capital. The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

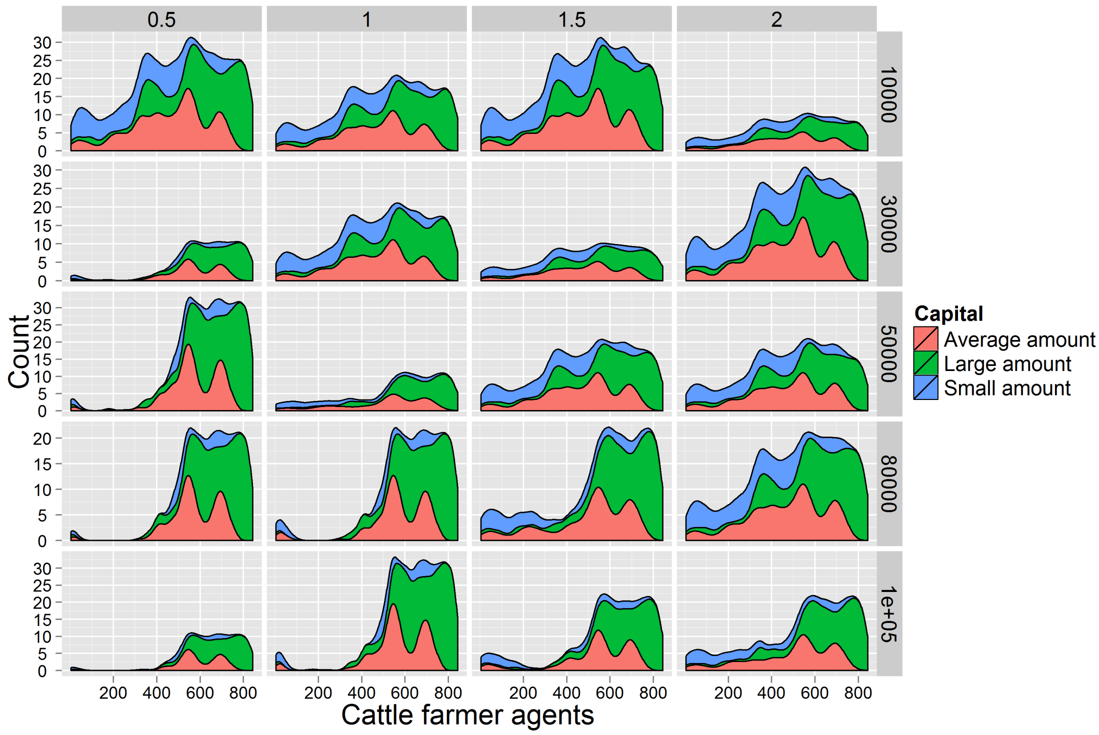

Figure 5.29: Cattle farmer agents cooperating in green gas production marked for their investment capital. The figure presents a facet-grid plot in which the *revenue* (€/Nm^3) is presented on the top and the *annual technology costs* (€) at the right of the plot.

5.4.4 Group formation

Farmer agents who decide to cooperate will form groups that might be composed of both cattle and pig farmer agents. These groups can be large or small depending on the specific number of farmer agents that cooperate. In addition, we might observe many groups formed or only a few.

A correlation might exists between the number of groups (formed in each run) and the size of these groups as we can imagine that - under more favourable (economic) conditions - more groups might be formed that are smaller in size.

In order to explore a possible correlation, we plotted the size of groups against the number of groups. We smoothed the data[9] and the result is presented in figures 5.30 and 5.31.

[9] We applied a *loess line* with the standard error represented by a semi-transparent ribbon.

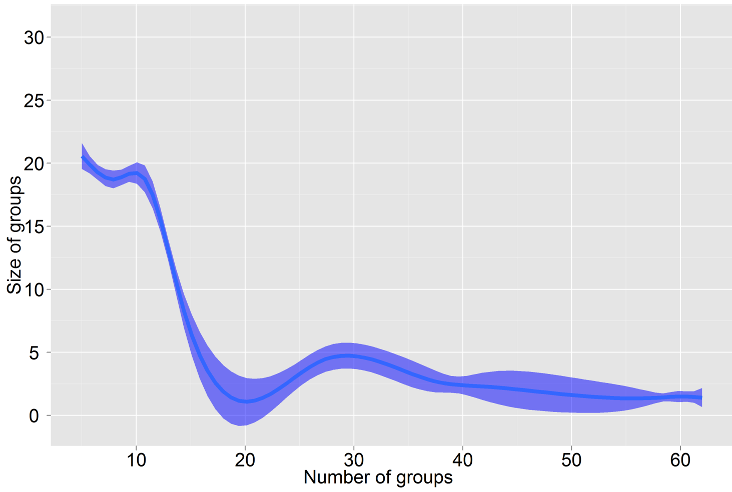

Figure 5.30: Group formation by pig farmer agents.

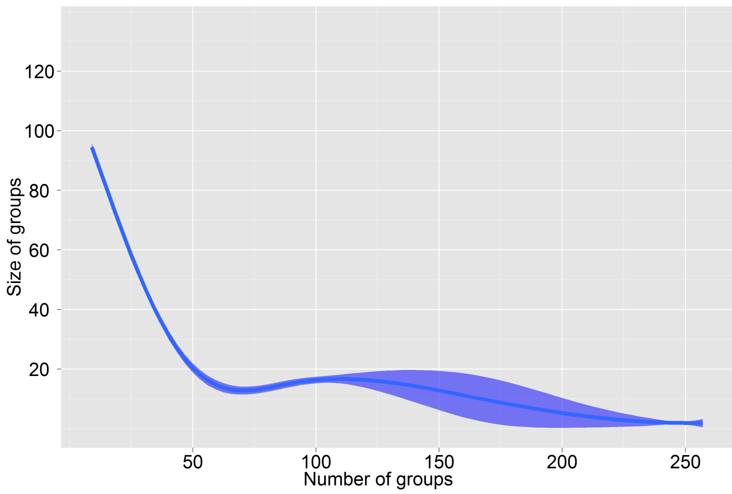

Figure 5.31: Group formation by cattle farmer agents.

Considering these figures, we do observe a pattern. With respect to the observed system behaviour we state the following:

- The size of the groups declines as the number of the groups increases. This observation confirms our expectation and as a result, we suggest that the system might strive to an optimal state with respect to the economic settings.
- We explained that both pig and cattle farmer agents might cooperate together within one group. As a result, the pattern in figure 5.30 might be less 'smooth' when compared to the pattern observed in figure 5.31 due to the lower number of pig farmer agents that cooperate.

5.5 Conclusion

In this chapter we presented the model outcome regarding three experiments. Within these three experiments we explored the:

- dynamics within the manure distribution system.
- potential for ME production by individual farms.
- effect of cooperation on the potential for ME production.

In the following paragraphs we present the conclusions with respect to the obtained model outcome.

Manure distribution system

We explored the dynamics within the manure distribution system under different institutional settings. Based on the model outcome with respect to this experiment we observed that:

- Both cattle and pig farms decrease over time. This decrease is more abrupt with respect to pig farms.
- The volume of manure produced within the region remains stable. Furthermore, the volume of manure that is considered to be abundant will increase as the amount of land available for manuring decreases.

Factors that influence the adoption of manure-based energy production

In order to obtain an understanding of the factors that influence the adoption of manure-based energy production, we explored the characteristics of producers under different economic settings.

Successor We observed that all farmer agents that invested in green gas production have a successor.

Scale of the farm When we consider individual production, we observed that only middle-scale farms and large-scale farms were involved in green gas production. This changed in case farmer agents cooperated as also small-scale farms were involved.

Capital In case of individual production, we observed only farmer agents involved that possess the average to large amount of capital. In case farmer agents were allowed to cooperate, farmer agents that possessed a small amount of capital were also involved in green gas production.

Economic factors In case of individual production, we observed farmer agents to be clearly influenced by the economic factors as more farms were present in case the economic conditions improved, this especially with respect to the annual technology costs. In case of cooperation, we observed the farmer agents to be less influenced by these economic factors as we observed a more and broader variety of farmer agents being involved in green gas production.

