Economic and social impact of environmental measures in the Dutch dairy sector

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1/11/2018

ECONOMIC AND SOCIAL IMPACT OF ENVIRONMENTAL MEASURES IN THE DUTCH DAIRY SECTOR

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Wageningen University, Wageningen, 1-11-2018

ABSTRACT

The societal and political pressure on the Dutch dairy sector to invest in sustainability and to change management practices that benefit the environment is steadily increasing. There is however reluctance from farmers when the costs are to be paid by themselves, without additional income in return. Besides that, farmers and policy makers often do not know what the economic and social impact of these sustainability measures is. To overcome these issues, this research investigates the economic and social impact of sustainability measures. Included in the study are all measures that, according to the Dutch Sustainable Dairy Chain, dairy farmers can apply to reduce ammonia and greenhouse gas emissions. Indicators have been defined to measure the environmental, economic and social impact of all these measures. For all measures hypotheses are drawn on the economic and social impact and these are formulated based on literature review. A data-analysis followed to see whether these (economic) effects could also be discovered among specified groups based on the mitigation measures. Measures that are related to productivity, change of nutrition and the optimal usage of resources showed most potential to be profitable for the farmer. Other measures, related to investment in buildings or manure storage and processing still result in a loss for the farmers investing in them. The significance and size of the economic impacts needs to be compared to the social and environmental impact of any measure. Further steps that can be followed based on this research is the proper promotion of profitable measures, while more research or policy changes like subsidies could be developed to improve economic benefits for farmers.

Keywords: sustainable development, dairy industry, economic sustainability, ammonia, greenhouse gases.

ACKNOWLEDGEMENTS

I would like to thank everyone that in his or her way contributed to this master thesis. First of all I would like to thank my supervisors Frederic Ang, assistant professor at the department of Business Economics of Wageningen University and Joan Reijs, senior researcher at Wageningen Economic Research. Without their support and expertise this end result would not be possible. They learned to do academic research in a responsible way like professionals do, and I hope that this master thesis that lies in front of you proves I have mastered these skills thanks to them.

I would like to thank every one within Wageningen Economic Research for offering me the opportunity to conduct a master thesis research within a research department of Wageningen University and Research. Also I would like to thank Co Daatselaar who helped facilitating the data-analysis that is conducted in this research. Last but not least I would like to thank everyone that supported me in a more personal manner to do this work.

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1. INTRODUCTION

1.1 BACKGROUND INFORMATION

Sustainable development is crucial for continuation of our current welfare and has drawn the attention of most institutions and businesses. The damage done to the environment due to human beings is inevitable and comes with continuous growing problems due to changing climatic circumstances, ecological issues and food insecurity. To overcome these challenges, sustainable development is required. Brundtland et al. (1987) defined sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*

Livestock farming is known to have a large effect on both environmental and social aspects of sustainability, and dairy farming is one of the main contributors to this effect. The Netherlands has one of the world's most efficient and intensive systems and is therefore one of the global industry leaders. This is because limited land availability pressurizes Dutch farmers to get most out of the resources they have at their disposal. Production efficiency in the Netherlands is higher compared to its peers in Western-Europe (Zhu et al., 2012). Some of the most notable companies in the worldwide dairy industry have their roots in the Netherlands (Meerburg et al., 2009). With this perspective in mind, the Dutch dairy industry is a vital link for transforming the industry into a more sustainable one. This will also be necessary to retain the leading position in the global industry.

The abolishment of the quota imposed by the European Union in 2015 has led to significant production increases across Europe. This quota was a market instrument that gave every dairy farmer the right to produce a limited amount of milk, based on previous production volumes.

Many farmers invested in new housing systems to increase their production after the abolishment, but this increased emissions and manure production above nationally allowed ceilings. New legislation has been introduced that regulates phosphate production, preventing the Netherlands to rise above the ceiling for phosphate production (Jongeneel et al., 2017). Such shifting legislations are however not the only answer to sustainable development; truly sustainable foods only come from production systems that give more attention to the environment, animal welfare and/or social aspects in an integrated approach.

Sustainable milk production requires good practices on three areas; the production must be economically viable, environmentally sound and socially acceptable (Thomassen et al., 2009). There are plenty opportunities to make dairy farms more sustainable, but it requires some vast investments and these are not always paid back. Farmers have many reasons to not adopt sustainability changes, economic reasons are most commonly heard, together with suitability on individual farms (De Lauwere et al., 2014).

The extent to which sustainability measures are environmentally beneficial differs largely. Some measures have just a minor influence of emission reduction and other measures have over 10% mitigation potential. This should be considered when investing in sustainability, a big investment that leads to a limited environmental effect might be better spent when investing in other mitigation strategies.

Some environmental measures are profitable, so investing in or changing the management according to these measures will have a positive effect on financial results. This is possible with savings of resources or through other profitable effects, such as an increased production. Other measures are not profitable because the costs are greater than the potential for extra incomes to be generated. This leads to reluctance at farmer level, because they are the ones that have to bear these costs (Evers et al., 2015; van den Pol-Dasselaar, 2013).

Besides the economic impact, also the influences of sustainability measures on social indicators needs to be considered. Some installations may need regular maintenance or management changes can require a lot of attention of the entrepreneur to let them work properly. Social change can also be achieved by improving the labour circumstances at one of the many links in the value chain of milk and dairy products. This makes the social component very dynamic and improvements are possible for all stakeholders in the dairy chain (Buys et al., 2013).

Various parties try to motivate dairy farmers to implement sustainability measures. (Inter)-national governments do this by legislation that force entrepreneurs to implement these measures. An example is the low ammonia emission stable, all stables that are newly built need to be low ammonia emission stables (Rijksoverheid, 2017).

The Dutch initiative Sustainable Dairy Chain (SDC) (Dutch: Duurzame Zuivelketen) is an initiative that is started by the Dutch farmers (LTO) and the organized Dutch dairy industry (NZO). This organization tries to motivate farmers and processors to make progress on 10 sustainability themes, identified as important for Dutch farmers and processors. On these 10 themes quantitative targets are defined and the progress on these targets is annually monitored by Wageningen Economic Research (Duurzame Zuivelketen, 2018).

To make progress on the targets, dairy processors have programs in place to encourage farmers to improve on these 10 issues. Sometimes processors also financially motivate farmers to implement sustainability measures or to work more sustainable. Farmers that have a good score, get a premium on their milk price and farmers with a low score are discounted. Examples of these programs are FoqusPlanet (FrieslandCampina) and Caring Dairy (CONO). These are so-called chain initiatives that go further than the legal boundaries (Terwan et al., 2017). Farmers can also choose to participate in certification schemes that further increase sustainability on a farm, such as organic farming.

Next to that there is also stakeholder pressure from society at large, individual citizens and animal activists/NGOs. It is important for the dairy sector to have societal support, otherwise dairy products will not be bought and citizens will not accept development of dairy farmers in their area. Societal dissatisfaction can lead to political reactions, meaning legislation.

Summarized, entrepreneurs in the dairy industry are either forced and/or financially motivated to make their farm more sustainable. It can also be the case that farmers are not are not driven by financial gain or legislation but base their investments on intrinsic motivation. Improving on environmental indicators has economic and social consequences, since investments or management changes are necessary. It is often not clear to farmers what these consequences are. It might be valuable to communicate this to farmers. It can be a tool for farmers to invest in measures that are better suitable to their farm. On the industry level, the right measures can be promoted because of their profitability. Sustainability measures that have a negative economic impact could be financially supported by e.g. governments or the dairy industry as a whole (Reijs, 2018).

Therefore, this research will look in to the social and economic consequences of measures at farm level aiming to improve (environmental) sustainability. To keep the workload manageable, this is only conducted for the measures related to the reduction of ammonia and greenhouse gas emissions. Both are crucial for the future development of the dairy sector as a sustainable sector. It has also been advised by Wageningen Economic Research to focus on these two themes.

Ammonia emissions have a great impact on ecosystems, soils and water quality. The damage to biodiversity is caused by acidification, which is deposited in the form of ammonia (NH_3), ammonium (NH_4^+) and nitrous oxide (N_2O). This leads to a bigger occurrence of plant species that are rich in nitrogen, such as grass. What follows is an unbalanced biodiversity and loss of other species. The deposition of these substances has risen enormously since 1900, due to the increase of industry and agriculture. Agriculture is the largest emitter, and the dairy industry is the largest emitter of ammonia compared to all agricultural industries in the Netherlands (Kros et al., 2008).

Greenhouse gases cause one of the greatest challenge regarding sustainability, global warming. The greenhouse gases that are emitted by the dairy industry are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These substances lead to the phenomenon that is most commonly known as the greenhouse effect. While the exact relationship between greenhouse gases and temperature rises cannot be explained by science directly, it has been proven that the increase of greenhouse gases in the atmosphere is related to temperature increases and heavier rainfalls all over the world in the last few decades. The effects of climate change are harmful for the dairy industry as well, as it can cause loss of harvests and more unstable conditions for dairy cows. Agriculture in total is responsible for 10 - 12% of anthropogenic greenhouse gas emissions that are emitted worldwide (Koneswaran and Nierenberg, 2008; Reisinger and Clark, 2017).

1.2 Problem Statement

The targets of SDC describe sector-wide change, but in order to be successful as industry, individual farmers should be working on these targets as well. Governments are obliging agricultural entrepreneurs to comply with certain legislations and this pressure is increasing rapidly, e.g. with phosphate regulations and extra administrative work (de Wit & van Veluw, 2017). Milk processors have further reaching programs in which farmers are motivated to work more sustainable. However, according to Wageningen Economic Research, the economic and/or social consequences of a certain measure to increase (environmental) sustainability are not sufficiently communicated. Therefore, the problem statement of this research is:

'The economic and/or social consequences of environmental mitigation measures at farm level are often unclear, which can restrain sustainable development due to ineffective incentives and communication at sector level.'

This may lead to uncertainty on the usefulness of the measures at farmer level. Some may feel that they are forced by external parties to implement sustainability systems while these are not necessarily beneficial for individual farmers. However, investments may give a positive return after a given period, like energy saving or energy generation (Noorduyn et al, 2009). Also it is proven that, in general, more sustainable dairy farms are more profitable (Reijs, 2016).

Therefore, it is beneficial to get a better insight in the economic and social consequence of these (environmental) mitigation measures, for two reasons:

- Policy instrument for governments and, especially, milk processors, which can be used to steer sustainability programs.
- Clear communication to farmers about what to expect in financial and social terms.

Often, only the environmental advantages are communicated to farmers. Therefore communication about economic and social impact may lead to more understanding and less uncertainty among farmers. Eventually this may lead to more sustainable development and contribute to the goals set by SDC. Also, when average returns or losses of a certain measure are known, external parties could use this in their rewarding policies. Nowadays, sustainable development may be rewarded but returns or losses are often neglected, profitable measures might be rewarded while loss-making investments that are still sustainable are not rewarded (van den Burg et al., 2016).

This research gap is identified by Wageningen Economic Research, as they think that it would be valuable to know and inform farmers about the economic and social impact of the environmental sustainability measures opted by SDC. Some studies are conducted that look into these economic impacts, such as van den Pol-Dasselaar et al. (2013), and Evers et al. (2015). Nevertheless, this has never been done for the measures within the SDC and it has never been directly communicated to farmers.

1.3 RESEARCH OBJECTIVES

In connection with the problem statement, the aim of this thesis is to quantify the economic impact and define the social impact of measures at farm level to mitigate ammonia and greenhouse gas emissions. The environmental impact is also taken into account. These research objectives mentioned below are developed to tackle the problems that were pointed in the problem statement and to fill the present knowledge gap. The following procedure and forthcoming objectives are followed. These specific objectives include:

I. Determining indicators to measure economic, social and environmental impact of the mitigation measures.
II. Literature review to draw hypotheses on the economic, social and environmental impact of sustainability measures.
III. Data-analysis on the hypotheses with the use of empirical data, to see whether statements made in the literature are tested in practice, when farms that have implemented sustainability measures are compared to farms that have not.

1.4 THEORETICAL FRAMEWORK

DEFINITIONS

This theoretical framework presents definitions for sustainability as a whole, and for the terms of environmental, economic and social sustainability. The Brundtland commission has defined sustainable development as:

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987).

This Brundtland Report by the UN was concerned with the tension between the aspirations of mankind to improve its life at one side and the limitations imposed by nature on the other side. In the period after the Brundtland report, sustainability has mostly been translated as encompassing on three dimensions, namely social, economic and environmental (Kuhlman & Farrington, 2010).

The terms of environmental, social, and economic sustainability together make up the total definition of sustainability, according to Kuhlman & Farrington (2010). The three are strongly interconnected with each other and overlap exists. The following three papers define the three concepts as follows:

- Goodland (1995) defines environmental sustainability as a concept that seeks to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks of human wastes are not exceeded, in order to prevent harm to humans.
- Meadows et al., (1972) posit that economies will not be sustainable if natural resources are used beyond the limits and if society continues to depend on phenomena that drove growth in the past. Redefined, this means that economic sustainability means that economic systems are sustainable when they can be continued without using natural resources beyond their limits.
- McKenzie (2004) argues that social sustainability occurs when the formal and informal processes, systems, structures and relationships actively support the capacity of current and future generations to create health and liveable communities. Socially sustainable communities are equitable, diverse, connected and democratic and provide a good quality of life.

Whether sustainability measures have a positive, negative or dependent influence on environmental, economic and social sustainability will be tested in accordance with these definitions.

Following on these definitions the current developments regarding ammonia and greenhouse gas mitigation are presented.

AMMONIA EMISSIONS

Nitrogen (N) is one of the most important minerals in dairy farming. Animal-based products contain nitrogen and soils are made fertile with manure and fertilizers that contain nitrogen. Nitrogen can be emitted in the form of ammonia (NH_3), which is formed by a chemical reaction between nitrogen and hydrogen (Nemecek & Ledgard, 2016).

After ammonia is emitted, it is deposited on the ground again. At this point, the process of nitrification starts, in which ammonia is converted into nitrate by bacteria. This nitrate causes acidification with adverse biodiversity effects. When the biodiversity of plants changes, other organisms are influenced and this creates unbalanced ecosystems (Stolk et al., 2017). Besides this, ammonia emissions are also causing eutrophication of surface waters and fine particulate matter formation. It can also induce nitrogen oxide emissions, which are linked to global warming (Hristov et al., 2011).

There is European legislation in the form of the National Emission Ceilings (NEC) directive. This gives a 'ceiling' that defines the maximum emissions in a country, this is 128 million kg for the Netherlands. Dutch atmospheric concentrations of ammonia and ammonium emissions are among the highest in Europe, due to the high density of agricultural activities in the country. Dairy farming is responsible for approximately 40% of all ammonia emissions in the Netherlands (van Zanten et al., 2017).

The total ammonia emissions in Dutch agriculture has been reduced by two thirds since 1990. In 2014, the emission has shown an increasing trend for the first time. Emission rose from 123 to 127 million kg. It is expected that emissions didn't increase or decrease in 2015 and 2016. The increased ammonia emissions in 2014 were mainly caused by an increase in dairy cows and nitrogen content in feed (Doornewaard et al., 2017).

Besides the continental and national targets, the Dutch dairy sector is facing stricter regional targets near Natura 2000 areas. These are nature areas that are vulnerable to the effects of ammonia emissions. Achieving these goals is pursued by the PAS-program (Doornewaard et al., 2017).

Ammonia is emitted in the housing system and manure storage, and during manure disposal. Emissions from housing systems are related to urine and faeces. Ammonia is formed when these come together. Ammonia emissions after manure disposal occur when N is not taken up by the plants. A small portion is emitted during grazing. Ammonia emissions are mostly calculated with the emission factor and Total Ammonia Nitrogen (Hristov et al., 2011). Figure 1 shows the ammonia emissions per kg of milk and the sources of these emissions. While grazing only takes up a small portion of total ammonia emissions, the emissions from housing and storages is nearly equal to the emissions due to manure disposal

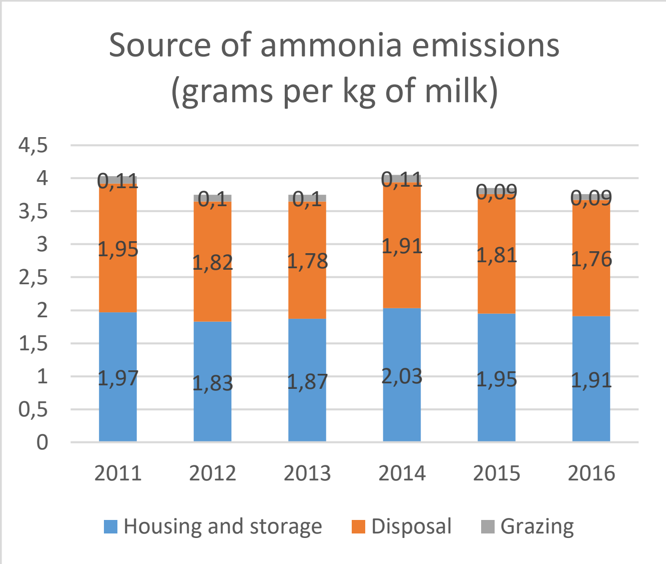

FIGURE 1: SOURCE OF AMMONIA EMISSIONS (DOORNEWAARD ET AL., 2017).

GREENHOUSE GASES

Carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are greenhouse gases (GHG) that have the function of regulating temperature on earth. GHG absorb and reflect sunlight. Because humanity emits an increasing amount of GHG, heat cannot be lost anymore. This creates a so called 'greenhouse' effect and will lead to disastrous changes in weather, which will make it harder to cultivate food, to protect cities against sea level rise and to maintain our current living standards (Wallington et al., 2009).

Agriculture (crop and livestock production) is worldwide recognized as one of main contributors of global warming. Tubiello et al. (2015) estimated that agriculture contributes 11.2% to the total GHG emissions worldwide. Animal-based products are the main cause of this contribution, as these products are very inefficient regarding the input which is needed for their production (Hedenus et al., 2014).

In 2015, all notable countries worldwide signed the Paris agreement in which was determined that the increase in temperature should not go above 2 ^{0}C compared to the pre-industrial era temperature, and preferably not above 1.5 ^{0}C. Actions that will slow down the process of global warming should be 'nationally determined' (Robbins, 2016).

Therefore, the Dutch government and society are putting pressure on dairy farmers to decrease GHG emissions.

CH_4 is the most important greenhouse gas in the dairy industry. It is responsible for around 80% of all GHG emissions at the dairy farm and 52% of all GHG emissions that is emitted to produce milk until the farm gate. Methane is formed by anaerobic processes in the rumen of the cow (75%) and in manure storage (25%). The gas is much more damaging than CO_2, it has a conversion rate of 28 CO_2 equivalents (Doornewaard et al., 2017).

CO_2 is mostly emitted with the production of inputs for the dairy farm (mainly feeds and fertilizers), but energy (electricity, natural gas and fuel) is also used by dairy farmers. Besides that, stored carbon is released when fields are ploughed. Concentrate production is the greatest source of CO_2 emissions. Carbon dioxide is responsible for approximately 37% of all emissions until the farm gate (Doornewaard et al., 2017).

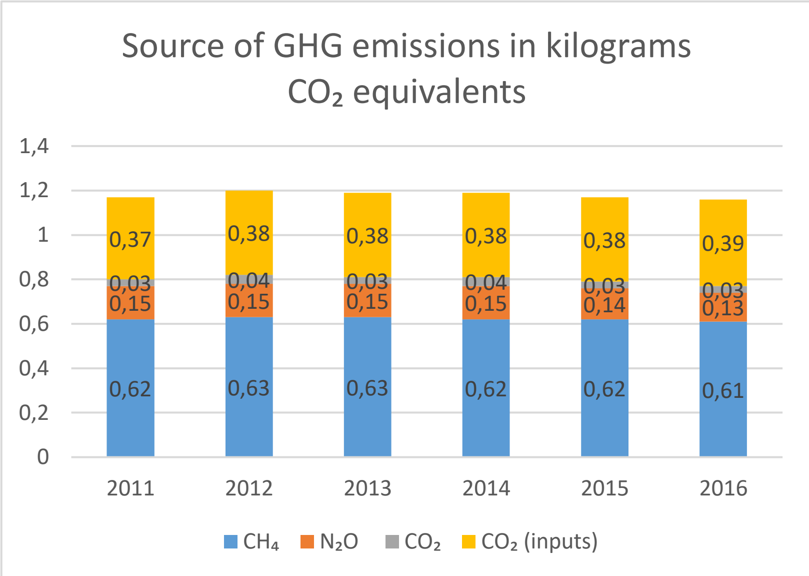

FIGURE 2: SOURCE OF GHG EMISSIONS IN CO2 EMISSIONS (DOORNEWAARD ET AL., 2017)

N_2O has the lowest share of GHG emissions. It is emitted when nitrification and denitrification processes have formed nitrous oxide out of nitrogen. A balanced N content in the soil mitigates N_2O emissions. N_2O has a greater global warming potential 298 times greater than the one of CO_2 (Doornewaard et al., 2017).