Potential for manure-based energy production

Based on the model outcome with respect the potential for ME production we state:

- Irrespective of the economic settings, we consider the potential for ME production quite low.

- This potential is increased in case farmer agents are allowed to cooperate.
- When we consider an annual technology cost of €$80,000$ and a revenue of €1.04 per Nm^3 the production potential in case of individual production amounts approximately $3.92 \cdot 10^7$ m^3. In case of cooperation we found a 5.5 higher production potential: $2.14 \cdot 10^8$ m^3.

In case of individual production only a few farmers were involved in green gas production. Based on an annual technology cost of €$80,000$ and a revenue of €1.04 per Nm^3, we observed a production potential of approximately $3.92 \cdot 10^7$ m^3. These farmer agents all have a successor, possess a large-scale farm (pig farms with 3000 pigs or more and cattle farms with 150 cattle or more) and were able to invest a large amount of capital.

In case of cooperation, the number of farmer agents that were involved in green gas production increased largely. Furthermore, the number of cattle farmer agents that cooperate in groups exceeds the number of pig farmer agents, probably due to the larger number of cattle farms present in the system.

Chapter 6

Discussion

6.1 Introduction

As presented at the beginning of this master thesis, the objective of this research is to explore the potential for ME within the evolving manure distribution system in the region of Salland, by means of agent-based social simulation.

With respect to our research approach, in section 6.2 we discuss the use of agent-based modelling in combination with the MAIA methodology.

In chapter 5 we presented the model outcome that we generated by means of social simulation. In section 6.3 of this chapter, we discuss the research outcome with respect to the formulated research questions and our research objective. Furthermore, we present our insights obtained by carrying out this research project.

6.2 Applied research approach

We chose an exploratory research approach in which we used agent-based modelling to investigate the potential for ME production within Salland as we did not know what possibilities might exist with respect to the evolving manure distribution system.

As described in the chapter 1, agent-based modelling allows a system to emerge from bottom-up. By means of the developed agent-based model we were able to model farmers and their decision making within complex algorithms. As a result, the system was simulated and did emerge from bottom-up as we saw the formation of groups in which farmers did cooperate in ME production. By varying the model settings, we were able to generate a large amount of data, on basis of which we obtained insight in the effects of different factors on the emergent system behaviour.

As described in chapter 4, we made several modelling choices and assumptions with respect to the system. As a result, we learnt that the model comprises a simplified and very abstract representation of the system under study. For that reason, we experienced that the applied modelling approach should be viewed as an attempt to capture real world complexity and the model outcome should be evaluated with respect to the modelling choices made. We highly valued the process of modelling as this gave us the following insights:

- The used abstract representation of the system for modelling, required a good understanding of the same system. Within this process we recognised that it is very important to understand what macro-level behaviour might be of special interest in order to make appropriate and feasible choices. We learnt that we should carefully evaluate the system boundaries in order to obtain the desired model output.

- As the implemented model comprises a coded representation of the system, knowledge of the domain expert with respect to the concept of object-oriented programming is very useful. This is especially the case for the validation and verification part to make use of the model, understand its output and perform the data analysis by means of the programming language *R*. Furthermore, it needs no further explanation that knowledge with respect to programming languages enhances the communication between domain expert and modeller.

6.2.1 MAIA

Since many of the important modelling decisions are made during conceptualisation, we like to emphasise the importance of this process phase. Furthermore, the conceptualisation process highly iterative, hence one should be aware that it consumes a lot of time.

As explained, we experienced that a good understanding of the different system components is required in order to capture them for modelling. In general, we perceived that the conceptualisation process by means of the MAIA framework constitutes a good way for identifying relevant system components. The fact that the MAIA framework is comprised of a divers range of relational *structures* encouraged us to explore different system components and forced us to truly evaluate their relevance for capturing.

As described in chapter 3, the MAIA framework supports the use of institutions as a major structure for conceptualising social systems. As a result, we were able to model institutions in agent decision making and see for example the influence of the manure policy giving rise to the distribution of manure.

We learnt that conceptualisation by means of MAIA resulted in an enhanced documentation. We consider this documentation very beneficial since:

- the documented concepts allowed for an efficient communication between on the one hand the domain expert and on the other the modeller.
- we experienced the documentation very feasible for translating the concepts into a computer model as the documentation is comprised of relational tables and diagrams that can be easily coded.
- we obtained a compact overview of the system. Due to this overview, we were able to revise certain concepts whenever needed in an easy way.

6.2.2 Data collection

With respect to our objective to develop a agent-based model for social simulation, we required a good understanding of the system. As described in chapter 3, we carried out interviews and performed a literature review in order to obtain relevant (empirical) data and information.

The system under study is complex as many different actors are involved who are influenced by various factors. Many challenges exist and uncertainties are present with respect to the potential energy that can be generated.

Considering the inexperienced character of a ME system and the fact that we defined our scope to local circumstances, it felt like a natural consequence to carry out interviews. Especially since we were highly interested in the perceptions of local actors with respect to their decision making behaviour.

We experienced that knowledge regarding the system was dispersed. As a result, we held interviews with a broad variety of actors. Furthermore, we learnt that little is documented with respect to so called 'success factors' for developing a ME system. A substantial part of the found reports only deal with technological system aspects. We therefore value the performed interviews highly as it enabled us to apply an integrated system perspective within this research project.

6.2.3 Data analysis

The modelled system comprises in total 1039 agents (196 pig farmer agents and 843 cattle farmer agents). The run time of the model amounts 26 years and at every tick (a year), the situation of every unique agent was saved. The model was simulated (repeatedly) at least 50 times, generating a large amount of data. Since the behaviour of each individual agent over time was considered important, the analysis of the data was quite challenging. As a result, data analysis was very time consuming and we suggest to make choices in advance with respect to the output requirements. In order to carry out the data analysis, we used *R*[1]. Especially in combination with *RStudio*, the open source integrated development environment (IDE) for R, this software is very user friendly. In addition, we recommend to explore R first to make sufficient use of the possibilities.

6.3 Research outcome

In the introduction we introduced the research question. We are interested to obtain insights with respect to the factors that influence the adoption of ME production, this in the light of the manure distribution present in the region of Salland. In addition, we are interested to see whether there are possible benefits with respect to this production for the manure distribution system in the long run.

Based on the model outcome, we discuss what insights we have obtained with respect to this research project.

6.3.1 Manure distribution system

We modelled the manure distribution system and studied the system behaviour over time with respect to the number of farms, the number of animals and the volume of manure that is considered to be abundantly present within the system.

Under the influence of different institutions we observed a decrease in the number of farms over the years. We expected this decrease to happen, considering the current changes with respect to the rules and regulations for farming activities. Based on the current trends within the livestock farming sector we presume that:

- many farmers - especially the ones who own a small-scale farm - might not be capable of carrying out the required investments in compliance with the stated regulations.
- a substantial part of the farmers has a poor financial situation as their obtained revenues are considered low. As a result, a trend of up scaling is observed and farmers may explore additional tasks.

[1] A programming language and software environment for statistical computing and graphics

- the future of the livestock farming sector will remain uncertain as the impact of many influential factors (e.g. market dynamics and regulations) is not known. Furthermore, the vision a particular farmer applies to his farm is important. Moreover, this vision might be influenced by the presence of a successor.

When we consider these presumptions, we are able to explain a trend in which a few percent might abandon each year and some others might expand. Based on this trend, we are able to explain the observation that the volume of manure produced in the system remains steady over the years.

We observed an increase in the volume of manure that is considered to be abundantly present as the options for local manuring became limited. As a consequence, high costs remain associated with the distribution of manure and circumstances are not improved with respect to the encountered mineral unbalance.

6.3.2 The potential for manure-based energy production

We observe a relatively small minority of the farmers investing in ME (or green gas) production. Based on their individual circumstances and possible gains, they make the decision to invest. This minority is increased in case we allow for cooperation. We will carefully evaluate this outcome with respect to our modelling assumptions as we presume the observed potential to be lower in reality:

Subsidy and permits When the decision is made to invest in ME production, we make the assumption that subsidy (by means of the SDE+ regulation) is granted and will result in a specified amount of revenue (referred to as *basic amount*). Furthermore, we also assume permits to be granted. In reality, this might not be true as subsidy and permits can be denied. Furthermore, we state that these institutions might be perceived as barriers as they create uncertainties with respect to the possible gains. With respect to institutional barriers, we suggest that a certain threshold should be overcome in order to start considering ME.

Cooperation We allow farmers to consider cooperation in case individual production is not feasible. In reality we should not take cooperation for granted as perceptions can be quite different in this respect.

Biogas infrastructure Besides farmers, other actors are involved in the development of a biogas infrastructure and the fact that they all should cooperate adds another complex layer to the notion of ME production. Furthermore, we assume that *all* farmers will be confronted with an investment decision, irrespective of the current energy infrastructure and the possibilities for green gas injection within the region of Salland.

Production facility We assume that every farmer would be able to carry out the logistics associated with the operations and will have space available at his farm for placing a production facility. When we consider the reality, we do not expect every farmer to be willing and able to operate a production facility at his farm.

Manure-based energy Within this research project we are concerned with the utilisation of manure for energy production by means of the anaerobic digestion process. We are aware of the co-digestion process in which - additional to manure - co-substrates are used. In general, this co-digestion process results in more energy per volume of organic material[2]. We decided

[2] This depends mainly on the composition of the input stream.

to limit our research scope to the utilisation of manure solely for energy as this type of biomass is assumed to be abundantly present within this region and we are interested in the decision making of local farmers.

In order to obtain an understanding of the factors that influence this decision, we simulated the system under different economic settings. The economic factors (e.g. the possible revenue and the annual technology costs) do influence the decision to invest, but we consider their influence limited.

Based on the model outcome, we state that the farm-scale determines to a high extent the production capacity. As a consequence, we do not expect small-scale farms to be involved in (individual) ME production as we consider production not feasible at this scale. In case of cooperation we observed a difference between pig and cattle farmers as cattle farmers are more frequently involved in ME production with respect to their farm-scale. As a consequence, we presume that the latter own a higher production potential. Furthermore, farmers must be willing to make a specific amount of investment capital available in order to start with ME production. With respect to the current circumstances within the livestock farming sector, we believe the willingness is rather low.

The factor *willingness* to invest in ME should not be underestimated. In addition, we emphasise that the *perception* a farmer has regarding ME production, is highly influential to his final decision making. Regarding this statement, we present the following important question:

'*What benefit do farmers obtain with respect to manure-based energy production?*'

Based on the research outcome we consider the production of ME not beneficial for the manure distribution system as the production of digestate is no solution for the issues currently faced with respect to the abundance of manure. We believe that this should change in order to increase the adoption of ME production.

Chapter 7

Conclusions and recommendations

7.1 Introduction

In this research project we used the MAIA methodology to develop an agent-based model for system exploration. By means of social simulation we were able to explore the effects of influential factors on the potential of ME within the region of Salland. Based upon these insights we present in this final chapter the conclusions (section 7.2) and the recommendations in section 7.3. Finally, we will conclude with a reflection on the research process.

7.2 Conclusions

Due to the set sustainability goals within the province of Overijssel, the Netherlands, opportunities are explored for the production of green gas in the region of Salland by the GGS project group. Since within the region of Salland (intensive) livestock farming is practised, manure - a potential source of biomass for bioenergy production - is assumed to be abundantly present. As the technology for anaerobic digestion is mature and facilities are available at different scales, the utilisation of manure may constitute a considerable energy potential. As a result, local farmers are approach for collaboration and hence are confronted with the decision to produce ME.

Manure contains valuable minerals and is - in particular for that reason - used as a fertiliser. Due to intensive livestock farming the manure production exceeds the local demand for manure-based fertilisers. As a result, manure is distributed against high costs and this is considered a problem. Several policies are directed towards limiting the detrimental consequences of excessive manuring. As a consequence, manure is considered as a waste product and valuable minerals are lost. The implication is that high costs remain associated with the distribution of manure.

Circumstances within the (intensive) livestock farming sector are changing, especially due to the amendment of policies that monitor farming activities. Farmers are highly influenced by these changes. Based on the insights obtained in this research, it is expected that a substantial part of the farmers will abandon their farm as they do no longer envision a future for their farm. Furthermore, with respect to the individual circumstances of a farmer, it is expected the impact of these changes is higher for pig farmers when compared to cattle farmers.

Based on the outcome of this research, we consider the potential for ME low as outlined in the following argumentation:

- The feasibility of ME production is influenced by institutions (e.g. the granting of subsidy) and the costs of technology. With the uncertainties about both the amount of subsidy that will be granted and the order of the specific technology costs, a clear expectation of what will be gained is lacking. As a result, risks are present and these risks will decrease the willingness to invest in ME.

- A sufficient production capacity is required to allow for a feasible production. As a consequence, many small-scale to middle-scale farms will not consider ME production, due to the above mentioned uncertainties about benefits and costs.

- The production of ME requires a considerable investment by the farmer, requiring sufficient investment capital. This puts a lot of pressure upon the farmers, who often experience at the same time poor financial situations and ongoing changes in the policies. Their main source of income is and will be farming, hence their main attention is farming. This makes it unlikely to consider their own ME production.

- In addition to the aforementioned statement, farmers do not obtain a clear benefit with respect to the production of ME. We consider the production of ME production not beneficial for the manure distribution system: current issues with respect to the abundance of manure are not solved and meanwhile the produced digestate, almost identical in volume and composition to manure, had to find its way back to the manure distribution system.

Although cooperation between farmers should not be taken for granted, in case farmers do cooperate, the potential for ME production is highly increased:

- Cooperation allows for the involvement of a broader variety of farms as the individual circumstances become less influential for the decision to invest in ME production.

- Cooperation allows for an increase in production capacity. Due to economy of scale, gains are increased as production costs are reduced (and risks are shared).

7.3 Recommendations

With respect to the stated conclusions, we make the following recommendations to the GGS project group as they are concerned with exploring the opportunities of green gas production through a biogas infrastructure within the region of Salland:

- We suggest to create a clear benefit from a farmer's point of view. The fact that high costs remain associated with the distribution of digestate is perceived as a burden. As a result, it is suggested to improve this situation by exploring the opportunities for manure - and therefore digestate - processing as this may promote the reuse of minerals.

- In order to decrease the indecisiveness of local farmers to investment in ME production, their knowledge and understanding regarding ME production (with respect to the development of biogas infrastructure) should be improved. Subsequently, it is suggested to promote cooperation as this will possibly result in an increased potential.

Furthermore, we suggest to reduce institutional barriers, especially with respect to the SDE+ regulation which is perceived as complex. To stimulate the production of renewable energy, a clear supportive legal framework should be formulated that does not give rise to uncertainties. Furthermore, this framework should provide guarantees for the long run, this is specifically required taking into account the poor financial situation of most farmers.

Suggestions for further work

Within this paragraph we state a few suggestions for further research:

- With respect to the reuse of minerals, we suggest to explore the effects of manure (or digestate) processing on the potential for ME.
- Since many policies (directed to livestock farming activities) are currently subject to change, we suggest to explore these amendments to obtain an improved understanding of their possible impact. This applies in particular to the *animal production rights* and the *EU milk quota regime*.

7.4 Reflection

Within this research project we explored are rather new concept since we built an agent-based model of a manure distribution system to explore the potential for ME production. We obtained many insights by carrying out this research project.

At the beginning of our research process we experienced a challenging exercise in defining our research scope and in applying the system boundaries as we encountered numerous issues that we were able to relate to the subject of study in some way. Within this respect, we learnt to separate details from the main matter as we proceeded in this research process.