The total average emissions at the farm were 0.77 CO_2 equivalents per kg milk in 2016. In total, taking the production of resources into account, this number was 1.15 CO_2 equivalents for 2016. For this research, this total of 1.15 is taken as total because the farmer can also influence the footprint of the production of inputs, either by changing the type of inputs or by reducing the amount of inputs needed.

2. METHODOLOGY

Based on the problem statement and research objectives as presented in the introduction, the following main question has been formulated:

What are the economic and social effects of measures that mitigate the emissions of ammonia and greenhouse gases?

To answer this main question, the following sub questions are formulated:

1 What indicators can be used to measure environmental, economic and social sustainability effects of mitigation measures?
2 What is the current knowledge about the economic and social effect of (environmental) mitigation measures and what is, according to literature, the total effect of these measures?
3 What environmental, economic and social impacts of the mitigation measures can be found on Dutch dairy farms based on data-analysis?

This chapter presents the materials and methods that are used to answer the main question and the sub questions. Besides that, the indicators are determined in this chapter as well.

2.1 GENERAL

The SDC identified 24 measures that reduce ammonia emissions and 35 measures that mitigate the emission of greenhouse gases. These measures can all be implemented at farm-level. These are categorized in different clusters of related issues as presented below. The groups and measures will be presented in this order throughout the whole report.

<u>Ammonia</u>

1) Productivity
2) Low protein feed
3) Grazing
4) Low-emission housing systems
5) Existing stables
6) Manure application grassland
7) Manure application arable land

<u>Greenhouse gases</u>

1) Productivity
2) Feed
3) Manure storage
4) Crop and fertilization
5) Energy
6) Land

Table 1 on the next page presents an overview in which all the measures that will be investigated are included. This table includes numbering of the measures, this numbering is not included in the literature review. This would cause inaccuracy with the chapter and paragraph numbering of this report. In all the other parts throughout this report this numbering is taken into account.

TABLE 1: OVERVIEW OF ALL MITIGATION MEASURES INVESTIGATED

Ammonia measures	Greenhouse gas measures
1.1 Productivity	***2.1 Productivity***
1.1.1. Reduce young cattle	2.1.1. Reduce young cattle
1.1.2. Increase longevity of dairy cows	2.1.2. Increase longevity of dairy cows
1.1.3. Increase milk production per cow	2.1.3. Increase milk production per cow
1.2 Low protein feed	***2.2 Feed***
1.2.1. Feed more maize and less grass	2.2.1. Improve feed conversion efficiency
1.2.2. Less crude protein in grass silage	2.2.2. Feed more maize and less grass
1.2.3. Less crude protein in pasture grass	2.2.3. Feed more fresh grass and less grass silage
1.2.4. Less crude protein in concentrates	2.2.4. Improve digestibility of grass
1.3 Grazing	2.2.5. Feed additives
1.3.1. Grazing by dairy cows	2.2.6. Concentrates with lower footprint
1.3.2. Grazing by young cattle	2.2.7. Use of wet by-products
1.4 Low emission housing systems	***2.3 Manure storage***
1.4.1. Category 1 – RAV housing systems with < 10 kg NH_3 per animal place	2.3.1. Methane oxidation
1.4.2. Category 2 – RAV housing systems with > 10 kg NH_3 per animal place	2.3.2. Manure acidification
1.4.3. Category 3 – Mechanical ventilated system with chemical air washing system	2.3.3. Manure fermentation
1.4.4. Category 4 – Natural ventilated systems with chemical air washing system	2.3.4. Manure separation
1.5 Existing stables	2.3.5. Decrease manure temperature
1.5.1. Roof insulation	***2.4 Crop and fertilization***
1.5.2. ANCV	2.4.1. Use of grass-clover
1.5.3. Manure dilution in manure cellar	2.4.2. Nitrification inhibitors
1.5.4. Manure dilution on walking floors	2.4.3. Precision application of fertilizer
1.5.5. Manure sliding	2.4.4. Lower fertilizer gift of N
1.5.6. Manure acidification	2.4.5. Footprint chemical fertilizer
1.6 Manure application grassland	2.4.6. Cultivation of concentrate substitutes
1.6.1. Manure dilution before application	***2.5 Energy***
1.6.2. Accurate manure application	2.5.1. Solar panels
1.6.3. Manure application under favourable weather conditions	2.5.2. Windmills
1.7 Manure application arable land	2.5.3. Heat recovery
1.7.1. Incorporation in two rounds	2.5.4. Pre-cooler
1.7.2. Manure injection	2.5.5. LED-lightning
	2.5.6. Optimal usage of electricity
	2.5.7. Reduce diesel consumption
	2.5.8. Biodiesel
	2.6 Land
	2.6.1. Not ploughing permanent grassland
	2.6.2. Reduce grassland renewal
	2.6.3. Catch crops and green manures
	2.6.4. Drainage in peat areas
	2.6.5. Non-inversion tillage
	2.6.6. More grass in crop rotation plan

2.2 INDICATORS

Indicators are vital for this research as these define how to measure the impacts. All measures are assessed on their environmental, economic and social effect, based on literature review. The effects have also been tested by the use of data-analysis. To make sure that all measures are assessed in the same way, indicators are defined, which are based on the definitions in the theoretical framework.

INDICATORS TO ASSESS ENVIRONMENTAL SUSTAINABILITY

The most common way to measure and express the amount of ammonia emitted is the amount of NH_3 emitted per livestock unit (LU) (Amon et al., 2001; Demmers et al., 2001; Monteny & Erisman 1998). Other ways to measure ammonia is to express ammonia emissions in square meters (Gay et al., 2003), or heat producing units (HPU) (Zhang et al., 2005). Because it is the most familiar to farmers and the industry, <u>the reduction of NH_3 emissions per livestock units</u> will be used. Dairy cows (1.00), young cattle older than 1 year (0.53) and young cattle younger than 1 year (0.23) all have their own unit.

It will however be different for the first set of measures, which is productivity (1.1). These measures will be assessed on their environmental mitigation potential with the <u>reduction of NH_3 emissions per kilogram of milk</u>. This is done because the aim of mitigation strategies related to efficiency improvements is to use less resources per unit of product. It would bypass the aim of the measures to calculate emissions per livestock unit.

Only the ammonia emissions that can be directly allocated to the farm are taken into account. This means that emissions from housing systems and storages, grazing and manure disposal are taken into account. Emissions released during the production of feed or the disposal of manure that is sold is not taken into account. This is line with the calculation method of Wageningen Economic Research (Doornewaard et al., 2017).

For greenhouse gases, emissions in CO_2 equivalents per kilogram of milk are typically used in research to measure the emissions of different greenhouse gases (Phetteplace et al., 2001; Doornewaard et al., 2017). CO_2 equivalents are calculated through emission numbers per greenhouse gas, which describes how much global warming a given type of greenhouse gas can cause, using the equivalent of carbon dioxide as a reference. This number is 1 for CO_2 obviously, 28 for methane (CH_4) and 298 for nitrous oxide (N_2O).

There are no other methods that are regularly used in the dairy industry, so the mitigation potential of greenhouse gases is expressed in <u>the reduction of CO_2 equivalents per kilogram of milk</u>.

Compared to the sort of ammonia emissions taken into account in this research, the production of resources for the dairy industry are included in the total number of greenhouse gas emissions at farm-level. This is line with the approach of Wageningen Economic Research (Doornewaard et al., 2017).

INDICATORS TO ASSESS ECONOMIC SUSTAINABILITY

There are many ways to assess the economic sustainability of dairy farms, but the economic performance in this research is assessed with the scheme used in the research conducted by Evers et al. (2015). The indicators in Evers et al. (2015) and this research are in table 2, which visualizes the difference between the two. All the units are euros per enterprise (€).

TABLE 2: ECONOMIC INDICATORS IN EVERS ET AL. (2015) AND THIS RESEARCH

Evers et al. (2015)	**This research**
Change in revenues	Change in revenues
Milk	Milk
Sales of animals	Sales of animals
Remaining	Remaining
Change in allocated costs	Change in allocated costs
Feed	(Purchased) roughage
Animals	Concentrates
Crop	Animals
	Crop
Change in non-allocated costs	Change in non-allocated costs
Contractor	Contractor
Machines and installations	Machines and installations
Ground and buildings	Ground and buildings
Quota	Water and energy
Water and energy	Manure disposal
Remaining (incl. manure disposal)	Remaining
Change in income	Change in income

There are three differences between the two schemes. These are the following:

- Feed, which is one parameter in Evers et al. (2015), is divided in to (purchased) roughage costs and concentrate costs. This is done because some measures have a positive influence on one of these parameters and a negative on the other.
- Quota costs are taken out since the milk quota has been abolished in 2015.
- Manure disposal is defined as a separate post, because there are various measures that have economic impacts that relate to manure disposal. This makes it is more valuable to take manure disposal as a separate post, rather than describe it under 'remaining'.

INDICATORS TO ASSESS SOCIAL SUSTAINABILITY

The indicators for social sustainability have been discussed with the supervisors Joan Reijs and Frederic Ang. Since it is not possible to assess all the indicators in the definition of social sustainability, only three indicators that directly relate to the farmers' wellbeing are picked. These are:

- Labour (Unit: Hours of work required)
- Administrative burden (Unit: Score 1 – 5)
- Safety (Unit: Score 1 – 5)

2.3 CURRENT KNOWLEDGE

In Chapter 3, the literature review, current knowledge is used to determine the environmental, economic and social impact of each measure. The overall conclusions are organised in the same way as the indicators. This chapter presents the methodology that has been used in the literature review chapter.

The environmental impact of the sustainability measures is assessed based on the literature dedicated to environmental mitigation effects. Table 3 shows classification of the ammonia mitigation measures, table 4 shows this for GHG mitigation classifications.

Measures that mitigate ammonia emissions have often a higher relative environmental effect (in percentages) compared to measures that reduce GHG emissions, therefore the boundaries of classification classes are different.

TABLE 3: ENVIRONMENTAL ASSESSMENT CATEGORIES AMMONIA

Category	Colour	Explanation
Low		Reduction of NH_3 emissions per LU < 5%
Average		Reduction of NH_3 emissions per LU 5 – 10%
High		Reduction of NH_3 emissions per LU > 10%
Dependent		Reduction of NH_3 emissions per LU dependent on farm characteristics
Unknown		Reduction of NH_3 emissions per LU is not discussed or is not clear in literature

TABLE 4: ENVIRONMENTAL ASSESSMENT CATEGORIES GHG

Category	Colour	Explanation
Low		Reduction of CO_2 equivalents per kilogram of milk < 1%
Average		Reduction of CO_2 equivalents per kilogram of milk 1 – 5%
High		Reduction of CO_2 equivalents per kilogram of milk > 5%
Dependent		Reduction of CO_2 equivalents per kilogram of milk dependent on farm characteristics
Unknown		Reduction of CO_2 equivalents per kilogram of milk is not discussed or is not clear in literature

Tables 5 & 6 show the classes that are distinguished to score the economic and social impact. These are the same for either measures aiming to mitigate ammonia and measures that seek to mitigate GHG emissions.

Since the social effect is not quantifiable it is more of an 'assessment' compared to the economic and environmental impact. When the social effect is doubtable, it got the assessment 'unknown'.

TABLE 5: ECONOMIC ASSESSMENT CATEGORIES

Category	Colour	Explanation
Negative		Overall economic result is expected to go down after implementation
Break-even		No effect or a slight negative or positive overall economic result is expected to be found after implementation
Positive		Overall economic result is expected to go up after implementation
Dependent		Overall economic result is dependent on farm characteristics
Unknown		Overall economic result not is discussed or is not clear in literature

TABLE 6: SOCIAL ASSESSMENT CATEGORIES

Category	Colour	Explanation
Negative		Implementation has a negative effect on the social indicators
Positive		Implementation has a positive effect on the social indicators
Dependent		Overall economic result dependent on farm characteristics
Unknown		Overall social effect not is discussed or is not clear in literature

Environmental	Average
Economic	Positive
Social	Unknown

In this report, all measures are shortly explained and the conclusions per impact are presented both in-text and in a column next to the heading. This quickly summarizes the hypotheses on environmental, economic and social impact when the mitigation measure is implemented.

There is a separate Excel file that includes an overview of all the effects on all the indicators for all the mitigation measures. This can be found in appendix I and II, as well as in this separate Excel file.

Since there is one single environmental indicator, the outcome of this indicator will automatically be the complete assessment for the environmental impact. The impact on the economic result is presented with plusses (+) and minuses (-), if '+' is indicated, the revenues or costs go up when a measure is implemented. If '-' is indicated, the revenues or costs go down when a measure is implemented. If '+/-' is indicated it can either go up or go down, dependent on other influences. If the impact is presented between brackets '()', not all farms are economically influenced on that indicator after implementation. After this, the total conclusion is indicated that shows what the overall economic impact of the related measure will be.

The same system is used for the social indicators. The overall outcome for the social indicators can be subjective because these cannot be quantified.

2.4 DATA-ANALYSIS

A data-analysis was preformed o test the hypotheses drawn from the literature study. This made it possible to see whether there is a significant difference on the indicators between specified groups based on the sustainability measures. This has been done with the help of the BIN-database of Wageningen Economic Research. This database contains 2204 samples over the time period of 2011-2016. In many cases, one farmer has contributed six samples to the database, one for each year. This may not be the case if a farmer has started or quit the company in this time span, or started or stopped contributing. All this information can be found in the first section of the results chapter: section 4.1.

It was not possible to test the hypotheses for every measure in the data-analysis. A bit more than half of the measures could not be tested. This was caused by unavailability of data, because the measure were not quantifiable when the measure was implemented in less than 10 samples. In these cases, the measures were omitted for data-analysis, because of privacy sensitivity. Table 6 shows which measures are tested with the use of data-analysis and which ones are not.

TABLE 7: MEASURES IN DATA-ANALYSIS

Ammonia measures	Suitable	Greenhouse gas measures	Suitable
1.1 Productivity		***2.1 Productivity***	
1.1.1. Reduce of young cattle	X	2.1.1. Reduce of young cattle	X
1.1.2. Increase longevity of dairy cows	X	2.1.2. Increase longevity of dairy cows	X
1.1.3. Increase milk production per cow	X	2.1.3. Increase milk production per cow	X
1.2 Low protein feed		***2.2 Feed***	
1.2.1. Feed more maize and less grass	X	2.2.1. Improve feed conversion efficiency	X
1.2.2. Less crude protein in grass silage	X	2.2.2. Feed more maize and less grass	X
1.2.3. Less crude protein in pasture grass	X	2.2.3. Feed more fresh grass and less grass silage	X
1.2.4. Less crude protein in concentrates	X	2.2.4. Improve digestibility of grass	
1.3 Grazing		2.2.5. Feed additives	
1.3.1. Grazing by dairy cows	X	2.2.6. Concentrates with lower footprint	
1.3.2. Grazing by young cattle	X	2.2.7. Use of wet by-products	X
1.4 Low emission housing systems		***3 Manure storage***	
1.4.1. Category 1 – RAV housing systems with < 10 kg NH_3 per animal place	X	2.3.1. Methane oxidation	
1.4.2. Category 2 – RAV housing systems with > 10 kg NH_3 per animal place	X	2.3.2. Manure acidification	
1.4.3. Category 3 – Mechanical ventilated system with chemical air washing system		2.3.3. Manure fermentation	
1.4.4. Category 4 – Natural ventilated systems with chemical air washing system		2.3.4. Manure separation	
1.5 Existing stables		2.3.5. Decrease manure temperature	
1.5.1. Roof insulation		***4 Crop and fertilization***	
1.5.2. ANCV		2.4.1. Use of grass-clover	X
1.5.3. Manure dilution in manure cellar		2.4.2. Nitrification inhibitors	
1.5.4. Manure dilution on walking floors		2.4.3. Precision application of fertilizer	
1.5.5. Manure sliding		2.4.4. Lower fertilizer gift of N	X
1.5.6. Manure acidification		2.4.5. Footprint chemical fertilizer	
1.6 Manure application grassland		2.4.6. Cultivation of concentrate substitutes	X
1.6.1. Manure application before application		***5 Energy***	
1.6.2. Accurate manure disposal		2.5.1. Solar panels	X
1.6.3. Manure application under favourable weather conditions		2.5.2. Windmills	
1.7 Manure application arable land		2.5.3. Heat recovery	
1.7.1. Incorporation in two rounds		2.5.4. Pre-cooler	
1.7.2. Manure injection	X	2.5.5. LED-lightning	
		2.5.6. Optimal usage of electricity	X
		2.5.7. Reduce diesel consumption	X
		2.5.8. Biodiesel	
		6 Land	
		2.6.1. Not ploughing permanent grassland	
		2.6.2. Reduce grassland renewal	X
		2.6.3. Catch crops and green manures	
		2.6.4. Drainage in peat areas	
		2.6.5. Non-inversion tillage	
		2.6.6. More grass in crop rotation plan	

The economic impact of these measures is analysed by multiple linear regression. Linear regression is an approach to model the relationship between a response variable, or dependent variable, and one or more explanatory variables, or independent variables. Since all multiple linear regression models used have more than one explanatory variable, the process used is called multiple linear regression.

The goal of the model in this research is to explain variation in the dependent variable by the independent variables. To put this into practice, the aim of the model is to see whether sustainability measures (independent variables) have an effect on profitability (dependent variable). Furthermore, with the use of these variables it is possible to predict the profitability of dairy farms with particular characteristics. This can be done with the following formula:

$$y = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_k x_{ki} + \varepsilon_i$$

In this formula, y is the predicted outcome of the dependent variable, in the case of this research, profitability. $\beta 0$ stands for beta coefficient of the constant and βj for the beta coefficient attributed to the corresponding independent variable. The x's represent the independent variables that are put in the model. To put this more into practice, when x changes by 1 unit, the corresponding beta coefficient is added or deducted from the expected outcome of the dependent variable (y). εi represents the error term in each sample, which can be explained as the variation in the dependent variable which cannot be explained by the independent variables.

It should however be mentioned that this research cannot make causal claims based on the data-analysis. There are too many variables that cannot be kept constant. These variables also influence the result. It is rather about comparing the profitability of the group that did implement a sustainability measure with the group that did not implement the sustainability measure. Or, about comparing the group that performs better on a sustainability indicator with the group that performs worse.

The environmental and social impact has been analysed with the use of Pearson's correlation. This shows whether two variables are correlated to each other. This does not show a causal relationship. It does show the degree to which variables are connected with each other; positively or negatively.

In the following paragraphs the two separate multiple regression models that are used in this research will be explained. Also the Pearson's correlation matrices are shortly discussed.

MULTIPLE MEASURES MODEL (MODEL 1)

This research includes two multiple measures models, one in which the ammonia mitigation measures are analysed and one in which the greenhouse gas mitigation measures are analysed.

Before data analysis by a multiple linear regression model, all the measures are compared using the Pearson's Correlation Test. If the correlation between two measures rises above 0.5, only one measure is taken in to the model, and the conclusion for the one measure put in the model was taken over for the measure that was not put in the model. This to prevent that a set of measures becomes too influential in the model.

Only the measures suitable for data-analysis can be found in this analysis. The dependent variable in both these models is total margin (in euro). This 'total margin' variable takes all direct costs that are related to the dairy farm into account. There are five categories of independent variables, which can be found in the columns of the tables.

- Variables explaining the size of the farm: amount of hectares (utilized agricultural area), amount of dairy cows and annual work units (FTE).
- Variables explaining situation of entrepreneur: age main decision maker, education level and successor.
- Dummy variables corresponding to soil type of farm: sand (dummy variable taken out of analysis), clay, peat and loess.
- Dummy variables corresponding to year of sample taken: 2011 (dummy variable taken out of analysis), 2012, 2013, 2014, 2015 and 2016.
- Variables corresponding to the sustainability measures.

It has been decided to add the first to fourth categories of variables because these can have an effect on the profitability of any farm, and therefore can influence the analysis of the measures. The size of the farm has obviously an effect on the margin of the company. Wageningen Economic Research has suggested that the situation of the entrepreneur can also have an effect of the profitability, therefore some available variables are added as well to reflect these effects.

The soil type is decisive for the efficiency of the soil to uptake minerals and the ability to produce crops, and can therefore have a significant effect on the incomes and costs on a farm (Rotz et al., 1999). Annual income typically varies because of changing milk prices and changing costs for resources such as feed and fertilizer (van Leeuwen et al., 2014).

For every variable, four statistics are displayed in the tables presented in this research, these can be found in the rows. These are the following:

- Beta-coefficient: change in mean response when increasing the j-th regressor by 1 unit, keeping all other regressors constant.
- Standard error: the value of the standard deviation of the prediction.
- T-statistic: determines the difference between two samples.
- Significance: the result is significant when it is unlikely that the effect is due to coincidence.

The ANOVA-table and a table with essential information can also be found in the results chapter.

SINGLE MEASURE MODELS (MODEL 2)

Any measure suitable for data analysis is also put in to a single measure model. These models indicate whether there is a difference in profitability between groups based on an individual measure. The main text of this report only shows the significance levels of the measures in these models, the whole models are enclosed in appendix III. Because this model takes into account less variables, it is of lesser importance than the multiple measures models.

The independent variable for these models that predicts the profitability difference between specified groups is the margin per annual work units. The margin comprises the incomes from milk output and the turnover and growth of cattle. The total costs that are directly linked to the dairy farm and milk production are deducted from these incomes. This total margin is divided by annual working units, a unit that defines the availability of labour on the farm. This is used to take the size of the farm into account. In other economic researches, this unit is also known as full-time equivalent (FTE).

The dummy variables related to year and soil type are added to these models, to prevent that the effect of these variables is taken in to the analysis of the sustainability measures. Essential information and ANOVA statistics has been added as well to every model, which can be found in appendix III.

However, as earlier mentioned, the focus and final conclusions of the data-analysis are based on the multiple measure model, since this takes more variables into account.

ENVIRONMENTAL AND SOCIAL IMPACT MODELS

To check the environmental and social impact the variables used for the mitigation measures have been correlated in a Pearson's Correlation Matrix with the environmental impact and the social impact. The same samples that were available for the economic models were used in these correlation matrices, in some cases the number of samples reduced a little, in others the sample size remains the same compared to the economic model. The Pearson's correlation and significance are displayed in the table. These two mean:

- Pearson's correlation: describes the linear relationship between two variables. The value can vary between -1 and +1. The closer the number is to -1 and +1, the greater the correlation between the two variables is.
- Significance: the result is significant when it is unlikely that the effect is due to coincidence.

The correlation matrix is not able to show causal relationship, but not all significant correlations do automatically represent causal relationship. Therefore, the conclusions from these social and environmental matrices are similar to the conclusions from the economic models, namely e.g. Farms that have implemented measure X have less labour required than farms that did not implement measure X.

For the social indicator, only labour is taken into account since this is the most important indicator for the social part. This also makes more sense because it is the only quantifiable social indicator, since administrative burden and safety are not quantifiable. This should be considered when studying the social indicator results of literature review and the social indicator results in the data-analysis.

3. LITERATURE REVIEW

3.1 AMMONIA EMISSIONS

This chapter presents all the conclusions and motivation for these conclusions, for all the measures related to the mitigation of ammonia emissions. This follows the order of the list presented in paragraph 2.1, table 1.

3.1.1 PRODUCTIVITY

Productivity is an essential indicator of farm performance, both environmentally and financially. It defines what inputs are used to produce a certain unit of production. An optimal production lowers the costs and emissions per unit of product, making a product more sustainable and economically attractive. The recent introduction of ammonia and phosphate laws make it more valuable to increase efficiency at farm level, which can relate to increasing milk production per cow or livestock unit present (Booij, 2015).

REDUCE YOUNG CATTLE

Environmental	Average
Economic	Positive
Social	Positive

Keeping more heifers than required is economically and environmentally inefficient because they consume financial and environmental resources without return in the form of milk production (Mandersloot, 1993). However, they safeguard the milk production for the future. An optimal balance in this needs to be found. Ammonia emissions decrease by 3% on farm level (per unit of production) when one less heifer is held per 10 milking cows. A reduction of 2 heifers per 10 dairy cows is achievable on most farms (Evers et al., 2015).

Van der Straeten (2015) concludes that a lower amount of heifers per 10 milking cows is economically beneficial. The indicators and expected results used are based on research conducted by Evers et al. (2015). Calculated with a standard of 5 minutes daily labour per calf or heifer, significant labour savings can be reached (Vuylsteke, 2017). Besides this, less animals have to be registered.

INCREASE LONGEVITY OF DAIRY COWS

Environmental	Average
Economic	Positive
Social	Positive

In case dairy cows live longer, the replacement rate decreases and it becomes less necessary to keep a large amount of heifers (Booij, 2015). Since this measure is related to keeping a low amount of young cattle, the expected environmental mitigation potential is similar. When a famer manages to lower the replacement rate by 3%, NH_3 emissions go down with 1% (Evers et al., 2015).

Because less young cattle is needed, farms with low replacement rates typically require less labour per unit of production, which also includes the administrative burden of e.g. registering animals (Vuylsteke, 2017). The change in economic indicators and the expected results are based on Evers et al. (2015). This research has shown that increasing longevity and decreasing replacement rates is economically beneficial for dairy farmers.

Increase milk production per cow

Environmental	High
Economic	Positive
Social	Negative

Increasing the milk production with the same amount of cows reduces the amount of ammonia emitted per unit of product. Factors influencing the milk production per cow are the feed intake, conversion rate and genetics (van Zessen, 2017). Ammonia emissions per kilogram of milk produced are reduced by 11% when milk production increases from 7,800 kg per cow to 9,000 kg per cow, which is often achievable (Evers et al., 2015).

It takes time to achieve a higher milk production, many farmers are always trying to achieve this. It also takes a lot of management capabilities and skills (Vuylsteke, 2017). Evers et al. (2015) show that increasing the milk production is beneficial. The same change in indicators and expected results are used.

3.1.2 Low protein feed

Lowering the protein content in feed is beneficial for mitigating ammonia emissions because the produced manure contains a lower concentration of mineral nitrogen. This mineral nitrogen is later converted into ammonia. Farmers are free to determine the amount of protein in their feed, but a certain amount of protein content is required to sustain milk production on a decent level (Reijs et al., 2007).

Feed more maize and less grass

Environmental	Average
Economic	Break-even
Social	Positive

Increasing the share of maize in the ration is beneficial to reduce ammonia emissions because maize contains less proteins than grass. For each per cent (absolute value) decrease in protein content of animal feed, NH_3 emissions from manure are decreased by 5 to 15%, depending on other farm-specific variables (Bittman et al., 2014). Feeding diets lower in crude protein increases efficiency of N on the dairy farm, decreases ammonia excretion but also decreases the short-term N availability of the manure (Paul et al., 1998).

Because maize only requires one round of harvesting, it has a positive effect on the labour required. The cultivation of maize is often completely executed by a contractor.

It is uncertain whether this measure will lead to a positive result. It is likely that farmers end up with a slightly positive, break-even or slightly negative result (Vellinga, 2009).

Less crude protein in grass silage

Environmental	Average
Economic	Positive
Social	Unknown

Grass is a relatively protein-rich ingredient but the protein levels can be lowered by e.g. balanced N fertilization and grazing/harvesting the grassland at a later growth stage. This measure is more applicable to housed-animals than for grazing animals. For animal health it doesn't matter as long amino acids requirements are met (Bittman et al., 2014). The expected ammonia emission reduction is comparable with that in the previous measure.

There might be a small social influence regarding labour, as it requires some feed management changes, but this is not specified by any literature study. Low-scale research by Evers et al. (2015) showed that e.g. harvesting later is economically beneficial. The same indicators and expected outcomes are used.

Less crude protein in pasture grass

Environmental	Dependent
Economic	Unknown
Social	Unknown

At farms where the cattle is grazed, or fresh grass is fed, it is possible to bring back the protein content in the pasture grass by e.g. less N fertilization and variety choice. The environmental impact of this measure depends on the amount of days that cows are grazed, or the proportion of pasture grass in the average ratio (Bittman et al., 2014).

A big impact on labour hours or other social indicators is not expected, as it requires some feed management changes. Literature does not state which indicators change or what the expected result is after implementing this measure. Therefore, the author used the social indicators according to own interpretation, and the expected financial result will remain unknown.

Less crude protein in concentrates

Environmental	Average
Economic	Positive
Social	Unknown

There are solutions offered containing different levels of crude protein, which influences N efficiency and ammonia release. The same environmental impact according to Bittman et al. (2014) is expected with this measure to other measures that lower protein contents. Because roughage has a major stake in the total diet, the overall expected environmental reduction is expected to be average.

Socially, one does not expect a high influence regarding labour, as it requires just some feed management changes. Low-scale research by Evers et al. (2015) showed that lowering crude protein in concentrates is economically beneficial, the same indicators have been used. Related costs and benefits do only comprise the lesser cost of concentrates and the milk production which might be influenced (Swensson, 2003).

3.1.3 Grazing

Grazing is one of the most important and most debated issues nowadays in the Dutch dairy sector. The practice of grazing is a traditional element in the dairy sector but scaling and a more automatic way of working (e.g. AMS) have caused the percentage of grazed cows to decline in recent years (Reijs et al., 2013). Calculations by Hoving et al. (2015) have shown that an increase in grazing results in a reduction of ammonia emissions. This is because the share of manure that ends up in the stable decreases so ammonia has less time to be extracted from the cycle. Besides that, faeces and urine do not come together, which prevents ammonia from being formed. This research distinguishes grazing of milking cows and young cattle.

Grazing by dairy cows

Environmental	High
Economic	Positive
Social	Dependent

Grazing is an effective strategy to reduce ammonia emissions. Overall ammonia emissions per cow can reduce from over 35 kg/year to 25 to 30 kg/year, dependent on the number of days that cows spend in the meadow (Hoving et al., 2015).

Grazing makes the sector visible in the landscape, consumers and citizens often argue that cows should be allowed to graze to exploit their natural behaviour and many people like the view of dairy cows in the meadow (Reijs et al., 2013). The labour intensity of grazing is very dependent on the system that is used and the hours that cows are grazed. The conclusions of this research in 2002 are outdated, but this is the most recent investigation in to the relationship between labour and grazing. Since then, enterprises have changed drastically (scaling and modernization) (van den Pol-van Dasselaar, 2016).

The economic indicators that change when a farmer decides to let their cows graze or not, are numerous. Van den Pol-van Dasselaar et al. (2013b) however recognize a few indicators that determine the change in results. A change in milk production and sales is taken into account as well. Farmers often receive a premium for letting their cows graze. Since this is part of the price paid for the milk so this is automatically part of the milk sales.

Grazing by young cattle

Environmental	High
Economic	Positive
Social	Unknown

Not all farmers that let their dairy cows graze also graze their young cattle. No premiums are paid by milk processors and raising young cattle is easier with a constant ration instead of a changing diet (Colenbrander, 2014). To assess the economic and environmental impact of young cattle grazing, the same indicators and expected results by Van den Pol-van Dasselaar et al. (2013b) are used. There is no exact knowledge on the labour intensity of young cattle grazing. This is not necessarily the same as grazing dairy cows, because young cattle are unlimited grazed.

3.1.4 Low emission housing systems

The Dutch government has approved 30 housing systems that have satisfying ammonia reduction levels, these can be found on the RAV-list (Rijksoverheid, 2017). For every new built stable one is obliged to implement one of these systems. For the sake of this research, the 30 available systems plus one have been divided into 4 categories.

Because this division is artificial, it is not possible to discuss the categories in the same manner as done with the other sets of measures. Due to the artificialness of these categories, it is not possible to draw explicit hypotheses based on literature. However, it is fair to state that each of the categories is environmentally highly beneficial and economically negative, due to the high costs of installation (Agrifirm, 2017; van Dooren & Mosquera, 2016; Feenstra et al.. 2013). It is not possible to give a classification based on social indicators. Therefore, all categories receive the assessment of a high environmental impact, a negative economic impact and an unknown social impact. The emissions and costs per RAV housing system can be found in appendix V.

Environmental	High
Economic	Negative
Social	Unknown

Category 1 - Floor systems with low emissions < 10 NH_3 per animal place

The first category belongs to the systems with the lowest emissions per animal place. The average price per square meter of these systems is €92. The RAV-systems that have this low emission number can be found in the textbox.

A 1.1, A 1.4, A 1.9, A 1.10, A 1.13, A 1.14, A 1.18, A 1.21, A 1.23, A 1.24, A 1.26, A 1.28, A 1.29, A 1.30

Category 2 – Floor systems with high emissions > 10 NH3 per animal place

The housing systems with relatively higher emissions can be found in this category. The average price per square meter is €104. The RAV-systems that are put in this category can be found in the textbox.

A 1.2, A 1.3, A 1.5, A 1.6, A 1.7, A 1.8, A 1.11, A 1.12, A 1.15, A 1.16, A 1.19, A 1.20, A 1.22, A 1.25, A 1.27

Category 3 – Mechanical ventilated system

This category is only for RAV-system A 1.17, which is the mechanically ventilated system. The emission standard is 5.1 kg NH3 per animal place and the costs are €113 per square meter.

Category 4 – Natural ventilated system

The natural ventilated system cannot be found on the most recent published list of possible RAV housing systems. The exact and official numbers are not available, its emissions is below 10 kg NH3 per animal place and the costs are over €100 per square meter.

3.1.5 Existing stables

Most ammonia emissions come from manure in the stable. Besides building a new low emission stable it is possible to lower ammonia emissions by adaptions in existing stables. Housing systems have a certain emission factor that can be decreased by ammonia reducing options. This emission factor multiplied with TAN (total ammoniacal N) determines the amount of ammonia emitted in a stable. However, when the emission in the stable is reduced, the potential emissions of ammonia on the land and in storages is greater. This potential emission can be mitigated with measures applicable to these phases of the cycle (Velthof et al., 2009; van Dooren & Smits, 2007).

Roof insulation

Environmental	Low
Economic	Unknown
Social	Negative

Roof insulation decreases the temperature in the stable, which decreases the emission factor as less ammonia is formed at lower temperatures. An additional advantage of roof insulation is that it prevents, or at least reduces, heat stress among the cattle. Heat stress causes less feed intake and therefore lowers milk production (Hofstee, 2014). Environmental benefits regarding ammonia can go up to a maximum of 5% (Proeftuin Natura 2000, 2017).

There is no scientific evidence on the economic benefits of roof insulation, but it requires an investment and the milk production is influenced. It also requires extra labour and safety of applying the insulation must be considered.

ACNV

Environmental	Average
Economic	Negative
Social	Unknown

An ACNV (automatic controlled natural ventilation) system reduces the air speed and ventilation flow within the stable, which lowers the ammonia emission. It opens or closes the curtains on the sides of the stables automatically, depending on the climatic circumstances within and outside the stable (Brockett & Albright, 1987). ACNV is expected to reduce emissions by, maximum, 10% on stable level. however not scientifically proven yet (Mosquera et al., 2016). There is no significant change expected on the social indicators, it may increase or decrease labour a bit.

Research shows no relation between the system and production, but a limited amount of energy is typically used (Mosquera et al., 2016). Maintenance costs may also arise outside the investment that is made before installation.

Manure dilution in manure cellar

Environmental	High
Economic	Negative
Social	Negative

Manure dilution in the manure cellar with water decreases the concentration of ammonium and thereby reduces the emission of ammonia. In theory, this relation is directly proportional, which means that halving the concentration of ammonium will lead to a halved emission of ammonia. In practice, a saving of 30% on housing emissions can be reached, which is still high in terms of overall ammonia emissions (van Dooren & Mosquera, 2016).

Water needs to be added and more manure is to be disposed on the land which means that it will take more labour to apply it on the land.

Small scale research by Proeftuin Veenweiden (2017) has shown that the added water to the manure increase the amount of crude protein in grass, reducing necessary costs for concentrates. It also means that extra manure disposal costs are to be made. However, Evers et al. (2015) state that this not holds for dilution in the manure cellar, and that the income decreases when this measure is implemented.

Manure dilution on walking floors

Environmental	High
Economic	Negative
Social	Negative

Manure can also be diluted on walking floors with the use of flushing systems, the reduction in emission works similar to the previous measure. On housing level, an emission reduction of 28% to 34% can be achieved when water use for flushing is 20-50 liters per day per cow, which is a very high saving on overall farm emissions (van Dooren & Mosquera, 2016).

The costs and benefits that occur if this measure is implemented are comparable to dilution in the manure cellar (van Dooren & Smits, 2007). However, Bittman et al. (2014) argue that these flushing systems can cause slipping which is detrimental to cow health.

Manure sliding

Environmental	Unknown
Economic	Negative
Social	Unknown

The effectiveness of manure sliding in the stable is important, because clean floors make sure that the contact between faeces and urine is limited. There is hardly any numerical evidence that shows what the reduction of ammonia emissions is. The floor type used is also very important for the effectiveness of manure sliding.

The literature shows no unit that can define the effectiveness of manure sliding (van Dooren & Mosquera, 2016). The most important financial indicator is maintenance and the investment that needs to be made.

Manure acidification

Environmental	High
Economic	Negative
Social	Negative

Acidification of manure reduces the pH, which means that the vapor pressure of ammonia is reduced. Most international research that is conducted focuses on adding an inorganic acid to the manure. There are several acids available to acidify manure, such as nitric acid (HNO_3) and sulphuric acid (H_2SO_4). Bussink & van Rotterdam-Los (2011) assume a reduction of 35% of ammonia extracted from the stable. However, acidification of manure has some environmental downsides. It also has safety implications on the farm and leads to extra labour required (Fangueiro et al., 2014).

The costs of acidification vary between 54 and 87 € per animal, mainly depending on the size of the farm. The costs for the system are relatively high and annual maintenance is required. Lime should be added to restore the mineral balance in the manure, which is costly. On the other hand, less S and N needs to be fertilized (Bussink & van Rotterdam-Los, 2011).

3.1.6 MANURE APPLICATION GRASSLAND

Ammonia can be extracted from the cycle when manure is applied to the grassland. High NH_3 concentrations in the manure, application under unfavourable weather conditions, and leaving manure on top of the soil can all lead to extensive ammonia reductions. If all these things are not taken care of, emissions of ammonia as a percentage of TAN can rise to 40 – 60%, emissions outside this range are also common. However, the exact emission is also dependent on soil type and drainage rates. Dry soils have lower emissions than wet and compact soils with reduced infiltration rate (Bittman et al., 2014).

MANURE DILUTION BEFORE APPLICATION

Environmental	High
Economic	Positive
Social	Unknown

Manure infiltrates better in the soil if it is diluted with water before application and the concentration of ammonium is reduced. Because less N is extracted, there is a better utilization of N which should lead to a higher amount of crude protein in the grass. A significant effect of water dilution can be achieved when the water to manure ratio is 2:1 or higher (Amon et al., 2015). The ammonia emission from surface-applied slurry can be reduced by 55% if water to manure ratio is 3:1 (Huijsmans et al., 2016).

There are not many changes to be expected on the social indicators as most extra work is done by the contractor. Indicators and expected outcomes are the same as manure dilution in the stable. Evers et al. (2015) have shown that this measure is profitable. The same indicators and expected results are used.

ACCURATE MANURE APPLICATION

Environmental	Average
Economic	Positive
Social	Unknown

When manure is not accurately applied, it remains on top of the soil and is not used in the soil, which enlarges ammonia emissions. Accurate disposal means slow driving and application in small quantities, so uptake of minerals is optimal. Responsible disposal should lead to a higher utilization of N in the soil, therefore having less NH_3 emissions. Non-scientific evidence by Proeftuin Natura (2015) states that an average ammonia emission reduction of 18% can be achieved. This is only considering the potential of mitigation on the level of application.

One does not expect many social changes as most extra work is done by the contractor. Proeftuin Natura (2015) defined the indicators and expected outcomes for this measure and show that this measure is profitable.