With respect to the content of this research project, we learnt that we can apply two different perspectives on ME. On the one hand we may consider the utilisation of the abundantly available manure for energy. This as a (potentially) practical way to increase the share of renewable energy production with respect to the formulated sustainability goals. On the other hand, we may consider manure as a fertiliser that contains valuable minerals and due to its organic matter we are introduced to the notion of potential energy product. Since local farmers are confronted with the decision to use manure for energy production, we explored the factors that influence the adoption of ME production by especially these farmers.

We experienced that the encountered complexity was much larger than we were able to foresee at the beginning of this research. We heard many different opinions, observed numerous influential factors with respect to the production of ME and perceived the issues regarding the (local) abundance of manure. These findings made us realise that the main challenges came from the organisational (institutional) aspects of the system, and not so much from technological part, as the various options in case of the latter are mostly available.

The model outcome might seem a bit trivial at first glance, nonetheless we like to emphasise that we understand modelling as a means to an end. The objective of this research is to obtain an understanding of the system with respect to the stated research questions. Especially due to our modelling approach, we were able to obtain a good understanding of the system as we understood the connections between different system components and the underlying mechanisms that caused certain system behaviour. Furthermore, we carried out a thorough analysis and conceptualised the system in a structured and systematic way. As a result, by means of the developed model we are able to provide a valid argumentation for our research findings.

Appendices

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Appendix A

Additional information

A.1 Phosphates

Phosphorus (P) is an essential nutrient for all life forms. In nature P is supplied through the weathering and dissolution of rocks and minerals with very low solubility. Due to this rather slow process, P is usually a critical limiting element for animal and plant production.

Current processes in agriculture are key to the disturbed P-balance. Due to erosion of agricultural land P gets lost. It is stated that worldwide this loss exceeds the amount of P that is taken up by crops (de Haes et al., 2009). Minerals in animal feed that are not consumed by the animal will end up in manure. As a consequence, especially within intensive livestock farming, minerals will accumulate. Furthermore, it is estimated that within the EU the surpluses of P per unit area of agricultural land ranges from values close to zero in Eastern Europe to 20 kg phosphorus per hectare in parts of Western Europe (Schroder et al., 2011).

The current use of phosphorus causes fast depletion of high grade phosphate rock reserves. The result is scarcity that is accompanied with high costs and additional quality losses. Since the production of food heavenly depends on the availability of phosphorus, significant effects are expected for the global food security. In order to maintain a mineral balance, opportunities for recovering phosphorus and reducing demand are suggested (Cordell et al., 2009; Schroder et al., 2011; de Haes et al., 2009; Steen, 1998).

Phosphate for mineral fertilisers is derived from Depending on the purpose, phosphate rock will either be dissolved to produce phosphoric acid (for application in mineral fertilisers) or melted to produce elemental phosphorus. Besides the production of mineral fertilisers (80%), P from rock phosphate is also used for the production of detergents (12%), animal feeds (5%) and speciality applications (3%) (Steen, 1998).

A.2 Action Programme Ammonia

The Action Programme Ammonia is concerned with the reduction of ammonia emissions from animal housing systems at farms. Within this programme it is stated that farms should meet the requirements stated in the *'Besluit ammoniakemissie huisvesting veehouderij (Besluit huisvesting)'*. This Decision states that only an animal housing system that has an emission factor (defined per animal place) lower or equal to the maximum emission value formulated for that particular housing system is permitted. Substantially, intensive livestock farms fall under the IPPC Directive. As a consequence, the housing system that is requested for, when submitting a new (integral) environmental permit, should be in compliance with the *Best Available Techniques*[1]. The approved housing systems are listed within the regulation *'Regeling ammoniak en veehouderij (Rav)'* (CBS, 2011a).

The Action Programme Ammonia is directed towards the medium-sized pig and poultry farms. The cattle farms are put into a different track, although it is stated that cattle farms that house their cattle the entire year fall under the same regulation. Substantially, by 2012 cattle farms should obey similar regulations (NL, 2011a).

Originally, it is stated that farms should satisfy the conditions stated within this regulation since the first of January 2010. However, many farms were not able to realise the required adjustments and the date has been postponed to the first of July 2012 (for existing housing systems) and first of January 2013 (for new housing systems). Until this date a policy of tolerance applies in which farms are obliged to hand in a *'bedrijfsontwikkelplan (BOP)'* before first of April 2010, this is a farm development plan in which it is stated how a farm will meet its required adjustments.

Substantially, the category of farms that were obliged to make an application for a permit before first of July 2011 (previously first of January 2011) might be granted a delay. In order to be eligible, these farms should satisfy several conditions, e.g. an approved 'BOP'. The delay is caused by the administrative burden for the appropriate authorities and the additional expenditures for implementation by these particular farms. As a result the realisation of the required adjustments is postponed until the first of July 2013 for these particular farms.

Farms that finish their farming activities before January 2013, do not fall under the Action Programme Ammonia. In addition, farms that have the intention to finish by January 2013 are provided the opportunity to phase out until 2020 on the condition that they take equivalent measures for reducing emissions (e.g. not registered in Rav, and might comprise the reduction of the number of animals) (NL, 2011a). Currently, these measures are part of regulations that are still under development.

A.3 Anaerobic digestion

In figure A.1 the co-digestion process is presented. The co-substrates are subdivided into smaller pieces before they are put into the facility together with manure. The anaerobic process can take place at different temperature levels: *thermophilic* (50-60 Celsius), *mesophilic* (30-40 Celsius) and *psychrophilic* (10-20 Celsius). The thermophilic and mesophilic temperature levels are considered to be more efficient compared to the psychrophilic temperature level, but require additional heat for the process to take place. Although it is stated that the retention time on average amounts 25-40 days for mesophilic co-digestion (Kool et al., 2005), this depends highly on the local process circumstances as it is experienced that a reflux of the output material digestate - hence increasing the retention time - results in an increased yield (Jansen, 2011).

A.3.1 Legal aspects concerning the anaerobic digestion process

Several laws and regulations are concerned with the production of biogas from anaerobic (co-)digestion (Morgenstern and de Groot, 2010). A building permit and a permit for processing the manure and co-products should be obtained under the laws of environmental management and land use planning. Depending on the scale and category by 'Inrichtingen en vergunningbesluit Wm (IvB)' the municipality or the province is the appropriate authority.

At European level the IPPC[2] Directive 96/61/EC requires industrial and agricultural activities

[1] 'Best Beschikbare Techniek (BBT)'