MANURE APPLICATION UNDER FAVOURABLE WEATHER CONDITIONS

Environmental	Average
Economic	Positive
Social	Unknown

Ammonia emissions depend crucially on the atmospheric conditions. It is environmentally beneficial to dispose manure when there is a low temperature, low wind speed, limited sunlight and a high relative humidity (Parkinson et al., 2004). Huijsmans et al. (2001) found an average effect of weather conditions on ammonia emissions in comparison with other variables. Smits et al. (2013) estimate the potential emission reduction to be under 30% of total emitted ammonia related to applying manure on grassland.

Since this measure is comparable to the previous measure, it is expected that manure disposal under favourable weather conditions is also profitable, the same indicators and expected outcomes have been used.

3.1.7 MANURE APPLICATION ARABLE LAND

Similar to manure application on grassland, manure application on arable land can cause an extensive emission of ammonia. Ammonia can be extracted when it is not well applied on the land, or when it remains on top of the soil. Similar to grassland, the exact emission is also dependent on the soil type and drainage rates. Dry soils have lower emissions than wet and compact soils with reduced infiltration rate (Bittman et al., 2014).

INCORPORATION IN TWO ROUNDS

Environmental	Average
Economic	Negative
Social	Unknown

Dutch farmers are obliged to incorporate the manure in the soil. The time between the application and the second round, if done so, of incorporation mainly determines the amount of N that is emitted. Smits et al. (2013) argue that incorporation in the second round saves 33% compared to top soil application, which gives an average overall effect.

Similar to different techniques to apply manure on grassland, the costs for manure disposal are expected to rise (Bittman et al., 2014). There is not much economic difference compared to other manure application methods. The literature gives no clearance on the possible economic benefits of a second round of incorporation of manure, so it is assumed that this measure has a negative economic result. For the social indicators, one should consider that most extra work is done by contractors.

MANURE INJECTION

Environmental	Average
Economic	Unknown
Social	Unknown

Manure injection is used to inject the slurry directly in the soil. This way of applying manure to the arable land has the greatest reduction of ammonia; 80% less ammonia is emitted compared to a reference situation in which manure remains on top of the soil. There is a significant difference compared to application and incorporation, slurry injection has the highest ammonia mitigation potential (Hou et al., 2015).

Rotz et al. (2011) show that manure injection provided the greatest environmental benefit at the least cost or greatest profit for the farmer. However, it should be considered that this research is done in the United States, where most farmers have their own equipment instead of contractors that do the work for them. They show a rise in tons dry matter produced, meaning that more N and P is utilized in the soil when using manure injection (Rotz et al., 2011). It is highly doubtful whether the same situation applies to the Netherlands, but, so far, no research has been in done on the economic impacts in Netherlands.

3.1.8 Conclusions literature review – Ammonia

Table 8 gives an overview of all the conclusions based on the literature review for the ammonia mitigation measures.

TABLE 8: ALL CONCLUSIONS OF AMMONIA MITIGATION MEASURES

Measures	Environmental effect	Economic effect	Social effect
1.1 Productivity			
1.1.1 Reduce of young cattle	Average	Positive	Positive
1.1.2 Increase longevity of dairy cows	Average	Positive	Positive
1.1.3 Increase milk production per cow	High	Positive	Negative
1.2 Low protein feed			
1.2.1 Feed more maize and less grass	Average	Break-even	Positive
1.2.2 Less crude protein in grass silage	Average	Positive	Unknown
1.2.3 Less crude protein in pasture grass	Dependent	Unknown	Unknown
1.2.4 Less crude protein in concentrates	Average	Positive	Unknown
1.3 Grazing			
1.3.1 Grazing by dairy cows	High	Positive	Dependent
1.3.2 Grazing by young cattle	High	Positive	Unknown
1.4 Low emission housing systems			
1.4.1 Category 1 - RAV housing systems with < 10 KG NH_3 per animal place	High	Negative	Unknown
1.4.2 Category 2 - RAV housing systems with > 10 KG NH_3 per animal place	High	Negative	Unknown
1.4.3 Category 3 – Mechanical ventilated system	High	Negative	Unknown
1.4.4 Category 4 – Natural ventilated systems	High	Negative	Unknown
1.5 Existing stables			
1.5.1 Roof insulation	Low	Unknown	Negative
1.5.2 ACNV	Average	Negative	Unknown
1.5.3 Manure dilution in manure cellar	High	Negative	Negative
1.5.4 Manure dilution on walking floors	High	Negative	Negative
1.5.5 Manure sliding	Unknown	Negative	Unknown
1.5.6 Manure acidification	High	Negative	Negative
1.6 Manure application grassland			
1.6.1 Manure dilution before application	High	Positive	Unknown
1.6.2 Accurate manure disposal	Average	Positive	Unknown
1.6.3 Manure disposal under favorable weather conditions	Average	Positive	Unknown
1.7 Manure application arable land			
1.7.1 Incorporation in two rounds	Average	Negative	Unknown
1.7.2 Manure injection	High	Unknown	Unknown

3.2 Greenhouse gases

This section presents all the conclusions and motivation for these conclusions, for all the measures related to the mitigation of greenhouse gas emissions.

3.2.1 Productivity

The same economic and social effects are to be expected as in paragraph 3.1.1. Therefore, the text in this paragraph will only focus on the environmental impact (reduction of GHG) of these measures.

Reduce young cattle

Environmental	Average
Economic	Positive
Social	Positive

Reducing the amount of heifers per 10 dairy cows, in combination with increasing the longevity of dairy cows can reduce GHG emissions by 20 to 40 grams per kg of milk, which is 2 to 3 percent of total GHG emissions. Increasing longevity of dairy cows is required when less heifers are held (Vellinga et al., 2009).

Increase longevity of dairy cows

Environmental	Average
Economic	Positive
Social	Positive

Vellinga et al. (2009) calculates that the emission when this measure is applied is the same as in the previous measure. These two measures go together; less young cattle is needed for increased longevity of dairy cows. Therefore the estimated reduction of GHG of 2 to 3 percent applies here as well.

Increase milk production per cow

Environmental	Dependent
Economic	Positive
Social	Negative

Research conducted by Vellinga et al. (2009) shows that the emissions related to increasing the milk production are dependent on extra feed required. Farms that have an initial low milk production per cow can achieve a significant reduction of GHG when increasing production per cow, but no extra feed should be needed to obtain this increase. Farms that already have an average or high milk production and need to produce extra feed to increase their milk production per cow, will end up with an increase of GHG emitted.

3.2.2 Feed

Feed production and digestion has a significant contribution to the total GHG produced at a regular dairy farm. The production of roughage and concentrates can cause extensive emissions of N_2O and CO_2, respectively (van Cappellen, 2014). The digestion of feed by the dairy cows results in CH_4 emissions. Because methane is a product of the fermentation process in the rumen, ration changes can reduce these methane emissions. Fermentation is responsible for 75% of all methane emissions. The remaining 25% of methane emissions is emitted during manure storage (Valk et al., 2011; Bannink et al., 2009).

Improve feed conversion efficiency

Environmental	Average
Economic	Positive
Social	Negative

Improvements in feed conversion efficiency (more milk per kg dry matter) can be gained by having efficient animals that produce more milk with the same amount of dry matter. Because methane production depends on the amount of dry matter fed, a more efficient feed conversion ratio leads to less methane emissions per unit of product (van Duinkerken et al., 2007). Waghorn & Hegarty (2011) suggest that an improved feed conversion efficiency can be obtained with good animal management practice, which includes appropriate genetics, reproductive performance and increased longevity.

Calculations by Van der Pol-Dasselaar et al. (2013) show that possible emission reductions are around 0.035 kg CO_2 equivalents per kg of milk, when feed conversion efficiency goes up by 500 kg milk/cow with an equal ration.

Van der Pol-Dasselaar et al. (2013) argue that this is a hard measure to implement, because it requires a lot of management time and skills. However, it is economically beneficial. Costs for genetics management will rise, since more efficient breeds are needed, but this is compensated by extra milk production and thus more income.

FEED MORE MAIZE AND LESS GRASS

Environmental	Average
Economic	Break-even
Social	Positive

Maize is typically less environmentally harmful because less methane is emitted during digestion (Bannink, 2002). Besides that, less tillage is required which lowers energy usage. Van der Pol-Dasselaar (2013) state that increasing the ratio of maize in the crop rotation plan from 10% to 20%, gives an emission reduction of 0.014 kg CO_2 equivalents per kg of milk.

An increased amount of maize in the crop rotation plan leads to a small loss or a small profit. Because maize contains less nitrogen and proteins, more concentrates will have to be bought compared to the original situation. Most tillage on maize fields is done by contractors, so this post will increase as well. Costs for fertilizer and pesticides decrease (Vellinga, 2009).

FEED MORE FRESH GRASS AND LESS GRASS SILAGE

Environmental	Average
Economic	Positive
Social	Negative

Grass that has been stored and conserved in a grass silage is less efficient compared to fresh grass. The phases of harvesting, conservation and feeding lead to both losses in quantity and quality. GHG emissions during these phases also depend on silage management. Overall, this mitigation strategy has an average environmental impact. Because fresh grass is more regularly harvested, the positive environmental effect is lowered a bit (van Schooten and Philipsen, 2011).

According to literature, grazing has proved to be economically profitable. According to Dekkers (2016) leads feeding fresh grass in the stable to less losses, lower contractor costs and lower costs for concentrates. The latter one is because the uptake of dry matter is typically higher for fresh grass compared to grass from the silage. Often, costs for roughage go up a bit due to trampling. Overall, the measure is profitable, but it takes up some more labour hours.

DIGESTIBILITY OF GRASS

Environmental	Average
Economic	Positive
Social	Negative

The digestibility of grass is vital because decreased digestibility of dietary nutrients increases enteric methane emissions and fermentable organic matter concentration in manure, which eventually increases CH_4 emissions in manure. To mitigate CH_4 emissions, feed supplements can be added or the quality of the grass can be improved. Also, grass variety choice has the potential to increase or decrease GHG emissions. Most of these measures reduce methane emissions between 5 to 10%, which lowers the overall GHG reduction under 5% (Gerber et al., 2013).

Oba and Allen (1999) argue that improving the digestibility of neutral detergent fibre (NDF) from forage by one unit, increases the milk production by 0.25 litres per day. Choosing a different variety of grass is the easiest way to achieve this and to increase in milk production. However, it requires management time, knowledge and skills to reach this improvement in milk production.

Feed additives

Environmental	High
Economic	Negative
Social	Negative

Adding an additive to dairy feed can drastically reduce methane emissions since they can bind hydrogen which leads to less methane emissions. Several researches have shown that adding 270 grams of nitrate reduces methane with 17% (Versteeg, 2016), while adding 40 to 80 grams of 3-nitrooxypropanol (3-NOP) reduces methane emissions by 30% (Hristov et al., 2015). These two substances do not influence milk production. Although fat addition above 6% also substantially lowers methane emissions, milk production appears to go down when fat content rises above 6%. This makes it financially less interesting (Patra, 2013).

There is not much impact on the social component, as it is just a change in feed management. It might require some extra labour to add the additives.

Since 3-NOP and nitrate do not affect milk production or lower any costs, these additives lead to a negative result in terms of economics (Versteeg, 2016). In case fat addition is used, milk production might even go down (Patra, 2013).

Concentrates with lower footprint

Environmental	High
Economic	Dependent
Social	Unknown

The production of concentrates has a major share in the total energy consumption of dairy farming, 46-73% of non-farm energy consumed is attributed to the production and distribution of concentrates (Thomassen et al., 2007). Farmers are given however limited tools, because concentrate producers mostly focus on sustainable procurement and production as a whole (Nevedi, 2016).

Only the costs regarding concentrates changes when concentrates with lower footprint are purchased, other posts are not expected to change. It might have a positive impact on societal thoughts, but on farmer-related issues no impacts are hypothesized.

Wet by-products

Environmental	Low
Economic	Dependent
Social	Negative

The use of wet by-products instead of compound feed does not lead to a significant environmental advantage. The energy which is used for transport is quite high as the same amount of dry matter is transported in wet material, which makes transport heavier. It might change a little when CO_2 equivalents produced during production of concentrates and wet by-products are allocated to the farm. These products are mostly used to bring dietary balance (Vellinga et al., 2009).

Wet by-products might influence milk production, but this is largely dependent on which product is fed. Any wet by-product carries costs in purchase and storage, but costs for concentrates go down. The literature does not give specific answer on the economics of wet by-products, but it is to be expected that economic results depend on the specific product. It might require some extra work to handle the feed within the farm and mix it with roughage feeds.

3.2.3 MANURE STORAGE

A quarter of all methane emissions emitted by an average dairy farm can be found in the storage of manure. When converting this to total GHG emissions, manure storage is responsible for approximately 12.5% of total GHG emissions. Storing manure also causes emissions of N_2O and these emissions can also be mitigated by the measures presented below. (Bannink et al., 2009).

METHANE OXIDATION

Environmental	High
Economic	Negative
Social	Negative

Methane oxidation is a process in which methane is converted into CO_2. One kilogram of methane is converted into three kilograms of carbon dioxide. Because methane causes 28 times more damage than carbon dioxide, this is very advantageous for GHG emissions. This method is still not fully developed and cannot be found on Dutch dairy farms yet, but it has a great mitigation potential. Economically, it would not be possible to implement such a system right now (van Kasteren, 2018). It would also take a lot of work to implement this new technology and to get it fully equipped on individual farm scale.

MANURE ACIDIFICATION

Environmental	High
Economic	Negative
Social	Negative

Acidification of manure reduces the pH, which reduces or stops formation of methane. Most international research is conducted on adding an inorganic acid to the manure. There are several acids available for this measure, such as nitric acid (HNO_3) and sulphuric acid (H_2SO_4). Research by Bussink & van Rotterdam-Los (2011) states that methane emissions in manure storage can be reduced by 90%.

The costs of acidification vary between 54 and 87 € per animal, mainly depending on the size of the farm. The costs for the system are relatively high and annual maintenance is required. To restore the balance in the manure, lime should be added which carries extra costs. On the other hand, less S and N need to be fertilized. Manure acidification brings some safety implications, as dangerous substances must be held and handled appropriately. Besides that it takes extra work, which results in a negative social assessment (Bussink & van Rotterdam-Los, 2011).

MANURE FERMENTATION

Environmental	High
Economic	Negative
Social	Negative

Manure fermentation is a technical option which uses bacteria to convert organic substances into methane gas, which can be used as natural gas (Beerling, 2016). Producers of these systems claim emission reductions from 0.16 to 0.21 CO_2 equivalents per kilogram of milk, but this is still uncertain because the supply of organic matter to the soil is compromised. This can lower the stored carbon in the soil (de Wit & van Veluw, 2017). There is co-fermentation, which uses also maize, and mono-fermentation, in which only manure is used. For this research, mono-fermentation is analysed because it is more sustainable.

Van den Pol-van Dasselaar et al., (2013a) state that the investment is very high and the installation is not profitable. Many farms do not have the ability to place such fermentation and continuous maintenance requires a lot of labour.

MANURE SEPARATION

Environmental	Average
Economic	Positive
Social	Negative

Separation in the storage of faeces and urine can lower CH_4 emissions in manure storage by 40%. However, N_2O emissions may rise during composting of the solid manure (Amon et al., 2006). Compared with all GHG emissions on a dairy farm, this leaves an average potential GHG reduction obtained by this measure. Manure separation can be executed either mechanically or non-mechanically.

Evers and Galama (2016) show that manure separation is economically beneficial, both mechanically and non-mechanically. The same indicators change when one of both is applied on the dairy farm. Costs for required fertilizers and manure disposal decrease, but contractor costs increase. Labour required may increase a bit, especially when mechanical separation is implemented.

DECREASE MANURE TEMPERATURE

Environmental	Average
Economic	Unknown
Social	Negative

The speed of methane production and emission processes are correlated with an increase in temperature. Reducing this temperature can lead to substantial GHG emissions reductions, emissions decrease by 66% if slurry temperature is decreased from 20 ^{0}C to 10^{0}C (Hilhorst et al., 1998). However, this is often not achievable without cooling, which requires a high energy consumption.

Transferring manure to an outdoor storage facility often reduces methane emissions by 5 to 10%, as the difference between average cattle stable temperature and average outdoor temperature is 1 to 2^{0}C. The place of the outdoor manure facility has an influence as well, it is preferred to have this facility at a cool spot. The effect of these measure is average (Hilhorst et al., 1998).

Emptying the manure cellar more often or determining the right place for the outdoor manure facility does not require extra costs, except for extra labour required.

3.2.4 CROP AND FERTILIZATION

Balanced and well-managed crop fertilizing can mitigate N_2O and CO_2 emissions because it is most ideal for environmental pollution if a limited amount of chemicals is fertilized. Otherwise e.g. nitrification and denitrification can occur which is the cause for nitrous oxide emissions. Also, the uptake of minerals by crops can be improved, which leaves less minerals that can be converted into greenhouse gases.

USE OF GRASS-CLOVER

Environmental	Average
Economic	Negative
Social	Unknown

Clover binds nitrogen from the air which can be used in the soil. This leads to a lower need for N from chemical fertilizers. There are no nitrous oxide emissions allocated to nitrogen bound by clover. There is not much clarity on the exact effect of clover on N_2O and CO_2 emissions, as stated by Corré and Kasper (2002). More recent publications can also not quantify this effect, there is however consensus on the fact that the effect of clover on nitrous oxide reduction is significantly high (van den Pol-van Dasselaar et al., 2013a). This has an average effect on the overall reduction, since nitrous oxide accounts for only 11% of total GHG emissions.

There is some discussion whether grass-clover is more profitable than regular grass with regular N fertilization. It appears that under current fertilization limits, regular grass with regular N fertilization is more profitable because the harvest of grass-clover decreases. The profitability also depends on the price of fertilizer relative to the milk price that is earned, when the price of fertilizer increases, the production advantage that regular grass has over grass-clover becomes less important. Under the current situation, the cultivation of grass-clover is not profitable (Humphreys et al., 2012; Schils et al., 2000). There is little known about the social effects on the use of clover.

NITRIFICATION INHIBITORS

Environmental	Average
Economic	Negative
Social	Negative

Nitrification inhibitors prevent that ammonium is converted into nitrate and can be added to both chemical fertilizers and manure. Since nitrate is the origin of nitrous oxide, these emissions can be reduced by adding nitrification inhibitors. The emission depends on the sort of nitrification inhibitor applied, temperature, moisture and soil type. An average 12% reduction of nitrous oxide is possible, which results in an average overall reduction of GHG (Lesschen & Kuikman, 2017).

Nitrification inhibitors can increase the harvest of grass, but this is not necessarily the case. Maize harvest is not influenced. The costs for nitrification inhibitors are sometimes earned back by increased harvest, depending on the sort of nitrification inhibitors used. In most cases, the overall result is negative. Safety should be considered when handling and storing nitrification inhibitors, as these are categorized as environment damaging substances (Kuikman et al., 2010).

PRECISION APPLICATION OF FERTILIZER

Environmental	Average
Economic	Dependent
Social	Negative

Precision application of fertilizer includes the use of injectors that apply fertilizer in the soil, near the root of the plant. This increases uptake of minerals and reduces leaching. Van den Pol-van Dasselaar et al. (2013a) estimate the reduction of GHG at 0.05 kg CO_2 equivalents per kg milk, making the effect average.

This measure saves costs for fertilizer, as less fertilizer is needed. On the other hand, specific machines have to be bought, but this can be done in cooperation with other farmers or fertilizing can be done by a contractor. Eventually, precision application of fertilizer leads to a tiny decrease or increase of costs. This depends on fertilizer and machinery prices. The social effect is expected to be negative after implementation, but most of this work is done by contractors. (Van den Pol-van Dasselaar et al., 2013a).

LOWER FERTILIZER GIFT OF N

Environmental	High
Economic	Positive
Social	Unknown

Using high levels of N fertilizer often results in poor utilization by crops, which leads to high N-losses to the environment. This causes leaching of nitrate and can result in excessive N_2O emissions (Valk et al., 2000). A significant decrease in N fertilizing can lead to a GHG reduction of 50 to 100 grams kg CO_2 equivalents per kg of milk. In practice this reduction might be lowered a bit because more land is required to cultivate maize (Vellinga et al., 2009).

In general, the economic result of this measure is positive, because less fertilizer is required. More concentrates and/or purchased maize might be needed to balance the ration and nutritional values, because grass harvests are likely to decrease. The result is heavily dependent on the prices for purchased feed and fertilizer, and under the current fertilization limits the savings might be low, while harvests may drop under a critical level. If the farmer is capable of keeping the harvest at a decent level, this measure is profitable (Vellinga et al., 2009).

Footprint chemical fertilizer

Environmental	Average
Economic	Dependent
Social	Unknown

Decreasing the footprint of chemical fertilizer is an effective mitigation strategy because a lot GHG are emitted during the production of these fertilizers. Nitrogen fertilizer is the biggest contributor (2.3-2.9 ton CO_2 equivalents per ton N), because it is the most energy intensive mineral to produce and nitrous oxide is emitted as well during the process (De Haas & van Dijk, 2010). The production of N fertilizer determines around 5% of the total GHG related to the milk that leaves the farm. Currently, there is N fertilizer on the market that reduces total production emissions by 60%, leaving only a share of 2% in total GHG (van den Pol-van Dasselaar et al., 2013a).

Whether lower amounts of GHG emitted in the production process will lower the price of chemical fertilizer is questionable, because this depends on much more variables such as production location and the price of natural gas (de Haas & van Dijk, 2010). Lako (2009) argues that the process needs drastic changes to reach even further energy reductions, as 'there are no easy reductions in energy consumption, or low hanging fruits'. Therefore, the economic result is dependent on the price of regular and more sustainable options for fertilizers.

Cultivation of concentrate substitutes

Environmental	Unknown
Economic	Negative
Social	Negative

There are crops that can be used instead of compound feeds, since they have similar nutritional attributes. These crops include, among others, protein-rich plants like winter wheat, beets and beans. There is not much known about the possible environmental effect, because this is heavily dependent on various factors, such as the sort of crop that is grown. It should be pointed out that the heavy use of energy for transport and processing of compound feeds is (partly) taken out when concentrate substitutes are cultivated.

Mons (2013b) argues that, in most cases, own cultivation of concentrated feed is not profitable. Land prices in the Netherlands are too high to use them for cultivation of these species, especially when the farmer is unexperienced with certain crops. When the prices for concentrates will further increase, it might be valuable to do this. Socially, it means a lot of extra work for the farmer to cultivate and get experienced with the crop.

3.2.5 Energy

This section is dedicated to the electricity, gas and fuel use on dairy farms. Electricity is mostly used by machines and equipment used for, among others, milk production, cooling and lightning. Gas is used for heating and fuel (diesel) is needed for feed production and feeding. Most variation in energy usage can be found in the diesel usage of the farms, as this is dependent on several factors such as intensity, use of contractors, distances between plots and buildings et cetera (Ruitenberg and Jacobs, 2014). It is possible to produce and/or consume green energy. Green energy, and especially electricity, can be generated by solar panels and wind turbines. Biomass can also contribute as a green energy source as well.

SOLAR PANELS

Environmental	Average
Economic	Dependent
Social	Negative

Solar panels are placed on the roof to collect solar energy and generate power out of this. There are many farmers that invested in solar panels, but some dairy farmers are still reluctant because of the large investment or unsuitable conditions at their farm. According to van den Pol-van Dasselaar (2013a) they can save 0,029 kg CO_2 equivalents per kg milk, giving it an average effect.

Economic performance depends on the electricity usage on the farm and the total area of solar panels that are placed. According to Dubbeldam (2012) the investment is earned back if the panels are placed in the right direction and with an annual energy usage that does not rise above 60,000 kWh. Besides the investment, some maintenance is required but it might be possible to get a subsidy for the use of solar power. However, safety needs to be considered, as the panels needs to be washed regularly.

WINDMILLS

Environmental	High
Economic	Positive
Social	Unknown

Power can also be generated through wind energy. Dairy farmers can participate in a cluster, or place a solitary windmill. However, these solitary windmills are often discouraged by local governments. Generally speaking, the impact of windmills can have a great energy saving which is much larger compared to solar energy. The exact environmental impact depends heavily on the wind speed on the location and the height of the wind turbine (Terbijhe et al., 2010).

If placed at the right location, wind energy is generally profitable on the long run. Farmers that participate in a cluster have a benefit in most cases because higher investments can be made. While farmers with solar panels can often receive a subsidy, owners of wind turbines do not get these subsidies. The energy generated by windmills is delivered to the electrical grid, instead of reducing energy usage at the dairy farm. Dairy farmers may find resistance, as societal groups often think they do not belong in the Dutch landscape. They require only a minimal amount of labour after construction (Terbijhe et al., 2010).

HEAT RECOVERY

Environmental	Low
Economic	Positive
Social	Unknown

Heat recovery is used to recover heat from disposed air and water. It is often used by dairy farmers, mostly for financial arguments. According to Van den Pol-van Dasselaar (2013a), reduction achieved with heat recovery is only 0.007 kg CO_2 equivalents per kg milk, making the overall effect very low. Whether the investment can be earned back depends on the source of energy. In case of natural gas the profitability is very low, when electricity is used the advantage is higher, but it also depends on the size of the farm. The investment is between €2,500 and €4,000. In most cases, the investment is earned back (Ruitenberg and Jacobs, 2014). There are no social indicators that are expected to change with this measure.

PRE-COOLER

Environmental	Low
Economic	Positive
Social	Unknown

A pre-cooler is used to quickly reduce the temperature of the milk just before it reaches the tank. This reduces energy usage for cooling the milk in the tank. The reduction of energy usage is very low, only 0.002 kg of CO_2 equivalents per kg of milk is saved with this measure. The change in income is positive, with a plus of €0.05 per 100 kg of milk (Vellinga et al., 2009). Social indicators are not expected to change.

LED-lightning

Environmental	Average
Economic	Dependent
Social	Unknown

Lightning of the stable comprises, on average, 10 to 15 percent of the total electricity use. LED-lightning typically gives more light and has a longer longevity. LED-lightning can reduce the CO_2 emissions due to lightning by half, compared to conventional lightning systems. However, purchasing costs of LED are higher than other substitutes that are less sustainable. Both environmentally and economically the result of LED lightning is dependent on many factors, but generally, LED-lightning has an average environmental effect. Own calculations based on information in the literature show that 0.016 kg CO_2 equivalents can be saved with the used of LED lightning compared to TL lightning. Whether the investment on LED-lightning will be earned back depends on light schedules, the size of the stable and the longevity of the LED-lightning (van Cappellen, 2012).

Optimal usage of electricity

Environmental	Low
Economic	Positive
Social	Negative

Optimal usage of electricity can reduce the electricity bill drastically. This can be reached by e.g. tight lighting schemes, optimal adjustments of machines and installations and no unnecessary use of these machines and installations. An exact environmental reduction cannot be given here, because optimal electricity use is different for every individual farm. It can however be stated that the overall effect is low, since energy only makes up a small part of total GHG emissions. Economically, it is always beneficial to take the electricity use into consideration, because energy costs go down without any investment taken. It is expected to require some extra time to find and implement potential sources of energy saving on the farm.

Reduce diesel consumption

Environmental	Low
Economic	Positive
Social	Negative

Diesel consumption is accountable for 60% of CO_2 emissions on the average dairy farm. Since the part of energy usage is rather low, the environmental effect of this measure is also low. Average costs for diesel consumption in 2012 were between €5,000 and €7,000, and a reduction of 40% (€2,000-€3,000) is possible, which gives a high achievable reduction. However, this depends on the starting situation. Driving behaviour has the largest influence on diesel consumption, but also, among others, tuning, tire pressure, and regular maintenance (Agentschap NL, 2012).

It is expected to require some extra time to find and implement potential sources of diesel saving on the farm.

Biodiesel

Environmental	Low
Economic	Dependent
Social	Unknown

Biodiesel can be won out of vegetable oils or animal fat. It can be mixed with conventional diesel or used as 100% biodiesel. Biodiesel can yield over 93% more energy than what is used in its production, making its environmental impact much smaller than conventional oils. Its economic competitiveness is highly dependent on prices for conventional oil, which determine the conventional diesel price. The use of biodiesel has some downsides, its combustion leads to larger nitrogen oxide emissions. Besides that, most crops used for biodiesel can also be used for human consumption, creating a price increase for these crops. Because energy use only makes up a small part of the total GHG emissions, and the effect on nitrogen oxide emission, the effect is rather low (Hill et al., 2006; Demirbas, 2009).

3.2.6 LAND

Land cultivation can lead to nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions. Nitrogen fertilizers and manures applied to agricultural soils are the main source of the emission of N_2O worldwide. CO_2 is typically emitted when lands are cultivated, because carbon is released during these processes. Nitrous oxide emissions are typically hard to measure, so most literature makes use of standardized estimates (Skiba & Rees, 2014).

NOT PLOUGHING PERMANENT GRASSLAND

Environmental	Dependent
Economic	Dependent
Social	Positive

Ploughing permanent grassland improves production circumstances, but has some negative environmental consequences. N_2O and CO_2 are released in this process, but the exact environmental impact depends on many factors. These are, among others, the weather after ploughing, time of ploughing, amount of mineral nitrogen in the soil, frequency of sowing and soil type (van Doorn et al., 2017). Due to previous reasons, farmers with permanent grasslands that are located near Natura 2000 areas are not allowed to plough these plots anymore

Not ploughing can lead to a reduction of harvest, since grassland cannot be renewed. It however depends on soil type and grassland management whether there really is a loss in production. Other measures such as overseeding, which does not require ploughing, can lead to production increases. Therefore, the economic result of not ploughing of permanent grassland depends on soil type and grassland management (van Doorn et al., 2017; Korevaar, 2016). This measure reduces labour required as well.

REDUCE GRASSLAND RENEWAL

Environmental	Average
Economic	Positive
Social	Positive

Correct grassland management can reduce the regularity of renewal needed. According to Mons (2013a) this entails, among others, the choice of grass variety, dewatering abilities of the soil and elevate soil compaction. Aiming for 10% less renewal annually leads to a reduction of 0.02 kg CO_2 equivalents per kg of milk (van der Pol-Dasselaar et al., 2013).

Roetert (2009) shows that this economically beneficial. In case ploughing is done by a contractor, less costs have to be spent. Otherwise, it saves labour hours.

CATCH CROPS AND GREEN MANURES

Environmental	Low
Economic	Dependent
Social	Negative

Catch crops and green manures are sown to prevent leaching of nutrients. These crops are planted after harvest and destroyed before new crops are cultivated. In several ways this leads to less CO_2 and N_2O emissions, such as a reduced need of fertilizers, increased organic matter in the soil, and reduced leaching of nutrients. The environmental impact relies on the time of sowing and the amount of hectares is dedicated to maize, but the average environmental impact lies around 0.01 kg CO_2 equivalents per kg of milk (Lesschen et al., 2012).

These crops will create a loss when all the extra work is done by contractors, it is however possible for some farmers to do these tasks themselves. It can however be beneficial on the long term because soil fertility typically increases. Still, economic results rely on the moment that these catch crops/green manures are sown.

Drainage in peat areas

Environmental	Dependent
Economic	Break-even
Social	Negative

Farmers on peat soils are dealing with soil subsidence and the emission of GHG due to peat oxidation. This process is enforced when the soil is dry and groundwater levels are low. Drainage systems can help to reduce these effects by keeping peat soils moist. These drains can reduce GHG emissions by almost 2 tons/hectare/year. For a dairy farm with a milk production of 1,000,000 litres of milk, this is almost 0.002 CO_2 equivalents per kg milk per hectare. Therefore, environmental impact depends on the magnitude with which these drains are implemented, but also on the level of the ditch (Jansen et al., 2010).

Van den Pol- van Dasselaar et al. (2011) argue that this measure can have a small positive effect, or a break-even/minimal effect. Purchasing costs are around 1600 euros per hectare but can be earned back by a larger harvest. It will require some labour to install the drains in the soil.

Non-inversion tillage

Environmental	Unknown
Economic	Positive
Social	Positive

Non-inversion tillage implies that there is minimal tillage on the soil. The term non-inversion tillage is a collective name for various systems that all have different results. It is not known what the exact environmental impact reduction is because literature does not specify this.

These systems are economically beneficial, since they save fuel, labour and machinery costs. Costs savings regarding nutrients and pesticides can be expected on the long term. Sometimes a better production is monitored, but this is not always the case (Morris et al., 2010; Bos et al., 2009).

More grass in crop rotation plan

Environmental	Unknown
Economic	Break-even
Social	Negative

When the ratio of grass in the total cropping plan is higher, less ploughing is required which means that stored carbon remains in the soil. Literature does not specify any exact GHG reduction number, because it is often assumed that the cultivation of maize has lower emissions compared to grass (De Boer et al., 2011).

Since there is not much information on this measure, it is assumed that the opposing effects of more maize cultivation are present. Overall, a small loss of small profit can be expected. Grass contains more proteins, requiring less concentrates. Less contractor costs are there as well, but there is an increase in own labour, costs for fertilizers, and costs for pesticides (Vellinga et al., 2009).

3.2.7 Conclusions literature review – Greenhouse gases

Table 9 gives an overview of all the conclusions based on the literature review for the greenhouse gases mitigation measures.

TABLE 9: CONCLUSIONS OF ALL GREENHOUSE GASES MITIGATION MEASURES

Measures	Environmental effect	Economic effect	Social effect
2.1 Productivity			
2.1.1 Reduce young cattle	Average	Positive	Positive
2.1.2 Increase longevity of dairy cows	Average	Positive	Positive
2.1.3 Increase milk production per cow	Dependent	Positive	Negative
2.2 Feed			
2.2.1 Improve feed conversion efficiency	Average	Positive	Negative
2.2.2 Feed more maize and less grass	Average	Break-even	Positive
2.2.3 Feed more fresh grass and less grass silage	Average	Positive	Negative
2.2.4 Improve digestibility of grass	Average	Positive	Negative
2.2.5 Feed additives	High	Negative	Negative
2.2.6 Concentrates with lower footprint	High	Dependent	Unknown
2.2.7 Use of wet by-products	Low	Dependent	Negative
2.3 Manure storage			
2.3.1 Methane oxidation	High	Negative	Negative
2.3.2 Manure acidification	High	Negative	Negative
2.3.3 Manure fermentation	High	Negative	Negative
2.3.4 Improve digestibility of grass	Average	Positive	Negative
2.3.5 Decrease manure temperature	Average	Unknown	Negative
2.4 Crop and fertilization			
2.4.1 Use of grass-clover	Average	Negative	Unknown
2.4.2 Nitrification inhibitors	Average	Negative	Negative
2.4.3 Precision application of fertilizer	Average	Break-even	Negative
2.4.4 Lower fertilizer gift of N	High	Positive	Unknown
2.4.5 Footprint chemical fertilizer	Average	Dependent	Unknown
2.4.6 Cultivation of concentrate substitutes	Unknown	Negative	Negative
2.5 Energy			
2.5.1 Solar panels	Average	Dependent	Negative
2.5.2 Windmills	High	Positive	Unknown
2.5.3 Heat recovery	Low	Positive	Unknown
2.5.4 Pre-cooler	Low	Positive	Unknown
2.5.5 LED-lightning	Average	Dependent	Unknown
2.5.6 Optimal usage of electricity	Low	Positive	Negative
2.5.7 Reduce diesel consumption	Low	Positive	Negative
2.5.8 Biodiesel	Low	Dependent	Unknown
2.6 Land			
2.6.1 Not ploughing permanent grassland	Dependent	Dependent	Positive
2.6.2 Reduce grassland renewal	Average	Positive	Positive
2.6.3 Catch crops and green manures	Low	Dependent	Negative
2.6.4 Drainage in peat areas	Dependent	Break-even	Negative
2.6.5 Non-inversion tillage	Unknown	Positive	Positive
2.6.6 More grass in crop rotation plan	Unknown	Break-even	Negative

4. RESULTS

In the literature review the environmental, economic and social impacts of all the sustainability measures have been investigated. This chapter describes the results of the data-analysis, in which the hypotheses are tested for the Dutch dairy farms.

The data-analysis comprises 2204 samples of farms that are recorded over a timespan of six years. This makes it impossible to keep all other variables constant while comparing implementation and absence or implementation under different scales/circumstances. This data-analysis compares the profitability of specified groups based on the sustainability measures. This is because there might be many confounding variables such as management style and ability, geographical location and others. These can impossibly be taken into account in the model made for this data-analysis. Therefore, only the following type of conclusions can be drawn from this data-analysis:

Farms that implemented measure X/achieve better on measure X are more/less profitable than farms that did not implement measure X/perform worse on measure X.

Firstly, the reliability and validity of the data used during this analysis are discussed, after which the multiple measure models are presented. The outcomes of the single measure models are discussed after the multiple measure models. Both the correlation between the mitigation measures and the environmental benefit, as the correlation between the mitigation measures and the most important social component (labour) is tested.

Only the measures that were suitable for data-analysis are investigated, an overview of this can be found in paragraph 2.4.

4.1 RELIABILITY AND VALIDITY DATA USED

This paragraph presents the reliability and validity of the data that is used during this research. The complete database comprises 2204 samples that were taken, spread over six years, from 2011 to 2016. There are farmers that contributed six years to the database, but also farmers that have quit the enterprise or quit contributing. Farmers may also have started contributing to the database after 2011. There are 444 unique farms in the database, together these farms make up the total amount of samples, which is 2204.

Not all samples have complete information and miss values on some variables. Also, outlier boundaries are set to prevent outliers from having an influence on the analysis. Samples that have one or more missing values for the variables included in the analysis, are not taken into account in the analysis. This also holds for samples that have a value outside the outlier boundaries. Appendix IV gives additional information on these missing values and outliers.

After the samples with missing values and outliers are taken out, 677 and 808 samples remained for the analysis on ammonia and greenhouse gas mitigation measures, respectively. From the 677 for ammonia measures, there are 202 unique farms that have contributed to the population. This is a number of 246 unique farms (out of 808 samples) for the greenhouse gas mitigation measures.

The farms that were taken into account should not be different compared to the rest of the farms. Table 10 shows an overview of the means and standard deviations on the extra variables that were analysed during the model. These variables were used to prevent size and entrepreneurial characteristics to have an influence in the model.

TABLE 10: SIZE AND ENTREPEURIAL CHARACTERISTICS IN ALL POPULATIONS

Variable	Population in ammonia analysis		Population in greenhouse gas analysis		Total population	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Hectares of utilized agricultural area	60.14	30.545	62.42	34.375	64.50	38.994
Dairy cows	116.51	59.423	125.68	69.630	115.34	76.071
Annual work units	1.98	1.111	2.05	1.374	1.986	1.221
Age main decision maker	47.60	8.003	47.35	7.986	48.34	8.022
% with successor	26.00	43.894	27.85	44.852	29.04	45.404
Education*	2.510	0.536	2.537	0.505	2.490	0.553

The characteristics of the populations investigated do not differ a lot from the characteristics in the complete population. It can be stated that this does not harm the reliability of this data-analysis.

*All farms are ranked from 1 to 3 based on the education of the entrepreneur, this variable has the following division:

- 1 = Only primary education
- 2 = Secondary and/or practical education
- 3 = Professional and/or academic education

As earlier mentioned, the samples are taken in a period of six years. Table 11 shows the division of samples over the years for the samples taken into account in the ammonia mitigation measures analysis, the greenhouse gas mitigation measures analysis and the total amount of samples available.

TABLE 11: YEARLY DIVSIONS OF ALL POPULATIONS

Year	Population in ammonia analysis		Population in greenhouse gas analysis		Total population	
	N	%	N	%	N	%
2011	93	13.7	88	10.9	379	17.1
2012	100	14.8	107	13.2	370	16.7
2013	111	16.4	117	14.5	363	16.4
2014	120	17.7	149	18.4	351	15.9
2015	119	17.6	169	20.9	366	16.5
2016	134	19.8	178	22.0	375	16.9
Total	677	100	808	100	2204	100

Table 11 visualizes that the percentages are not directly comparable with the total amount of samples. Because the quality of data is increasing over the years there are less missing values and outliers which are caused by inaccuracy. The total amount of samples remains the same, this explains the difference in proportions over the years.

It is also vital to check whether the samples taken into account are similar to the total amount of samples available. Table 12 shows the soil types that the farms in the different populations are cultivating.