[2] Integrated Pollution Prevention and Control

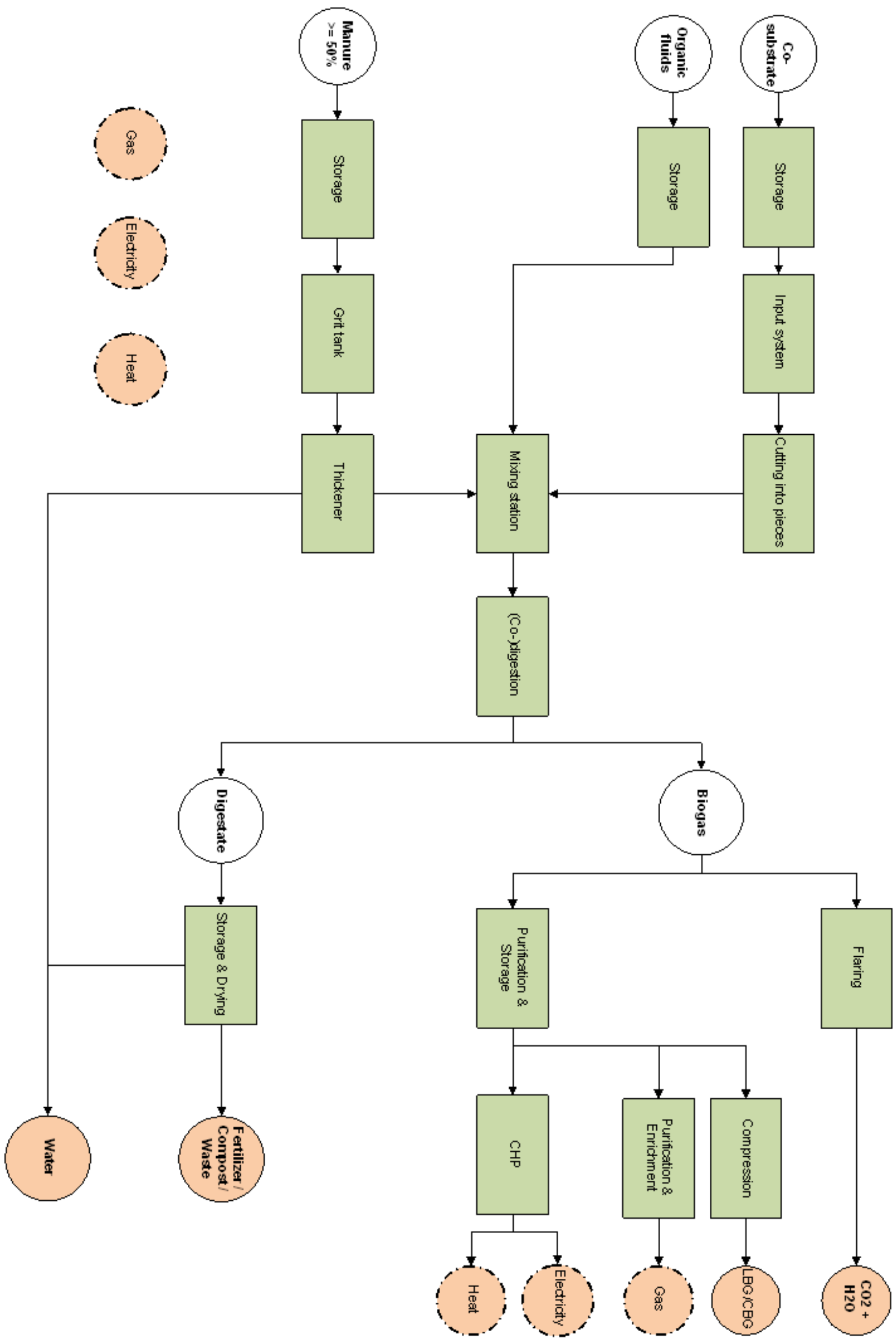

Figure A.1: Anaerobic (co-)digestion process with a high pollution potential to have a permit. This permit can only be issued if certain environmental conditions are met, so that the companies themselves bear responsibility to prevent and reduce any pollution they may cause (EC, 1996). In addition, the *Reference Document on Best Available Techniques for Intensive Rearing of Pigs and Poultry (July 2003)* provides guidance on what the best available techniques might be for the anaerobic digestion process (Eur, 2003). If the capacity of the facility exceeds 100 tonnes of product per day, an *Environmental Impact Assessment* (EIA) has to be carried out. According to the IPPC Directive, with respect to the local environmental circumstances and technical details of the facility, the appropriate authority decides upon the licence application and the necessity for carrying out an EIA.

A.4 Green gas

Green gas is gas produced from biogas. Furthermore, it has the same quality standard compared to natural gas. Green gas can be injected into the Dutch pipeline system. In the Netherlands *Gas Transport Services* (GTS), the Dutch Transmission System Operator (TSO), is responsible for the management, the operation and development of the national transmission grid (80/67 Bar) and the regional grid, a high-pressure gas pipeline (40 Bar). The gas is further distributed to end users through a distribution network comprising low-pressure pipelines (8 Bar and 100-200 milliBar), for which the (Local) Distribution System Operator (DSOs) is responsible (Welink et al., 2007). A high degree of co-ordination has to maintain a constant gas pressure and quality in the system, this in line with the requirements of the system itself and the appliances and installations supplied (Correljé et al., 2008). The *Wobbe Index* is an indicator of the interchangeability of fuel gasses and is frequently defined in the specification of gas supply and transport utilities. It is a function of the higher heating (caloric) value and the specific gravity and is used to compare the combustion energy output of different composition fuel gasses in an appliance.

In the Netherlands, the *Gronings* natural gas consists for 82% of methane and for 14% of Nitrogen and other substances like helium and ethane (Welink et al., 2007; Hagen et al., 2010). The calorific value of the gas is 32 MJ/Nm^3, this in contrast to Biogas, 20 MJ/Nm^3 (Verbeek and Werktuigbouw, 2011). To make biogas suitable for injection into the Dutch gas pipeline system, it has to be upgraded. Several upgrading technologies are available like (Vacuum) Pressure Swing Absorption (PSA), Membrane Gas Adsorption (MGA), Cryogene Separation, Chemical Absorption (CA), Pressurised Water Scrubbing (PWS) (Welink et al., 2007). By means of a membrane technology biogas is dried, then compressed till approximately 10 bar. In addition, under high pressure it is purified (by a membrane that is selective for methane) and the share of methane (to approximately 90%) is increased (HoS, 2010). The technology for upgrading biogas is a mature technology and can be applied to different biogas production capacities, ranging from a small-scale farm application (approximately 50 Nm^3 per hour) to large-scale (approximately 2200 Nm^3 per hour) (Dumont, 2010a).

The safety, efficiency and reliability of the gas system are key issues for the network operator. Important control parameters are the gas flow and gas pressure within the system. The pressure should be within the correct working pressure range: low enough to prevent damage to the pipelines (and maintain safety), but high enough to guarantee a reliable gas supply to the end users. In addition, the flow velocity should not exceed 30 m/s, this in relation to sound emission (Donders et al., 2010). To inject green gas into the system these specific network requirements should be met.

Another option besides the injection of green gas in the gas pipeline for natural gas substituting purposes, is the utilisation of green gas as a fuel in mobile transportation (Verbeek and Werktuigbouw, 2011; Roeterdink et al., 2010; Kampman et al., 2010). Depending on the infrastructure applied, biogas can be upgraded to green gas (methane content of approximately 90%) or biomethane (in which the methane content is approximately 97%) (Kampman et al., 2010; Verbeek and Werktuigbouw, 2011).

A.5 Biogas infrastructure

The fact that a biogas infrastructure is not regulated by the Dutch Gas Act has several consequences with respect to its development as it is uncertain who takes ownership and carries out the required investments. Since biogas does not have the same quality with respect to natural gas, the Dutch Gas Act does not apply to a biogas network. As a result, the network operations do not automatically fall under the responsibility of the network operator (Damste, 2011). The general idea for not regulating a biogas infrastructure is that the market should be able to develop itself. It's not desirable to regulate a biogas infrastructure, since the concept is still new and the availability of public money could create an advantage over other systems that are being developed for similar reasons. Since the development of a biogas infrastructure is inexperienced, technological uncertainty (still) exists and risks might be present as the party who is going to take responsibility for operating the network should be able to guarantee safety and security (van Gorkum, 2011).

A.6 List of interviewees

Table A.1: Project group GGS

Person	**Organisation**
Ron Sint Nicolaas	municipality of Deventer
Geke Kosse	municipality of Olst Wijhe
Jasper Arends	municipality of Raalte
Ruud van de Meeberg	Enexis
Ronald Eenkhoorn, Raphaël van der Velde (project leader), Astrid Pap, Arnout Potze	province of Overijssel
Coert Peters	ROVA
Johan Wempe (chair)	Saxion

Table A.2: List of Interviewees

Date	Person	Organization	Subject
May 12th, 2011	Mathieu Dumont	Agency NL	Development of a biogas infrastructure
May 17th, 2011	Kirsten van Gorkum	Biogas Innovator - Enexis	Regulations biogas infrastructure
May 17th, 2011	Harm Jan Bouwers	sr staff memeber Sustainable Energy Province Friesland	Green gas hub
May 18th, 2011 & June 27th, 2011	Han Jansen	Intermediary Jansen Wijhe	Local distribution of manure
May 20th, 2011	Willy Wolfkamp	Pig farmer	Local distribution of manure and manure-based energy
June 9th, 2011	Rik Ogink	Cattle farmer	Local distribution of manure and manure-based energy
June 15th, 2011	Gino Schrijver	Cattle and pig farmer	Local distribution of manure and manure-based energy
June 23rd, 2011	Bart Brouwer	Sales Manager Mircoferm	Manure-based energy
June 27th, 2011	Maikel Timmerman	Researcher at WUR	Manure processing
July 12th, 2011	Theo Duteweerd	Pig farmer (NVV)	Local distribution of manure, manure processing and manure-based energy.