TABLE 12: DIVISION IN SOIL TYPES OF ALL POPULATIONS

Year	Population in ammonia analysis		Population in greenhouse gas analysis		Total population	
	N	%	N	%	N	%
Sand	441	65.1	530	65.6	1124	50.8
Clay	135	19.9	166	20.5	617	27.9
Peat	52	7.7	64	7.9	319	14.4
Loess	45	6.6	44	5.4	129	5.8
Total	677	100	808	100	2204	100

The portion of companies in the populations investigated cultivating sandy soils is notably larger than the same portion in the total population. Farmers cultivating clay and peat soils are somewhat underrepresented in the model. This problem is overcome with the use of dummy variables representing the soil type that is cultivated, but these differences should be taken in mind while interpreting the results of this research.

4.2 AMMONIA MITIGATION MEASURES

All the outcomes that came out of the data-analysis for the ammonia mitigation measures are presented in this section. First the correlation with the environmental impact is discussed, after which the economic and social impacts follow. A summary table wraps up all the information that is shared in this section.

4.2.1 ENVIRONMENTAL IMPACT

The environmental impact of the mitigation measures have been tested with the use of correlations. Table 13 shows the correlations between the sustainability variables and the N emissions per LU, for the ammonia mitigation measures. The same 677 samples as in the economic and social analyses are taken for this model, but some missing values lowered the sample size to 641.

TABLE 13: CORRELATIONS BETWEEN AMMONIA MITIGATION MEASURES AND ENVRIONMENTAL IMPACT

Measures	Variables		N emissions per LU
1.1.1 Reduce young cattle	Heifers per 10 milking cows	Pearson's Correlation	-0.055
		Sig.	0.162
1.1.2 Increase longevity of dairy cows	Replacement rate	Pearson's Correlation	0.033
		Sig.	0.410
1.1.3 Increase milk production per cow	Milk production per cow (100 kg)	Pearson's Correlation	0.042
		Sig.	0.290
1.2.1 Feed more maize and less grass	Kg maize / kg dry matter total	Pearson's Correlation	-0.486
		Sig.	0.000***
1.2.2 Less crude protein in grass silage	% CP in grass silage	Pearson's Correlation	0.200
		Sig.	0.000***
1.2.3 Less crude protein in pasture grass	% CP in fresh grass	Pearson's Correlation	0.212
		Sig.	0.000***
1.2.4 Less crude protein in concentrates	% CP in concentrates	Pearson's Correlation	-0.315
		Sig.	0.000***
1.3.1 Grazing	Grazing: yes/no	Pearson's Correlation	-0.181
		Sig.	0.000***
1.3.2 Grazing by young cattle	Young cattle grazing: yes/mo	Pearson's Correlation	-0.170
		Sig.	0.000***
1.4.1 Category 1 - RAV housing systems < 10 NH3 kg per animal place	RAV housing systems < 10 NH3: yes/no	Pearson's Correlation	0.096
		Sig.	0.015**
1.4.2 Category 2 - RAV housing systems > 10 NH3 kg per animal place	RAV housing systems > 10 NH3: yes/no	Pearson's Correlation	0.057
		Sig.	0.149
1.7.2 Manure injection	% of arable land manure injected	Pearson's Correlation	-0.212
		Sig.	0.000**

It appears that not all sustainability measures have a significant correlation with the environmental indicator. The measures that have an advantageous association with reducing ammonia emissions are increasing the portion of maize in the ration, lower the crude protein in grass, grazing, grazing by young cattle and manure injection. Decreasing the crude protein in concentrates and implementing one of the RAV housing systems in the first category have a significant correlation, but the emissions of farmers performing better on these measures is higher than farmers that perform worse. The other measures do not have a significant outcome.

4.2.2 ECONOMIC IMPACT

The multiple measures model is presented first, because the focus of the research is primarily on this model. Table 14 presents the results of this analysis, table 15 shows the ANOVA-table that is related to the analysis.

TABLE 14: MULTIPLE MEASURES MODEL FOR AMMONIA MITIGATION MEASURES

N					**677**
Adjusted R^2					0.468
Measure	**Variable**	**B**	**Standard error**	**t**	**Sig.**
	(Constant)	81060	47730	1.698	0.090*
Size	Ha utilized agricultural area	1145	160	7.115	0.000***
	Dairy cows	447	84	5.251	0.000***
	Annual work units	-8331	2799	-2.976	0.003***
Characteristics entrepreneur	Age main decision maker	-337	343	-0.981	0.327
	Education	-5157	5203	-0.991	0.322
	Successor	278	6437	0.043	0.966
Soil type	Soil type: sand	Dummy variable taken out of analysis			
	Soil type: clay	-35241	6790	-5.190	0.000***
	Soil type: peat	935	10760	0.087	0.931
	Soil type: loess	-6322	11152	-0.567	0.571
Years	Year: 2011	Dummy variable taken out of analysis			
	Year: 2012	-22069	9617	-2.295	0.022**
	Year: 2013	1520	9534	0.159	0.873
	Year: 2014	5674	9390	0.604	0.546
	Year: 2015	-37528	9661	-3.884	0.000***
	Year: 2016	-55661	9393	-5.925	0.000***
1.1.1 Reduce young cattle	Heifers per 10 milking cows	2336	2449	0.954	0.341
1.1.2 Increase longevity of dairy cows	Replacement rate	-1594	368	-4.324	0.000***
1.1.3 Increase milk production per cow	Milk production per cow (100kg)	1003	256	3.909	0.000***
1.2.1 Feed more maize	Kg maize / kg dry matter total	374	192	1.943	0.052*
1.2.2 Less crude protein in grass silage	% CP in grass silage	5727	4074	1.405	0.160
1.2.3 Less crude protein in fresh grass	% CP in fresh grass	-7312	3795	-1.926	0.054*
1.2.4 Less crude protein in concentrates	% CP in concentrates	-2172	880	-2.466	0.014**
1.3.1 Grazing	Grazing: yes/no	-29371	10850	-2.707	0.007***
1.3.2 Grazing by young cattle	Young cattle grazing: yes/no	20854	6609	3.155	0.002***
1.4.1 Category 1 - RAV housing systems < 10 NH3 kg per animal place	RAV housing systems < 10 NH3: yes/no	-26510	18475	-1.435	0.152
1.4.2 Category 2 - RAV housing systems > 10 NH3 kg per animal place	RAV housing systems > 10 NH3: yes/no	-11618	12126	-0.958	0.338
1.7.2 Manure injection	% of arable land manure injected	-97	62	-1.552	0.121

TABLE 15: ANOVA TABLE FOR AMMONIA MITIGATION MEASURES MODEL

	Sum of Square	df	Mean Square	F	Sig.
Regression	2.659E+12	26	1.023E+11	23.890	0.000
Residual	2.782E+12	650	4280672771		
Total	5.441E+12	676			

The effects discussed in the following paragraph are different for any farm, this is an overview for the conclusions based on the 677 samples that were investigated in this model. For the ammonia mitigation measures, this model gives the following conclusions.

- Farms with a lower replacement rate have a higher profit. A decrease in replacement rate by 1% is associated with an increase in total margin by €1594.
- Farms with a higher milk production per cow are related to a better economic result. If a dairy farmer rise the milk production by 100 litres per cow, the total margin can increase by €1003.
- Farms that feed more maize compared to all other feeds have a higher profit. If the farmer increases the portion of maize in the total ration by 1%, a rise of €374 in profit can be reached.
- Farms with a lower percentage crude protein in their fresh grass have a higher profit. If the farmer decreases the crude protein percentage by 1%, the margin increases by €7312 is achievable.
- Farms with a lower percentage crude protein in their concentrates are less profitable. If the farmer decreases the crude protein percentage by 1%, an associated margin increase of €2172 is possible.
- Farms that practice grazing are less profitable compared to farms that do not practice grazing. Farms that practice grazing have an average profit that is €29371 less than farms that do not practice grazing.
- Farms that practice young cattle grazing are more profitable compared to farms that do not practice grazing. If the farmer practices young cattle grazing, the average margin goes up by €20854 compared to farms that do not practice young cattle grazing.

The remaining measures do not have a significant outcome.

Table 16 shows the outcomes of the single measure model that was made for the ammonia mitigation measures.

TABLE 16: SINGLE MEASURES MODEL FOR AMMONIA MITIGATION MEASURS

Measure	Variable	B	Standard error	t	Sig.
1.1.1 Reduce young cattle	Heifers per 10 milking cows	-1282	786	-1.631	0.103
1.1.2 Increase longevity of dairy cows	Replacement rate	-609	103	-5.924	0.000***
1.1.3 Increase milk production per cow	Milk production per cow (100kg)	406	64	6.312	0.000***
1.2.1 Feed more maize and less grass	Kg maize / kg dry matter total	-113	74	-1.522	0.128
1.2.2 Less crude protein in grass silage	% CP in grass silage	499	707	0.706	0.480
1.2.3 Less crude protein in fresh grass	% CP in fresh grass	-807	787	-1.026	0.305
1.2.4 Less crude protein in concentrates	% CP in concentrates	-606	327	-1.853	0.064*
1.3.1 Grazing	Grazing	3044	1949	1.562	0.119
1.3.2 Grazing by young cattle	Young cattle grazing	830	1817	1.812	0.648
1.4.1 Category 1 - RAV housing systems < 10 NH3 kg per animal place	RAV housing systems < 10 NH3	-4135	5572	-0.742	0.458
1.4.2 Category 2 - RAV housing systems > 10 NH3 kg per animal place	RAV housing systems > 10 NH3	-1157	3312	-0.349	0.727
1.7.2 Manure injection	% of land manure injection	-54	19	-2.850	0.004***

4.2.3 SOCIAL IMPACT

The only quantifiable indicator for the social component is labour, this is also the most important social indicator. Correlation has been checked with a Pearson' correlation matrix, which is presented in table 17 for all the ammonia mitigation measures. The sample size of this model is 677, so all the samples that were included in the economic model, are taken into account.

TABLE 17: CORRELATIONS BETWEEN AMMONIA MITIGATION MEASURES AND LABOUR

Measures	Variables		Annual work units
1.1.1 Reduce young cattle	Heifers per 10 milking cows	Pearson's Correlation	-0.005
		Sig.	0.898
1.1.2 Increase longevity of dairy cows	Replacement rate	Pearson's Correlation	-0.009
		Sig.	0.822
1.1.3 Increase milk production per cow	Milk production per cow (100 kg)	Pearson's Correlation	0.036
		Sig.	0.356
1.2.1 Feed more maize and less grass	Kg maize / kg dry matter total	Pearson's Correlation	-0.081
		Sig.	0.038**
1.2.2 Less crude protein in grass silage	% CP in grass silage	Pearson's Correlation	0.123
		Sig.	0.001***
1.2.3 Less crude protein in pasture grass	% CP in fresh grass	Pearson's Correlation	0.182
		Sig.	0.000***
1.2.4 Less crude protein in concentrates	% CP in concentrates	Pearson's Correlation	-0.025
		Sig.	0.511
1.3.1 Grazing	Grazing	Pearson's Correlation	-0.071
		Sig.	0.065*
1.3.2 Grazing by young cattle	Young cattle grazing	Pearson's Correlation	-0.069
		Sig.	0.074*
1.4.1 Category 1 - RAV housing systems < 10 NH3 kg per animal place	RAV housing systems < 10 NH3	Pearson's Correlation	0.073
		Sig.	0.059*
1.4.2 Category 2 - RAV housing systems > 10 NH3 kg per animal place	RAV housing systems > 10 NH3	Pearson's Correlation	-0.021
		Sig.	0.586
1.7.2 Manure injection	% of arable land manure injected	Pearson's Correlation	-0.067
		Sig.	0.081*

Measures that are associated with a significant reduction of the workload are increasing the portion of maize in the ration, reducing the crude protein content in the grass silage and fresh grass, grazing, young cattle grazing and manure injection. Groups of farmers that have a lower crude protein content in the concentrates and/or that have implemented a RAV housing system in category 1 have a significant higher workload.

4.2.4 SUMMARY OF ALL RESULTS

Table 18 shows a summary with all the conclusions based on the data-analysis, for the ammonia mitigation measures. The same summary can be found in the Excel file, or in appendix I.

TABLE 18: SUMMARY OF DATA-ANALYSIS ON AMMONIA MITIGATION MEASURS

Measures	Environ-mental effect	Economic effect (Model 1)	Economic effect (Model 2)	Social effect
1.1 Productivity				
1.1.1 Reduce young cattle	Not significant	Not significant	Not significant	Not significant
1.1.2 Increase longevity of dairy cows	Not significant	Positive	Positive	Not significant
1.1.3 Increase milk production per cow	Not significant	Positive	Positive	Not significant
1.2 Low protein feed				
1.2.1 Feed more maize and less grass	Positive	Positive	Not significant	Positive
1.2.2 Less crude protein in grass silage	Positive	Not significant	Not significant	Positive
1.2.3 Less crude protein in pasture grass	Positive	Positive	Not significant	Positive
1.2.4 Less crude protein in concentrates	Negative	Positive	Positive	Not significant
1.3 Grazing				
1.3.1 Grazing by dairy cows	Positive	Negative	Not significant	Positive
1.3.2 Grazing by young cattle	Positive	Positive	Not significant	Positive
1.4 Low emission housing systems				
1.4.1 Category 1 - RAV housing systems with < 10 KG NH_3 per animal place	Negative	Not significant	Not significant	Negative
1.4.2 Category 2 - RAV housing systems with > 10 KG NH_3 per animal place	Not significant	Not significant	Not significant	Not significant
1.4.3 Category 3 – Mechanical ventilated system	Not suitable for data-analysis			
1.4.4 Category 4 – Natural ventilated systems	Not suitable for data-analysis			
1.5 Existing stables				
1.5.1 Roof insulation	Not suitable for data-analysis			
1.5.2 ACNV	Not suitable for data-analysis			
1.5.3 Manure dilution in manure cellar	Not suitable for data-analysis			
1.5.4 Manure dilution on walking floors	Not suitable for data-analysis			
1.5.5 Manure sliding	Not suitable for data-analysis			
1.5.6 Manure acidification	Not suitable for data-analysis			
1.6 Manure application grassland				
1.6.1 Manure dilution before application	Not suitable for data-analysis			
1.6.2 Accurate manure disposal	Not suitable for data-analysis			
1.6.3 Manure disposal under favorable weather conditions	Not suitable for data-analysis			
1.7 Manure application arable land				
1.7.1 Incorporation in two rounds	Not suitable for data-analysis			
1.7.2 Manure injection	Positive	Not significant	Negative	Positive

4.3 GREENHOUSE GAS MITIGATION MEASURES

This part follows the same structure as the paragraph 4.2, but for the greenhouse gas mitigation measures.

4.3.1 ENVIRONMENTAL IMPACT

Table 19 presents the environmental impacts for the greenhouse mitigation measures. This correlation matrix compares the sustainability variables and the emissions of CO_2 equivalents per kg milk and checks whether there are correlations between the two. Two samples that were included in the economic model were deleted for this model, leaving 806 samples.

TABLE 19: CORRELATIONS BETWEEN GREENHOUSE GAS MITIGATION MEASURES AND ENVIRONMENTAL IMPACT

Measures	Variables		CO2 equivalents emitted per kg milk
2.1.1 Reduce young cattle	Heifers per 10 milking cows	Pearson's Correlation	0.182
		Sig.	0.000***
2.1.2 Increase longevity of dairy cows	Replacement rate	Pearson's Correlation	0.026
		Sig.	0.468
2.1.3 Increase milk production per cow	Milk production per cow (100kg)	Pearson's Correlation	-0.606
		Sig.	0.000***
2.2.1 Increase feed conversion efficiency	Kg dry matter / milk production	Pearson's Correlation	0.658
		Sig.	0.000***
2.2.2 Feed more maize and less grass	Kg maize / kg dry matter total	Pearson's Correlation	-0.401
		Sig.	0.000***
2.2.3 Feed more fresh grass and less grass silage	Kg fresh grass / grass total	Pearson's Correlation	0.179
		Sig.	0.000***
2.2.7 Use of wet by-products	Kg wet by-products / kg dry matter total	Pearson's Correlation	0.032
		Sig.	0.362
2.4.1 Use of grass-clover	% of clover	Pearson's Correlation	-0.009
		Sig.	0.789
2.4.4 Lower fertilizer gift of N	Nitrogen / ha UUA	Pearson's Correlation	0.119
		Sig.	0.001***
2.4.6 Cultivate concentrate substitutes	Ha concentrate substitutes / ha UUA	Pearson's Correlation	-0.173
		Sig.	0.057*
2.5.1 Solar panels	Solar panels: yes/no	Pearson's Correlation	-0.117
		Sig.	0.001***
2.5.6 Optimal usage of electricity	MJ use other energy / 1000	Pearson's Correlation	-0.067
		Sig.	0.057*
2.5.7 Reduce diesel consumption	MJ fuel machinery and contract work / 1000	Pearson's Correlation	-0.071
		Sig.	0.043**
2.6.2 Reduce grassland renewal	% of grassland renewed	Pearson's Correlation	-0.020
		Sig.	0.579

This model shows that many mitigation measures have a significant correlation with the CO_2 emissions. This holds for the reduction of young cattle, increasing the milk production per cow, improving the feed conversion efficiency, feeding more maize, lowering the fertilizer gift of N, the cultivation of concentrate substitutes and solar panels. Feeding more fresh grass and optimal usage of electricity and diesel show an negative correlation with the carbon dioxide emissions. The other correlations were not significant.

4.3.2 ECONOMIC IMPACT

Fourteen measures that are aiming to mitigate GHG emissions were suitable for data-analysis. However, the Pearson's Correlation Test showed a correlation of 0.668 between the fuel use and the energy use. Therefore, fuel use has been picked for continuation in this research, the conclusion for the use of energy will be the same as the conclusion for the use of fuel. Thirteen measures remained suitable for data-analysis. The outcomes of the model are presented in table 20, table 21 shows the ANOVA-table.

TABLE 20: MULTIPLE MEASURES MODEL FOR GREENHOUSE GAS MITIGATION MEASURES

N					808
Adjusted R^2					0.458
Measures	**Variables**	**B**	**Standard error**	**t**	**Sig.**
	(Constant)	-150566	89934	-1.674	0.094
Size	Ha utilized agricultural area	1270	155	8.187	0.000***
	Dairy cows	515	86	6.015	0.000***
	Annual work units	-3045	2155	-1.413	0.158
Characteristics entrepreneur	Age main decision maker	-178	321	-0.556	0.579
	Education	-14746	5110	-2.886	0.004***
	Successor	-7208	5935	-1.214	0.225
Soil type	Soil type: sand	Dummy variable taken out of analysis			
	Soil type: clay	-37804	6724	-5.623	0.000***
	Soil type: peat	-2605	9790	-0.266	0.790
	Soil type: loess	-20387	11513	-1.771	0.077*
Years	Year: 2011	Dummy variable taken out of analysis			
	Year: 2012	-29003	10025	-2.893	0.004***
	Year: 2013	-6820	9951	-0.685	0.493
	Year: 2014	-5280	9680	-0.545	0.586
	Year: 2015	-44175	9676	-4.621	0.000***
	Year: 2016	-57368	9350	-6.135	0.000***
2.1.1 Reduce young cattle	Heifers per 10 milking cows	1806	2784	0.649	0.517
2.1.2 Increase longevity of dairy cows	Replacement rate	-1795	350	-5.123	0.000***
2.1.3 Increase milk production per cow	Milk production per cow (100kg)	2112	475	4.451	0.000***
2.2.1 Increase feed conversion efficiency	Kg dry matter / milk production	550	525	1.048	0.295
2.2.2 Feed more maize and less grass	Kg maize / kg dry matter total	-114	188	-0.608	0.544
2.2.3 Feed more fresh grass and less grass silage	Kg fresh grass / kg grass total	1152	297	3.877	0.000***
2.2.7 Use of wet by-products	Kg wet by-products / kg dry matter total	-157	650	-0.241	0.810
2.4.1 Use of grass-clover	% of clover	-157	599	-0.262	0.793
2.4.4 Lower fertilizer gift of N	Nitrogen / ha UUA	59	47	1.242	0.215
2.4.6 Cultivation of concentrate substitutes	Ha concentrate substitutes / ha UUA	-149	1348	-0.110	0.912
2.5.1 Solar panels	Solar panels: yes/no	-11842	6623	-1.788	0.074*
2.5.7 Reduce diesel consumption	MJ fuel machinery and contract work / 1000	-236	24	-10.001	0.000***
2.6.2 Reduce grassland renewal	% of grassland renewal	282	196	1.442	0.150

TABLE 21: ANOVA TABLE FOR GREENHOUSE GAS MITIGATION MEASURES MODEL

	Sum of Square	df	Mean Square	F	Sig.
Regression	3.305E+12	27	1.224E+11	21.137	0.000
Residual	3.641E+12	779	4674346498		
Total	6.947E+12	807			

The effects given in the following paragraph are different for any farm, but this is an overview for the conclusions based on the 808 samples that were investigated in this model. For the GHG mitigation measures, this model gives the following conclusions.

- Farms that have a lower replacement rate are typically more profitable compared to their peers. Decreasing the replacement rate by 1% is associated with a €1795 gain on the margin of the farm.
- Farms that have a high milk production per cow are more profitable. Increasing the milk production per cow by 100 litres can give €2112 additional profit.
- Farmers that feed relatively more fresh grass than grass silage are more profitable. Increasing the portion of fresh grass by 1% can lead to an additional profit of €1152.
- Farms that have solar panels installed are less profitable compared to their peers. If solar panels are installed, the net result lowers with €11842.
- Farmers that have a lower energy usage are more profitable. Reducing the fuel usage by 1000 MJ leads to €236 additional profit. This also holds for electricity use.

The remaining measures do not have a significant outcome.

Table 22 contains the outcomes of the single measures model per measures.

TABLE 22: SINGLE MEASURES MODEL FOR GREENHOUSE GAS MITIGATION MEASURES

Measure	**Variable**	**B**	**Standard error**	**t**	**Sig.**
2.1.1 Reduce young cattle	Heifers per 10 milking cows	-1282	786	-1.631	0.103
2.1.2 Increase longevity of dairy cows	Replacement rate	-609	103	-5.924	0.000***
2.1.3 Increase milk production per cow	Milk production per cow (100kg)	406	64	6.312	0.000***
2.2.1 Feed more maize and less grass	Kg dry matter/ kg milk prod.	-160	122	-1.305	0.192
2.2.2 Increase feed conversion efficiency	Kg maize / kg dry matter total	-113	74	-1.522	0.128
2.2.3 Feed more fresh grass and less grass silage	Kg fresh grass / kg total grass	508	128	3.952	0.000***
2.2.7 Use of wet by-products	Wet by-products	434	299	1.451	0.147
2.4.1 Use of grass-clover	% of clover	-167	168	-0.992	0.321
2.4.4 Lower fertilizer gift of N	Kg nitrogen fertilized per ha	20	12	1.712	0.087*
2.4.6 Cultivate concentrate substitutes	% of hectares of concentrate substitutes	-411	343	-1.198	0.231
2.5.1 Solar panels	Solar panels	4341	2310	1.879	0.060*
2.5.6 Optimal usage of electricity	MJ electricity use (x1000)	-3	4	-0.757	0.449
2.5.7 Reduce diesel consumption	MJ fuel and contract work (x1000)	15	2	6.258	0.000***
2.6.2 Reduce grassland renewal	% of grassland renewed	38	77	0.490	0.624

4.3.3 SOCIAL IMPACT

The next table, table 23, presents the correlations for the measures related to greenhouse gas measures and the annual work units required for that farm. All 808 samples that were investigated in the previous models, are included.

TABLE 23: CORRELATIONS BETWEEN GREENHOUSE GAS MITIGATION MEASURES AND LABOUR

Measures	Variables		Annual work units
2.1.1 Reduce young cattle	Heifers per 10 milking cows	Pearson's Correlation	-0.017
		Sig.	0.620
2.1.2 Increase longevity of dairy cows	Replacement rate	Pearson's Correlation	0.015
		Sig.	0.674
2.1.3 Increase milk production per cow	Milk production per cow (100kg)	Pearson's Correlation	0.003
		Sig.	0.939
2.2.1 Increase feed conversion efficiency	Kg dry matter / milk production	Pearson's Correlation	0.004
		Sig.	0.899
2.2.2 Feed more maize and less grass	Kg maize / kg dry matter total	Pearson's Correlation	-0.060
		Sig.	0.089*
2.2.3 Feed more fresh grass and less grass silage	Kg fresh grass / grass silage	Pearson's Correlation	-0.152
		Sig.	0.000***
2.2.7 Use of wet by-products	Kg wet by-products / kg dry matter total	Pearson's Correlation	0.144
		Sig.	0.000***
2.4.1 Use of grass-clover	% of clover	Pearson's Correlation	-0.004
		Sig.	0.900
2.4.4 Lower fertilizer gift of N	Nitrogen / ha UUA	Pearson's Correlation	0.118
		Sig.	0.001***
2.4.6 Cultivate concentrate substitutes	Ha concentrate substitutes / ha UUA	Pearson's Correlation	-0.046
		Sig.	0.189
2.5.1 Solar panels	Solar panels: yes/no	Pearson's Correlation	0.020
		Sig.	0.577
2.5.6 Optimal usage of electricity	(MJ use other energy / 1000) / total milk production	Pearson's Correlation	0.123
		Sig.	0.000***
2.5.7 Reduce diesel consumption	(MJ fuel machinery and contract work / 1000) / total milk production	Pearson's Correlation	0.076
		Sig.	0.025**
2.6.2 Reduce grassland renewal	% of grassland renewed	Pearson's Correlation	0.097
		Sig.	0.006***

Mitigation measures that are implemented on farms with a lower workload are increasing the portion of maize, increasing the amount fresh grass compared to grass silage, feeding wet by-products, lowering the fertilized gift of N and reduce the percentage of grassland renewed. Measures that have are associated with a negative impact on labour required are the cultivation of wet by-products and the optimal usage of electricity and diesel.

4.3.4 Summary of all results

Table 24 summarizes all the results that were presented in this chapter for the greenhouse gas measures. The same summary can be found in the Excel file, or in appendix I.

TABLE 24: SUMMARY OF ALL THE IMPACTS OF THE GREENHOUSE GAS MITIGATION MEASURES

Measures	Environ-mental effect	Economic effect (Model 1)	Economic effect (Model 2)	Social effect
2.1 Productivity				
2.1.1 Reduce young cattle	Positive	Not significant	Not significant	Not significant
2.1.2 Increase longevity of dairy cows	Not significant	Positive	Positive	Not significant
2.1.3 Increase milk production per cow	Positive	Positive	Positive	Not significant
2.2 Feed				
2.2.1 Improve feed conversion efficiency	Positive	Not significant	Not significant	Not significant
2.2.2 Feed more maize and less grass	Positive	Not significant	Not significant	Positive
2.2.3 Feed more fresh grass and less grass silage	Negative	Positive	Positive	Positive
2.2.4 Improve digestibility of grass	Not suitable for data-analysis			
2.2.5 Feed additives	Not suitable for data-analysis			
2.2.6 Concentrates with lower footprint	Not suitable for data-analysis			
2.2.7 Use of wet by-products	Not significant	Not significant	Not significant	Positive
2.3 Manure storage				
2.3.1 Methane oxidation	Not suitable for data-analysis			
2.3.2 Manure acidification	Not suitable for data-analysis			
2.3.3 Manure fermentation	Not suitable for data-analysis			
2.3.4 Improve digestibility of grass	Not suitable for data-analysis			
2.3.5 Decrease manure temperature	Not suitable for data-analysis			
2.4 Crop and fertilization				
2.4.1 Use of grass-clover	Not significant	Not significant	Not significant	Not significant
2.4.2 Nitrification inhibitors	Not suitable for data-analysis			
2.4.3 Precision application of fertilizer	Not suitable for data-analysis			
2.4.4 Lower fertilizer gift of N	Positive	Not significant	Negative	Positive
2.4.5 Footprint chemical fertilizer	Not suitable for data-analysis			
2.4.6 Cultivation of concentrate substitutes	Positive	Not significant	Not significant	Not significant
2.5 Energy				
2.5.1 Solar panels	Positive	Negative	Positive	Not significant
2.5.2 Windmills	Not suitable for data-analysis			
2.5.3 Heat recovery	Not suitable for data-analysis			
2.5.4 Pre-cooler	Not suitable for data-analysis			
2.5.5 LED-lightning	Not suitable for data-analysis			
2.5.6 Optimal usage of electricity	Negative	Positive	Not significant	Negative
2.5.7 Reduce diesel consumption	Negative	Positive	Negative	Negative
2.5.8 Biodiesel	Not suitable for data-analysis			
2.6 Land				
2.6.1 Not ploughing permanent grassland	Not suitable for data-analysis			
2.6.2 Reduce grassland renewal	Not significant	Not significant	Not significant	Positive
2.6.3 Catch crops and green manures	Not suitable for data-analysis			
2.6.4 Drainage in peat areas	Not suitable for data-analysis			
2.6.5 Non-inversion tillage	Not suitable for data-analysis			
2.6.6 More grass in crop rotation plan	Not suitable for data-analysis			

5. CONCLUSION

This research provided an overview of the economic performance of sustainability measures proposed by the Sustainable Dairy Chain, but also on the environmental and social effects. This chapter presents the main conclusions of this research. In appendix VI all the conclusions are presented in the form of a table per measure.

PROFITABLE MEASURES

Sustainability measures that are profitable serve two causes, as these are profitable for the farmer and advantageous to the environment. It is hypothesized by previous studies that a numerous amount of measures proposed by the SDC are profitable. This includes measures related to productivity, different feeding strategies, grazing, different manure application on the grassland and saving electricity. Various single measures are also hypothesized to be profitable.

The data analysis of this research, that had a slightly different interpretation than the literature review, showed some of these effects as well. Measures related to productivity definitely contribute to economic sustainability. Different feeding strategies also came out positively. More optimal usage of energy turned out to be a good cost saving mitigation strategy. Farms that practice young cattle grazing are more profitable than farms that do not, but farms that practice grazing by dairy cows are less profitable than farms that do not. Some more explanation on this can be found in the discussion chapter. Not all measures could be investigated during the data-analysis.

LOSS-MAKING MEASURES

Some measures are were hypothesized as loss-making in the literature review. Mitigation strategies that are related to building new stables with a RAV-housing system or making adaptions in the existing stable that are beneficial to environmental causes, are loss-making according to the literature. Measures that are related focus on reducing the emissions from manure storage also appear to reduce the profitability of dairy farms. Some single measures are also loss-making, such as nitrification inhibitors, cultivation of concentrate substitutes and feed additives.

The data-analysis did not result in many loss-making measures. A lot of the measures that were hypothesized to be loss-making could not be included in the data-analysis, because of various reasons. This might be due to the fact that these mitigation measures are less developed and therefore less data is available. The only negative economic impact recorded were found in grazing by dairy cows and the use of solar panels.

ENVIRONMENTAL IMPACTS

When investing in sustainability measures it should be considered what the impact is on the environment. Measures related to grazing, new housing systems, adaptions in existing stables and manure storage were hypothesized to have a high overall impact. The data-analysis showed many measures were associated with lower emissions on the farms on which they were implemented. Changing diets, lowering the amount of N fertilized and cultivation of concentrate substitutes came out very positive as well in this data-analysis. Investing in these measures will lead to the highest environmental benefits. Measures that only have a low impact, should be placed on the bottom of the priority list if the environment is the most important indicator to consider.

SOCIAL IMPACTS

This research only focused on the social impacts for the farmer, this does not overarch the complete definition of social sustainability as presented in the theoretical framework. However, for this research it is more appropriate since it is more focused on the farmers' life. It would be fair to assume that one finds the social impacts on own life most important. To be truly socially sustainable, the other social impacts should be taken into account as well. For the data-analysis, only the most important indicator was taken into consideration, this is labour.

Most sustainability measures require some extra work, where just some reduce the workload on the entrepreneur. Some measures have an impact on the administrative burden and/or safety of the persons on the farm. Unfortunately, it was not possible to assess the social impact for many sustainability measures, because there was not sufficient literature available on this. Reducing the amount of heifers/increasing the longevity, increasing the portion of maize in the ration and some measures relating to land cultivation were hypothesized to be positive for social indicators. The majority was assessed to be negative or information was unavailable.

The data-analysis showed significant positive results on workload required for changing feeding strategies, grazing, lowering the fertilizer gift of N and reduction of grassland renewal. Productivity measures resulted in insignificant results.

6. DISCUSSION

This research concludes that sustainability measures aiming to mitigate ammonia and greenhouse gases all have different effects on environmental, economic and social indicators. For all 65 measures it has been attempted to find the environmental, economic and social impact after implementation of and/or better performance at the mitigation strategies.

The literature review, results and conclusion chapters presented which impacts are aligned to the measures. Only the measures focused on ammonia and greenhouse gas reduction were selected for this research, because otherwise the number of measures would be too large and the required depth in this research would not be achieved. Because ammonia emission and greenhouse gas emission reduction are vital for the future of the dairy industry and heavily debated items nowadays, these two themes were selected in consultation with Wageningen Economic Research.

The main limitation for the literature review was the unavailability of scientific research for some variables, especially for the social sustainability elements. There is not much known on the influences of sustainability measures on labour, administrative burden and safety. On the other side, if the measure has a big influence on one of these three, it is often indicated in literature. This means that if the conclusions are indicated as unknown, it is safe to assume that the effects of these indicators are minimal.

One important element to keep in mind when comparing the results from the literature review and the data-analysis is that the interpretation of the impact is different. Most scientists that research sustainability measures focus on a few farms on which a measure is implemented, or management changes during the research. In this way, keeping all other variables constant, the difference between the situation before implementation and the situation after implementation can be compared. Causal relationships can be determined with these methodologies. This means that the conclusions on the literature review are based on the differences before and after implementation or change in management, keeping all other variables constant for a few samples.

The data-analysis should be interpreted differently. It is impossible to keep all other variables constant for 2204 samples that are spread over six years. There are many influences that have an impact on the result. Variables that definitely have an influence were included in the model(s), such as size, entrepreneurial characteristics, year and soil type. However, these variables do not explain all the variation except for the variation caused by the sustainability measures. No conclusions based on causal relationships can be drawn from this data-analysis. Specified groups based on the sustainability measures are compared on their profitability.

If, for instance, the economic impact is positive based on the data-analysis, it means that the conclusion is as follows: farmers that have implemented measure X/perform better on measure X are more profitable compared to farmers that have no implemented measure X/perform worse on measure X. This holds for either the multiple regression analyses that investigated the economic impact and the correlation matrices that analysed the environmental and social impact. The coefficients in the economic models, and the correlations in the other models are comparisons between farms that did and did not implement measures. It cannot be concluded that after the implementation a X number of euro’s in increase or decrease that is represented by the coefficient is reached.

The unequal conclusions for grazing by dairy cows in the literature and data-analysis is caused by difference in interpretation and these both require some explanation. Most scientists agree that grazing is profitable, but the data-analysis gave a significant negative result. Gies et al. (2014) state that more greater farms are less likely to practice grazing, these are often the most profitable farms. This statement confirms both the conclusions from the literature review and data-analysis. Grazing on itself is profitable, however farms that do not practice grazing are more profitable than farms that do not practice grazing.

In comparing the results from the literature review and the data-analysis on the social indicators it should be considered that in the data-analysis only the indicator 'labour' is taken in to account. This is was due to the fact that the other two indicators were not quantifiable and there was no data available on this in the BIN-dataset. They were also of lesser importance than labour requirements.

Another limitation of this research is the great reduction in sample size after taking out all the missing variables and outliers. It sure had an influence on the data-analysis. The total samples available was 2204, the samples used were 677 in the ammonia mitigation measures model and 808 in the greenhouse gases mitigation model. This was caused by the great amount of outliers and missing values in the data-analysis.

The situation of farmers is different around the world due to many variables such as climate and production systems and methods. That is why not all conclusions in this research can be generalized for all dairy production systems around the world. One should consider the production system in the country to research, to see whether the conclusions can be taken over from this research.

NEXT STEPS & FURTHER RESEARCH

This research only focused on ammonia emission mitigation measures and greenhouse gas mitigation emission measures, but the same research could be conducted for the other themes. These themes also bring proposed mitigation strategies along which can be researched in the same way. The type of research can be reproduced for other measures, and the same outcomes could be expected if reproduced for the same sets of measures.

Next steps after this research are in the hands of Wageningen Economic Research and Sustainable Dairy Chain. In communication to policy makers from both governments and dairy processors they can use this research to assess how to communicate and fill in rewarding systems and laws towards dairy farmers. The most ideal way would be if rewards policies would promote measures that are economically beneficial as such, whereas farmers that invest in measures that will cost them money will be rewarded for their contribution to the targets that the dairy industry set.

It is important that all the three impacts together are considered in communication to farmers, because mitigation measures that do not have a large impact on emissions are of lesser importance compared to measures that have large mitigation potential. This, in combination with the economic and social benefits or losses needs to be communicated to entrepreneurs. In this way they can make a weighted decision.

Next to that, mitigation measures that are loss-making, especially those with a high mitigation potential, might be further studied. Certain technologies that are further developed, or potential new revenue models can help to turn loss-making measures into measures that are beneficial, without the use of subsidies or rewarding systems.

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Appendices

Appendix I – Excel overall overview

Literature review				
1. Ammonia	**Measure**	**Environmental impact**	**Economic impact**	**Social impact**
1.1 Productivity	1.1.1 Reduce young cattle	Average	Positive	Positive
1.1 AMM - Productivity	1.1.2 Increase longevity of dairy cows	Average	Positive	Positive
	1.1.3 Increase milk production per cow	High	Positive	Negative
1.2 Low protein feed	1.2.1 Feed more maize and less grass	Average	Break-even	Positive
1.2 AMM - Low protein feed	1.2.2 Less crude protein in grass silage	Average	Positive	Unknown
	1.2.3 Less crude protein in pasture grass	Dependent	Unknown	Unknown
	1.2.4 Less crude protein in concentrates	Average	Positive	Unknown
1.3 Grazing	1.3.1 Grazing by dairy cows	High	Positive	Dependent
1.3 AMM - Grazing	1.3.2 Grazing by young cattle	High	Positive	Unknown
1.4 Low emission housing systems	1.4.1 Category 1 - RAV housing systems with < 1	High	Negative	Unknown
1.4 AMM - Low e. housing system'!A1	1.4.2 Category 2 - RAV housing systems with > 1	High	Negative	Unknown
	1.4.3 Category 3 - Mechanical ventilated system	High	Negative	Unknown
	1.4.4 Category 4 - Natural ventilated systems	High	Negative	Unknown
1.5 Existing stables	1.5.1 Roof insulation	Low	Unknown	Negative
1.5 AMM - Existing stables	1.5.2 ACNV	Average	Negative	Unknown
	1.5.3 Manure dilution in manure cellar	High	Negative	Negative
	1.5.4 Manure dilution on walking floors	High	Negative	Negative
	1.5.5 Manure sliding	Unknown	Negative	Unknown
	1.5.6 Manure acidification	High	Negative	Negative
1.6 Manure application grassland	1.6.1 Manure dilution before application	High	Positive	Unknown
1.6 AMM - Manure grassland	1.6.2 Accurate manure disposal	Average	Positive	Unknown
	1.6.3 Manure disposal under favorable weather (	Average	Positive	Unknown
1.7 Manure application arable land	1.7.1 Incorporation in two rounds	Average	Negative	Unknown
1.7 AMM - Manure arable land	1.7.2 Manure injection	High	Unknown	Unknown