A.7 Manure distribution costs

Dienst Regelingen
Ministerie van Economische Zaken, Landbouw en Innovatie

overzicht

Monitor mestprijzen
Analyse, Selectie en Beschikbaar stellen
Bron: Diensten Centrum Agrarische Markt
Bijgewerkt tot 6 juni 2011

	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
week	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9	week 10	week 11	week 12	week 13	week 14	week 15	week 16	week 17	week 18	week 19	week 20
Vleesvarkendrijfmest																				
Deurne	€ 26,50	€ 26,00	€ 26,00	€ 25,00	€ 24,00	€ 21,50	€ 21,00	€ 21,00	€ 20,00	€ 20,00	€ 20,00	€ 19,50	€ 19,50	€ 20,00	€ 20,00	€ 20,00	€ 20,00	€ 20,00	€ 20,00	€ 20,50
Tilburg	€ 26,00	€ 26,00	€ 25,00	€ 24,00	€ 23,50	€ 21,50	€ 20,50	€ 19,00	€ 19,00	€ 18,50	€ 18,00	€ 17,50	€ 18,00	€ 18,00	€ 18,00	€ 18,00	€ 18,00	€ 18,00	€ 18,50	€ 19,00
Uden	€ 25,50	€ 25,00	€ 25,00	€ 24,00	€ 22,50	€ 21,00	€ 20,00	€ 19,50	€ 19,50	€ 19,50	€ 19,00	€ 19,00	€ 18,50	€ 19,00	€ 19,00	€ 19,00	€ 19,00	€ 19,50	€ 19,50	€ 19,50
Barneveld	€ 24,50	€ 24,50	€ 24,50	€ 24,00	€ 22,00	€ 19,00	€ 18,00	€ 18,00	€ 17,00	€ 16,50	€ 16,50	€ 16,00	€ 16,00	€ 16,00	€ 16,00	€ 16,00	€ 16,00	€ 16,00	€ 16,50	€ 16,00
Lichtenvoorde	€ 25,50	€ 25,50	€ 25,50	€ 25,50	€ 23,00	€ 21,00	€ 19,50	€ 19,50	€ 18,00	€ 18,00	€ 17,50	€ 18,00	€ 18,00	€ 17,50	€ 17,50	€ 17,50	€ 17,50	€ 18,00	€ 18,00	€ 18,00
Markelo	€ 23,50	€ 22,50	€ 22,50	€ 22,50	€ 21,00	€ 19,00	€ 17,50	€ 17,00	€ 16,00	€ 16,00	€ 15,50	€ 15,00	€ 14,50	€ 15,00	€ 14,50	€ 14,50	€ 14,50	€ 15,00	€ 15,00	€ 15,00
Rundveedrijfmest																				
Deurne	€ 20,00	€ 19,50	€ 19,50	€ 19,00	€ 19,00	€ 15,50	€ 16,50	€ 15,00	€ 14,00	€ 14,00	€ 12,50	€ 12,00	€ 12,00	€ 12,50	€ 12,50	€ 12,00	€ 12,50	€ 12,50	€ 12,50	€ 12,50
Tilburg										€ 13,50	€ 12,00	€ 12,50	€ 12,50	€ 12,50	€ 12,50	€ 12,50	€ 12,50	€ 12,50	€ 13,00	€ 13,00
Uden	€ 19,50	€ 19,50	€ 19,00	€ 18,50	€ 17,50	€ 14,50	€ 15,00	€ 12,50	€ 12,50	€ 12,50	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,00	€ 12,50	€ 12,00	€ 12,00	€ 12,50	€ 12,50
Barneveld	€ 19,00	€ 18,50	€ 18,50	€ 18,00	€ 17,50	€ 14,00	€ 13,00	€ 12,00	€ 12,00	€ 11,00	€ 10,50	€ 10,50	€ 11,00	€ 11,00	€ 10,50	€ 10,50	€ 10,50	€ 10,50	€ 10,50	€ 10,50
Lichtenvoorde	€ 18,50	€ 19,50	€ 20,00	€ 20,00	€ 16,50			€ 13,50	€ 13,50	€ 11,50					€ 11,00	€ 11,00	€ 11,00			
Markelo	€ 17,50	€ 16,50	€ 16,50	€ 16,50	€ 15,50	€ 12,00	€ 13,00	€ 10,50	€ 9,50	€ 9,00	€ 9,00	€ 8,50	€ 8,00	€ 8,50	€ 8,50	€ 8,50	€ 8,50	€ 8,50	€ 8,50	€ 9,00
Pluimveemest																				
Deurne	€ 20,50	€ 20,50	€ 20,50	€ 20,50	€ 20,50	€ 17,50	€ 17,50	€ 17,50	€ 17,50	€ 17,50	€ 17,50	€ 17,00	€ 17,00	€ 17,00	€ 17,00	€ 17,00	€ 17,00	€ 17,00	€ 17,00	€ 17,00
Uden																				
Barneveld	€ 27,00	€ 27,00	€ 27,50	€ 27,50	€ 25,00	€ 24,00	€ 22,50	€ 22,50	€ 20,50	€ 20,50	€ 19,50	€ 17,50	€ 17,50	€ 18,50	€ 18,50	€ 19,00	€ 19,00	€ 18,50	€ 18,00	€ 17,50
Markelo	€ 25,00	€ 26,50	€ 26,50	€ 26,50	€ 22,00	€ 22,00	€ 21,50	€ 20,50	€ 17,50	€ 17,50	€ 16,50	€ 16,50	€ 15,00	€ 15,50	€ 15,00	€ 15,50	€ 17,00	€ 16,00	€ 16,00	€ 16,50
Emmen	€ 24,00	€ 24,00	€ 24,00	€ 24,00	€ 21,50	€ 21,50	€ 18,50	€ 17,50	€ 15,50	€ 15,50	€ 15,00	€ 14,50	€ 14,50	€ 13,00	€ 13,00	€ 13,50	€ 13,50	€ 13,50	€ 13,50	€ 14,50
Leeuwarden	€ 30,00	€ 30,00	€ 30,00	€ 30,00	€ 23,00	€ 23,00	€ 22,50	€ 21,50	€ 19,00	€ 18,50	€ 18,50	€ 19,00	€ 19,00	€ 19,00	€ 19,00	€ 19,00	€ 19,00	€ 18,50	€ 18,50	€ 18,00

Specificaties:

Vleesvarkendrijfmest

Het betreft de ophaalbijdrage van vleesvarkensdrijfmest (mestcode 50) met de volgende specificaties:
4 kg fosfaat (P) en 7 kg stikstof (N) per ton af boerderij inclusief bemonsteren, wegen en analyseren,
mits geladen kan worden onder normale omstandigheden. Het betreft distributie alleen over lange afstand. Prijzen zijn ex BTW per ton.

Rundveedrijfmest

Het betreft de ophaalbijdrage van rundveedrijfmest (mestcode 14) met de volgende specificaties:
1,8 - 2 kg fosfaat (P) en 4 - 4,5 kg stikstof (N) per ton af boerderij inclusief bemonsteren, wegen en analyseren,
mits geladen kan worden onder normale omstandigheden. Het betreft distributie alleen over lange afstand. Prijzen zijn ex BTW per ton.

Pluimveemest

Het betreft de ophaalbijdrage van kippenmest mestband (mestcode 32) met de volgende specificaties:
50 - 70% droge stof, vrij verlaadbaar, minimaal 100 ton inclusief wegen, bemonsteren, analyseren en gezondheidscertificaten
en inclusief aanvragen vergunning (exportwaardig Duitsland). Prijzen zijn ex BTW per ton.

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Figure A.2: Manure distribution prices

Appendix B

MAIA tables

B.1 Constitutional structure

Table B.1: Roles

Role	Producer	Landowner
Objectives	Selling green gas	Manuring land
Sub-objectives	Obtaining revenue	
Institutions	Subsidy	Manure policy
Entry Conditions	Owning technology	Owning land
Institutional Capabilities	Production of green gas and obtaining revenue from green gas supply	Calculation of the amount of nitrogen and phosphate needed for manuring land.

B.2 Physical structure

Table B.2: Physical components

Physical Component Name	**Properties**	**Type (fenced/open)**	**Behaviours**
Pig manure	Volume (m^3) Nitrogen (N) (kg) Phosphate (P) (kg)	Fenced	None
Cattle manure	Volume (m^3) Nitrogen (N) (kg) Phosphate (P) (kg)	Fenced	None
Cattle digestate	Volume (m^3) Nitrogen (N) (kg) Phosphate (P) (kg)	Fenced	None
Pig digestate	Volume (m^3) Nitrogen (N) (kg) Phosphate (P) (kg)	Fenced	None
Artificial fertiliser	Nitrogen (N) (kg) Phosphates (P) (kg)	Fenced	None
Green gas	Volume (m^3)	Fenced	None
Cattle	Units (number)	Fenced	Production of manure
Pigs	Units (number)	Fenced	Production of manure
Land	Type (Grass or Crop) Amount (hectare)	Fenced	None
Money	Amount (€)	Fenced	None
Technology	(Yearly) Costs (€/year)	Fenced	Production of green gas and digestate Costs change annually by the changes in gas and electricity prices

B.3 Collective structure

Table B.3: Agents

Agent name	Animal Farmer Agent	Intermediary Agent	Artificial Fertiliser Supplier Agent
Properties	Size (number of animals), Investment capital, Successor (YES or NO), Location (place within region 'Salland': D, R, OW), Land (type: cropland or grassland, and amount: number of hectares)	-	-
Characteristics	Honest, Risk aversive, Individual	-	-
Personal values	Reduction of manure or digestate distribution costs	-	-
Type	Institutional	External	External
Role	Animal Farmer Agent (no role), Landowner, Producer	-	-
Information	Knowledge about agents within the same location; Knowledge about the number of agents taking the role of Producer within system	Knowledge about the volume of available (cattle and pig) manure within system; The mineral need within the region	-
Physical components	Pig or Cattle, Manure, Digestate, Green gas, Land, Money, Technology	Manure, Digestate	Artificial fertiliser
Intrinsic capabilities	Distribution of manure: manuring of own land, distribute to neighbours and distribute to Intermediary Agent; Buy artificial fertiliser; Make decision on investment; Search for participation for making decision on investment together with other Animal Farmer agents; Operate technology and pay annual technology costs; Decide upon abandoning farm; Decide upon expanding farm	Calculate (pig and cattle) manure acceptance price; Distribute obtained manure	Supply artificial fertiliser
Decision making behaviour	Distribution of manure Decision to invest in green gas production Decision to search for participation for making an investment in green gas production Decision to abandon farm Decision to expand farm	-	-

B.4 Operational structure

Table B.4: Action Situation

Situation	Farming	Manure distribution	Bio-production
Roles	Animal Farmer Agent, Landowner	Animal Farmer Agent, Landowner, Producer, Intermediary Agent	Animal Farmer Agent, Producer
Actions	• Manure own land if own land is available • Make decision on investment in green gas production • Calculate abandon potential and decide upon abandoning • Calculate growth potential and decide upon expanding	• Calculate mineral (nitrogen and phosphate) need for manuring land • Distribute manure (or digestate) to Landowners (in neighbourhood) • Accept manure • Calculate acceptance price of (cattle and pig) manure • Buy artificial fertiliser	• Updating technology costs • Produce manure • Produce green gas and digestate • Obtain revenue from green gas production • Pay (annual) technology costs
Costs and Benefits	Since the distribution of manure comes with costs it is beneficial to use as much manure as possible for meeting their own mineral requirements (in case the farmer agent owns land). For that same reason, cattle manure is preferred, since the mineral content per volume is lower, thereby saving transportation costs. Investing in green gas production could provide in additional benefit. To improve the financial situation - increasing the benefits or reducing the costs - abandoning or expanding a farm could be a reason to decide upon.	Within the manure distribution, the farmer agent tries to optimise the manure distribution costs: first he will try to distribute manure to their neighbours according to the farmer-farmer transport institution. If this is not possible the manure will be distributed to the intermediary. Since the intermediary collects the (cattle and pig) manure, he has knowledge about the availability of manure within a region. In addition, the intermediary has also knowledge about the mineral need within a region. This information is beneficial since he can distribute the manure in an optimal way to Landowners that are still in need of minerals within the system. Substantially this information makes the intermediary capable of calculating the acceptance price of (cattle and pig) manure. It is very beneficial for a Landowner to accept manure as a fertiliser for manuring as he will receive money by doing so. Since the manure policy institution puts restrictions to the usage of minerals from manure, a Landowner might need to buy (additional) artificial fertiliser. For his reason a Landowner will maximise his mineral usage from manure. In addition, since cattle manure has a better mineral composition, Landowners will prefer cattle manure above pig manure. The manure produced by the animals at a farm can be used by the same agent taking the role of Producer to produce green gas and digestate. Since the supply of green gas production might give revenue, producing green gas could be beneficial.	
Physical Components	Cattle, Pig, Land, Money	Cattle manure, Pig manure, Cattle digestate, Pig digestate, Artificial fertiliser, Land, Money	Cattle, Pig, Cattle Manure, Pig Manure, Cattle digestate, Pig digestate, Money, Technology, Green gas
Institutions	Abandon of farm, Growth of farm	Manure policy, Farmer-farmer transport	Subsidy

Appendix C

Data

C.1 Agent distribution

As presented in table B.3, the Animal Farmer Agent is defined. A distribution of the agents is made based on the '*meitellingen 2011 Salland*', which comprises the number and type of animals present at a particular farm in the municipalities *Deventer*, *Raalte* and *Olst-Wijhe* in the region of Salland.

Based on this data two separate Animal Farmer Agents types are selected: a cattle farmer agent and a pig farmer agent. The figures C.1 and C.2 present the distribution of cattle and pig animals.

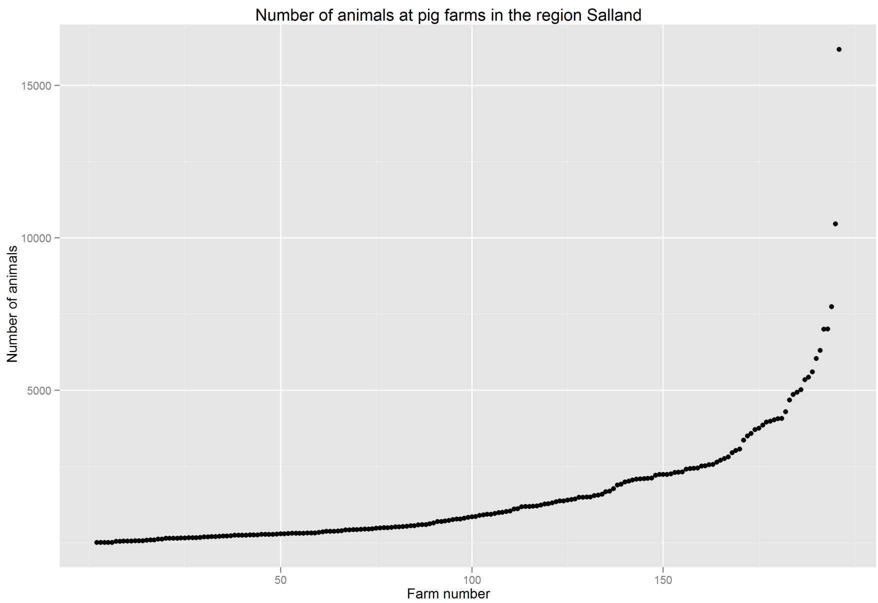

Figure C.1: Number of pigs per farm in Salland

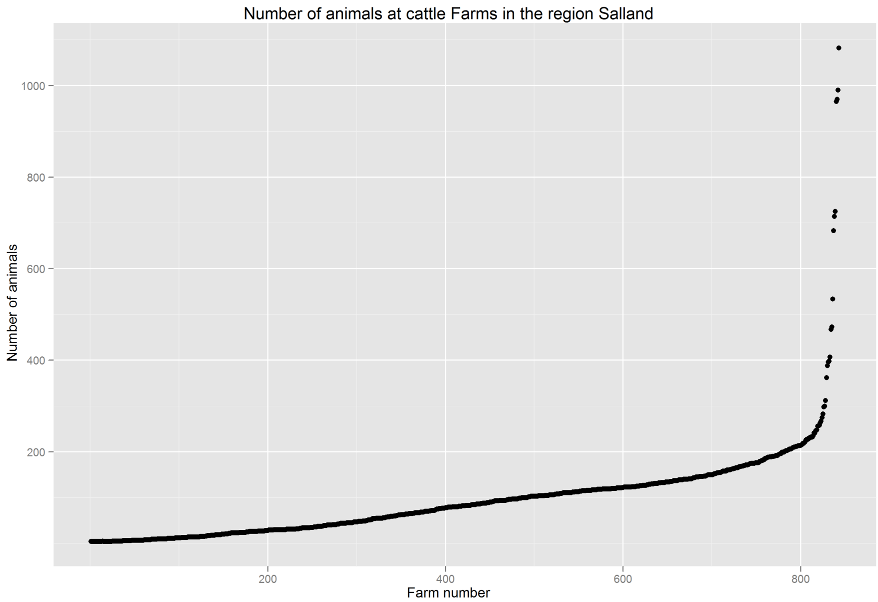

Figure C.2: Number of cattle per farm in Salland

As indicated in B.3, the Animal Farmer Agent possesses several properties. Details about how these properties are assigned to the different Animal Farmer Agent types is presented in table C.1.

Table C.1: Agent distribution

Cattle Farmer Agents **Pig Farmer Agents**	The number of farms: 843 The number of farms: 196
Size	The size indicates the number of animals at a particular farm. No distinction is made between different types of pig or cattle; all Animal Farmer Agents own a number of one particular type of animal, this is either pig or cattle.
Capital	Based on investment figures from literature (de Bont et al., 2010), the capital numbers €10,000 (small), €30,000 (average) and €70,000 (large) are assigned to each farm (mainly distributed according to the size of the farm).
Location	Since each farm is located in a particular municipality, different locations could be assigned to each farm: D for 'Deventer', R for 'Raalte' and OW for 'Olst-Wijhe'.
Successor	From literature it is suggested that bigger farms more often have a successor (van der Meulen et al., 2011) compared to smaller farms. According to the data found in literature, a distribution is applied and an Animal Farmer Agent has a successor or not.
Land	Based on interviews, we assumed that cattle farmers might own land and pig farmers do not. Based on statics about the Salland area from CBS[1] and literature (van der Meulen et al., 2011), a number of hectares grassland and cropland is assigned to cattle farms.

In tables C.2, C.3 and C.4 a summary of the distribution of investment Capital, Successor and

Location among both cattle and pig farms is presented.

Table C.2: Property: Investment capital

	Size	€10,000	€30,000	€70,000
Cattle farms				
	≤ 50	171	96	43
	50-100	51	72	53
	100-150	36	78	97
	≥ 150	4	22	121
Pig farms				
	≤ 500	41	32	5
	500-1500	23	13	16
	1500-3000	16	8	13
	≥ 3000	2	5	21

Table C.3: Property: Location

	Size	Number of farms in location R	Number of farms in location D	Number of farms in location OW
Cattle farms				
	≤ 50	150	220	90
	50-100	84	47	44
	100-150	95	64	51
	≥ 150	71	35	42
Pig farms				
	≤ 500	42	25	11
	500-1500	33	9	10
	1500-3000	22	8	8
	≥ 3000	16	3	9

Table C.4: Property: Successor

	Size	% that have NO Successor	Number of farms with a successor	Number of farms without a successor
Cattle farms				
	$\leq$ 50	0.71	220	90
	50-100	0.35	61	114
	100-150	0.22	46	164
	$\geq$ 150	0.20	30	118
Pig farms				
	$\leq$ 500	0.81	63	15
	500-1500	0.56	29	23
	1500-3000	0.21	8	30
	$\geq$ 3000	0.21	6	22

C.2 Manure

C.2.1 Characteristics

The amount of manure (volume in m^3) produced by an animal on an annual basis as well as the mineral content (nitrogen and ohosphate in kg/m^3) of the manure is based on data from literature (DR-Loket, 2011). The data are presented in table C.5 (it is estimated that the density of manure equals 1000 kg/m^3).

Table C.5: Manure and minerals produced by animals

Animal type	**Manure (m^3/year/animal)**	**Nitrogen(N) (kg/year/animal)**	**Phosphate(P) (kg/year/animal)**
Pig (Flesh)	1.3	8.7	5.0
Pig (Sow)	2.4	12.2	7.4
Cattle (Milk cow)	25	113	40
Cattle (Flesh calf)	6	24	11

C.2.2 Manure production

As shown in table C.5, different type of pigs and cattle differ in their manure and mineral production. Since we decided to capture only two types of animals in the system, the average manure and mineral production per cattle and pig is estimated: the number of a specific type of animal present at a particular farms (using the '*meitellingen 2011 Salland*') times the possible animal production of that specific type (using table C.5, added all together and divided by the total number of animals. The result is presented in table C.6.

Table C.6: Production by cattle and pig

	Cattle	Pig
Manure (m^3/year/animal)	17.0	1.2
N (kg/year/animal)	70	7
P (kg/year/animal)	30	4

C.2.3 Manure distribution costs

Costs are associated with the distribution of manure, table C.7 gives an overview of these costs per volume.

Table C.7: Distribution costs in euro

	Distribution of pig manure to intermediary	Distribution of cattle manure to intermediary	Distribution of cattle manure to neighbour	Usage of manure for own land
Transport	8	8	4	-
Acceptance	4	1	1	-
Storage	3	0	0	-
Analysis	1	1	0	-
Labour costs	-	-	-	3
Total	16	10	5	3

The data shown in table C.7 are based on interviews and a literature review, see also appendix A.

C.3 Artificial fertiliser

The prices for artificial fertiliser amount approximately 30 euro per 100 kg. Furthermore, it is expected that these prices may rise in the future [2].

C.4 Land

C.4.1 Salland area

As explained in table C.1, we obtained statistics about the area of Salland from CBS. In addition, data from (van der Meulen et al., 2011) is used for carrying out the distribution of hectares among the cattle farmers. Table C.8 presents the data obtained from CBS with respect to the area of Salland. And table C.9 assigns the land to cattle farmers according to the size (scale) of the farm.

[2] http://www.boerenbusiness.nl

Table C.8: Salland area

	Total hectare
Cropland	1204
Grassland	23647

Table C.9: Property: Land

Size	Average number of hectares per farm (literature data)	Percentage of grassland (literature data)	Average number of hectares grassland (estimation according to area Salland)	Average number of hectares cropland (estimation according to area Salland)
$\leq$ 50	24	0.85	14	0
50-100	44	0.81	24	1
100-150	67	0.78	34	2
$\geq$ 150	108	0.77	54	3

C.4.2 Soil conditions

From CBS we obtained that the phosphate condition of the *sandy soil* in Salland can be considered as medium-high (Hoogeveen et al., 2010). Subsequently, the limits for phosphate usage are based on figures of (DR-Loket, 2011). The result is presented in table C.10.

Table C.10: Amount of minerals permitted per hectare of land

	Nitrogen(N) (kg/ha)	Phosphate(P) (kg/ha)
Grassland (for grazing)	250	90
Cropland (crop:maize)	140	65

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