2. Greenhouse gases				
2.1 Productivity	2.1.1 Reduce young cattle	Average	Positive	Positive
2.1 GHG - Productivity	2.1.2 Increase longevity of dairy cows	Average	Positive	Positive
	2.1.3 Increase milk production per cow	Dependent	Positive	Negative
2.2 Feed	2.2.1 Improve feed conversion efficiency	Average	Positive	Negative
2.2 GHG - Feed	2.2.2 Feed more maize and less grass	Average	Break-even	Positive
	2.2.3 Feed more fresh grass and less grass silage	Average	Positive	Negative
	2.2.4 Improve digestibility of grass	Average	Positive	Negative
	2.2.5 Feed additives	High	Negative	Negative
	2.2.6 Concentrates with lower footprint	High	Dependent	Unknown
	2.2.7 Use of wet by-products	Low	Dependent	Negative
2.3 Manure storage	2.3.1 Methane oxidation	High	Negative	Negative
2.3 GHG - Manure storage	2.3.2 Manure acidification	High	Negative	Negative
	2.3.3 Manure fermentation	High	Negative	Negative
	2.3.4 Manure separation	Average	Positive	Negative
	2.3.5 Decrease manure temperature	Average	Unknown	Negative
2.4 Crop and fertilization	2.4.1 Use of grass-clover	Average	Negative	Unknown
2.4 GHG - Crop and Fertilizing	2.4.2 Nitrification inhibitors	Average	Negative	Negative
	2.4.3 Precision application of fertilizer	Average	Break-even	Negative
	2.4.4 Lower fertilizer gift of N	High	Positive	Unknown
	2.4.5 Footprint chemical fertilizer	Average	Dependent	Unknown
	2.4.6 Cultivation of concentrate substitutes	Unknown	Negative	Negative
2.5 Energy	2.5.1 Solar panels	Average	Dependent	Negative
2.5 GHG - Energy	2.5.2 Windmills	High	Positive	Unknown
	2.5.3 Heat recovery	Low	Positive	Unknown
	2.5.4 Pre-cooler	Low	Positive	Unknown
	2.5.5 LED-lightning	Average	Dependent	Unknown
	2.5.6 Optimal usage of electricity	Low	Positive	Negative
	2.5.7 Reduce diesel consumption	Low	Positive	Negative
	2.5.8 Biodiesel	Low	Dependent	Unknown
2.6 Land	2.6.1 Not ploughing permanent grassland	Dependent	Dependent	Positive
2.6 GHG - Land	2.6.2 Reduce grassland renewal	Average	Positive	Positive
	2.6.3 Catch crops and green manures	Low	Dependent	Negative
	2.6.4 Drainage in peat areas	Dependent	Break-even	Negative
	2.6.5 Non-inversion tillage	Unknown	Positive	Positive
	2.6.6 More grass in crop rotation plan	Unknown	Break-even	Negative

Data-analysis

1. Ammonia	Measure	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact (data)
1.1 Productivity	1.1.1 Reduce young cattle	Not significant	Not significant	Not significant	Not significant
1.1 AMM - Productivity	1.1.2 Increase longevity of dairy cows	Not significant	Positive	Positive	Not significant
	1.1.3 Increase milk production per cow	Not significant	Positive	Positive	Not significant
1.2 Low protein feed	1.2.1 Feed more maize and less grass	Positive	Positive	Not signicant	Positive
1.2 AMM - Low protein feed	1.2.2 Less crude protein in grass silage	Positive	Not significant	Not signicant	Positive
	1.2.3 Less crude protein in pasture grass	Positive	Positive	Not signicant	Positive
	1.2.4 Less crude protein in concentrates	Negative	Positive	Positive	Not significant
1.3 Grazing	1.3.1 Grazing by dairy cows	Positive	Negative	Not significant	Positive
1.3 AMM - Grazing	1.3.2 Grazing by young cattle	Positive	Positive	Not significant	Positive
1.4 Low emission housing systems	1.4.1 Category 1 - RAV housing systems with < 10 KG NH_3	Negative	Not significant	Not significant	Negative
1.4 AMM - Low e. housing system'!A1	1.4.2 Category 2 - RAV housing systems with > 10 KG NH_3	Not significant	Not significant	Not significant	Not significant
	1.4.3 Category 3 - Mechanical ventilated system	Not suitable for data-analysis			
	1.4.4 Category 4 - Natural ventilated systems	Not suitable for data-analysis			
1.5 Existing stables	1.5.1 Roof insulation	Not suitable for data-analysis			
1.5 AMM - Existing stables	1.5.2 ACNV	Not suitable for data-analysis			
	1.5.3 Manure dilution in manure cellar	Not suitable for data-analysis			
	1.5.4 Manure dilution on walking floors	Not suitable for data-analysis			
	1.5.5 Manure sliding	Not suitable for data-analysis			
	1.5.6 Manure acidification	Not suitable for data-analysis			
1.6 Manure application grassland	1.6.1 Manure dilution before application	Not suitable for data-analysis			
1.6 AMM - Manure grassland	1.6.2 Accurate manure disposal	Not suitable for data-analysis			
	1.6.3 Manure disposal under favorable weather condition	Not suitable for data-analysis			
1.7 Manure application arable land	1.7.1 Incorporation in two rounds	Not suitable for data-analysis			
1.7 AMM - Manure arable land	1.7.2 Manure injection	Positive	Not significant	Negative	Not significant

2. Greenhouse gases		Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact (data)
2.1 Productivity	2.1.1 Reduce young cattle	Positive	Not significant	Not significant	Not significant
2.1 GHG - Productivity	2.1.2 Increase longevity of dairy cows	Not significant	Positive	Positive	Not significant
	2.1.3 Increase milk production per cow	Positive	Positive	Positive	Not significant
2.2 Feed	2.2.1 Improve feed conversion efficiency	Positive	Not significant	Not significant	Not significant
2.2 GHG - Feed	2.2.2 Feed more maize and less grass	Positive	Not significant	Not significant	Positive
	2.2.3 Feed more fresh grass and less grass silage	Negative	Positive	Positive	Positive
	2.2.4 Improve digestibility of grass	Not suitable for data-analysis			
	2.2.5 Feed additives	Not suitable for data-analysis			
	2.2.6 Concentrates with lower footprint	Not suitable for data-analysis			
	2.2.7 Use of wet by-products	Not significant	Not significant	Not significant	Positive
2.3 Manure storage	2.3.1 Methane oxidation	Not suitable for data-analysis			
2.3 GHG - Manure storage	2.3.2 Manure acidification	Not suitable for data-analysis			
	2.3.3 Manure fermentation	Not suitable for data-analysis			
	2.3.4 Manure separation	Not suitable for data-analysis			
	2.3.5 Decrease manure temperature	Not suitable for data-analysis			
2.4 Crop and fertilization	2.4.1 Use of grass-clover	Not significant	Not significant	Not significant	Not significant
2.4 GHG - Crop and Fertilizing	2.4.2 Nitrification inhibitors	Not suitable for data-analysis			
	2.4.3 Precision application of fertilizer	Not suitable for data-analysis			
	2.4.4 Lower fertilizer gift of N	Positive	Not significant	Negative	Positive
	2.4.5 Footprint chemical fertilizer	Not suitable for data-analysis			
	2.4.6 Cultivation of concentrate substitutes	Positive	Not significant	Not significant	Negative
2.5 Energy	2.5.1 Solar panels	Positive	Negative	Positive	Not significant
2.5 GHG - Energy	2.5.2 Windmills	Not suitable for data-analysis			
	2.5.3 Heat recovery	Not suitable for data-analysis			
	2.5.4 Pre-cooler	Not suitable for data-analysis			
	2.5.5 LED-lightning	Not suitable for data-analysis			
	2.5.6 Optimal usage of electricity	Negative	Positive	Not significant	Negative
	2.5.7 Reduce diesel consumption	Negative	Positive	Negative	Negative
	2.5.8 Biodiesel	Not suitable for data-analysis			
2.6 Land	2.6.1 Not ploughing permanent grassland	Not suitable for data-analysis			
2.6 GHG - Land	2.6.2 Reduce grassland renewal	Not significant	Not significant	Not significant	Positive
	2.6.3 Catch crops and green manures	Not suitable for data-analysis			
	2.6.4 Drainage in peat areas	Not suitable for data-analysis			
	2.6.5 Non-inversion tillage	Not suitable for data-analysis			
	2.6.6 More grass in crop rotation plan	Not suitable for data-analysis			

Appendix II – Excel sheet per category

Ammonia - Production

Literature review	1.1.1	1.1.2	1.1.3
Environment			
NH_3 emission reduction per KG milk	Average	Average	High
Economy			
Change in revenues			
Milk	+	+	+
Sales of animals	-	-	-
Remaining	+		
Change in allocated costs			
(Purchased) roughage	-	-	+
Concentrates	-	-	+
Animals	-	-	+
Crop			
Change in non-allocated costs			
Contractor	-	-	+
Machines and installations			
Ground and buildings			
Water and energy	-	-	
Manure disposal	-	-	+
Remaining		-	
Total	Positive	Positive	Positive
Social			
Labour	+	±	-
Administrative burden	+	+	
Safety			
Overall	Positive	Positive	Negative

Data-analysis	1.1.1	1.1.2	1.1.3
Environmental model			
Pearson's Correlation	-0.055	0.033	0.042
Significance	0.162	0.410	0.290
Conclusion	Not significant	Not significant	Not significant
Multiple measure model			
Beta-coefficient	2336	-1594	1003
Standard error	2449	368	256
T-statistic	0,954	-4,324	3,909
Significance	0,341	0.000***	0.000***
Conclusion	Not significant	Positive	Positive
Single measure model			
Beta-coefficient	-1282	-609	406
Standard error	786	103	64
T-statistic	-1,631	-5,924	6,312
Significance	0,103	0.000***	0.000***
Conclusion	Not significant	Positive	Postive
Social model			
Pearson's Correlation	-0.005	-0.009	0.036
Significance	0.898	0.822	0.356
Conclusion	Not significant	Not significant	Not significant

Ammonia – Low protein feed

Literature review	1.2.1	1.2.2	1.2.3	1.2.4
Environment				
NH_3 emission per LU	Average	Average	Dependent*	Average
Economy				
Change in revenues				
Milk	±	±	±	±
Sales of animals				
Remaining				
Change in allocated costs				
(Purchased) roughage	±	-		
Concentrates	+	+	+	-
Animals				
Crop	-	±	-	-
Change in non-allocated costs				
Contractor	+	-		-
Machines and installations		-		
Ground and buildings				
Water and energy				
Manure disposal				
Remaining				
Total	Break-even	Positive	Unknown	Positive
Social				
Labour	+	±	±	
Administrative burden				
Safety				
Overall	Positive	Unknown	Unknown	Unknown

* Environmental impact of measure 1.2.3 depends on grazing time or pasture grass in the ratio

Data-analysis	1.2.1	1.2.2	1.2.3	1.2.4
Environmental model				
Pearson's Correlation	-0.486	0.200	0.212	-0.315
Significance	0.000***	0.000***	0.000***	0.000***
Conclusion	Positive	Positive	Positive	Negative
Multiple measure model				
Beta-coefficient	374	5727	-7312	-2172
Standard error	192	4074	3795	880
T-statistic	1,943	1,405	-1,972	-2,466
Significance	0.052*	0,16	0.054*	0.014**
Conclusion	Positive	Not significant	Positive	Positive
Single measure model				
Beta-coefficient	-113	499	-807	-606
Standard error	74	707	787	327
T-statistic	-1,522	0,706	-1,026	-1,853
Significance	0,128	0,48	0,305	0.064*
Conclusion	Not significant	Not significant	Not significant	Positive
Social model				
Pearson's Correlation	-0.081	0.123	0.182	0.025
Significance	0.038**	0.001***	0.000***	0.511
Conclusion	Positive	Positive	Positive	Not significant

Ammonia – Grazing

Literature review	1.3.1	1.3.2
Environment		
NH_3 emission per LU	High	High
Economy		
Change in revenues		
Milk	+	
Sales of animals		
Remaining		
Change in allocated costs		
(Purchased) roughage	+	+
Concentrates	-	-
Animals		
Crop		
Change in non-allocated costs		
Contractor	-	-
Machines and installations		
Ground and buildings		
Water and energy		
Manure disposal	-	-
Remaining		
Total	Positive	Positive
Social		
Labour	±	-
Administrative burden		
Safety		
Overall	Dependent*	Unknown

* Social impact of measure 1.3.1 depends on system that is used

Data-analysis	1.3.1	1.3.2
Environmental model		
Pearson's Correlation	-0.181	-0.170
Significance	0.000***	0.000***
Conclusion	Positive	Positive
Multiple measure model		
Beta-coefficient	-29371	20854
Standard error	10850	6609
T-statistic	-2,707	3,155
Significance	0.007***	0.002***
Conclusion	Negative	Positive
Single measure model		
Beta-coefficient	3044	830
Standard error	1949	1817
T-statistic	1,562	1,812
Significance	0,119	0,648
Conclusion	Not significant	Not significant
Social model		
Pearson's Correlation	-0.071	-0.069
Significance	0.065*	0.074*
Conclusion	Positive	Positive

Ammonia – Low emission housing systems

Literature review	1.4.1	1.4.2	1.4.3	1.4.4
Environment				
NH_3 emission per LU	High*	High*	High*	High*
Economy				
Change in revenues				
Milk				
Sales of animals				
Remaining				
Change in allocated costs				
(Purchased) roughage				
Concentrates				
Animals				
Crop				
Change in non-allocated costs				
Contractor				
Machines and installations				
Ground and buildings				
Water and energy				
Manure disposal				
Remaining				
Total	Negative*	Negative*	Negative*	Negative*
Social				
Labour				
Administrative burden				
Safety				
Overall	Unknown*	Unknown*	Unknown*	Unknown*

* Hypotheses based on own interpretation because of artificial grouping

Data-analysis	1.4.1	1.4.2
Environmental model		
Pearson's Correlation	0.096	0.057
Significance	0.015**	0.149
Conclusion	Negative	Not significant
Multiple measure model		
Beta-coefficient	-26510	-11618
Standard error	18475	12126
T-statistic	-1,435	-0,958
Significance	0,152	0,338
Conclusion	Not significant	Not significant
Single measure model		
Beta-coefficient	-4135	-1157
Standard error	5572	3312
T-statistic	-0,742	-0,349
Significance	0,458	0,727
Conclusion	Not significant	Not significant
Social model		
Pearson's Correlation	0.073	-0.121
Significance	0.059*	0.586
Conclusion	Negative	Not significant

Ammonia – Existing stables

Literature review	1.5.1	1.5.2	1.5.3	1.5.4	1.5.5	1.5.6
Environment						
NH_3 emission per LU	Low	Average	High	High	Unknown	High
Economy						
Change in revenues						
Milk	+					
Sales of animals						
Remaining						
Change in allocated costs						
(Purchased) roughage			(-)	(-)		
Concentrates			(-)	(-)		
Animals						
Crop						-
Change in non-allocated costs						
Contractor						
Machines and installations					+	+
Ground and buildings	+	+				
Water and energy		+			+	
Manure disposal			+	+		
Remaining					+	+
Total	Unknown	Negative	Negative	Negative	Negative	Negative
Social						
Labour	-		-	-		-
Administrative burden						
Safety	-					-
Overall	Negative	Unknown	Negative	Negative	Unknown	Negative

Ammonia – Manure application grassland

Literature review	1.6.1	1.6.2	1.6.3
Environment			
NH_3 emission per LU	High	Average	Average
Economy			
Change in revenues			
Milk			
Sales of animals			
Remaining			
Change in allocated costs			
(Purchased) roughage			
Concentrates	-	-	-
Animals			
Crop			
Change in non-allocated costs			
Contractor			
Machines and installations			
Ground and buildings			
Water and energy			
Manure disposal	+	+	+
Remaining			
Total	Positive	Positive	Positive
Social			
Labour			
Administrative burden			
Safety			
Overall	Unknown	Unknown	Unknown

Ammonia – Manure application arable land

Literature review	1.7.1	1.7.2		Data-analysis	1.7.2
Environment					
NH_3 emission per LU	Average	High		**Environmental model**	
				Pearson's Correlation	-0.212
Economy				Significance	0.000***
Change in revenues					
Milk				Conclusion	Positive
Sales of animals					
Remaining					
				Multiple measure model	
Change in allocated costs				Beta-coefficient	-97
(Purchased) roughage				Standard error	62
Concentrates		-		T-statistic	-1,552
Animals				Significance	0,121
Crop					
				Conclusion	Not significant
Change in non-allocated costs					
Contractor					
Machines and installations				**Single measure model**	
Ground and buildings				Beta-coefficient	-54
Water and energy				Standard error	19
Manure disposal	+	+		T-statistic	-2,85
Remaining				Significance	0.004***
Total	Negative	Unknown		Conclusion	Negative
Social					
Labour				**Social model**	
Administrative burden				Pearson's Correlation	-0.067
Safety				Significance	0.081*
Overall	Unknown	Unknown		Conclusion	Positive

Greenhouse gases – Productivity

Literature review	2.1.1	2.1.2	2.1.3
Environment			
NH_3 emission reduction per KG milk	Average	Average	Dependent*
Economy			
Change in revenues			
Milk	+	+	+
Sales of animals	-	-	-
Remaining	+		
Change in allocated costs			
(Purchased) roughage	-	-	+
Concentrates	-	-	+
Animals	-	-	+
Crop			
Change in non-allocated costs			
Contractor	-	-	+
Machines and installations			
Ground and buildings			
Water and energy	-	-	
Manure disposal	-	-	+
Remaining		-	
Total	Positive	Positive	Positive
Social			
Labour	+	±	-
Administrative burden	+	+	
Safety			
Overall	Positive	Positive	Negative

* Environmental impact of measure 2.1.3 depends on extra feed required

Data-analysis	2.1.1	2.1.2	2.1.3
Environmental model			
Pearson's Correlation	0.182	0.026	-0.606
Significance	0.000***	0.468	0.000***
Conclusion	Positive	Not significant	Positive
Multiple measure model			
Beta-coefficient	1806	-1795	2112
Standard error	2784	350	475
T-statistic	0.649	-5.123	4.451
Significance	0.517	0.000***	0.000***
Conclusion	Not significant	Positive	Positive
Single measure model			
Beta-coefficient	-1282	-609	406
Standard error	786	103	64
T-statistic	-1,631	-5,924	6,312
Significance	0,103	0.000***	0.000***
Conclusion	Not significant	Positive	Postive
Social model			
Pearson's Correlation	-0.017	0.015	0.003
Significance	0.620	0.674	0.939
Conclusion	Not significant	Not significant	Not significant

Greenhouse gases – Feed

Literature review	2.2.1	2.2.2	2.2.3	2.2.4	2.2.5	2.2.6	2.2.7
Environment							
CO_2 equivalents emitted per kg milk	Average	Average	Average	Average	High	High	Low
Economy							
Change in revenues							
Milk	+	±		+			±
Sales of animals							
Remaining							
Change in allocated costs							
(Purchased) roughage		±	+				+
Concentrates		+	-			±	-
Animals							
Crop				+			
Change in non-allocated costs							
Contractor		+	-				
Machines and installations							
Ground and buildings							+
Water and energy							
Manure disposal							
Remaining	+				+		
Total	Positive	Break-even	Positive	Positive	Negative	Dependent*	Dependent*
Social							
Labour	-	+	-	-	-		-
Administrative burden							
Safety							
Overall	Negative	Positive	Negative	Negative	Negative	Unknown	Negative

* Economic impact of measure 2.2.6 depends on prices for responsible concentrates

* Economic impact of measure 2.2.7 depends on wet by-product that is fed

Data-analysis	2.2.1	2.2.2	2.2.3	2.2.7
Environmental model				
Pearson's Correlation	0.658	0.179	0.179	0.032
Significance	0.000***	0.000***	0.000***	0.362
Conclusion	Positive	Positive	Negative	Not significant
Multiple measure model				
Beta-coefficient	550	-114	2112	-157
Standard error	525	188	475	650
T-statistic	1.048	-0.608	4.451	-0.241
Significance	0.295	0.544	0.000***	0.810
Conclusion	Not significant	Not significant	Positive	Not significant
Single measure model				
Beta-coefficient	-160	-113	508	434
Standard error	122	74	128	299
T-statistic	-1.305	-1.522	3.952	1.451
Significance	0.192	0.128	0.000***	0.147
Conclusion	Not significant	Not significant	Positive	Not significant
Social model				
Pearson's Correlation	0.004	-0.060	-0.152	0.144
Significance	0.899	0.089*	0.000***	0.000***
Conclusion	Not significant	Positive	Positive	Negative

Greenhouse gases – Manure storage

Literature review	2.3.1	2.3.2	2.3.3	2.3.4	2.3.5
Environment					
CO_2 equivalents emitted per kg milk	High	High	High	Average	Average
Economy					
Change in revenues					
Milk					
Sales of animals					
Remaining			+		
Change in allocated costs					
(Purchased) roughage					
Concentrates					
Animals					
Crop		-		-	
Change in non-allocated costs					
Contractor				+	
Machines and installations	+	+	+		
Ground and buildings					
Water and energy			-		
Manure disposal				-	
Remaining			+		
Total	Negative	Negative	Negative	Positive	Unknown
Social					
Labour	-	-	-	-	-
Administrative burden					
Safety		-			
Overall	Negative	Negative	Negative	Negative	Negative

Greenhouse gases – Crop and fertilization

Literature review	2.4.1	2.4.2	2.4.3	2.4.4	2.4.5	2.4.6
Environment						
CO_2 equivalents emitted per kg milk	Average	Average	Average	High	Average	Unknown
Economy						
Change in revenues						
Milk						
Sales of animals						
Remaining						
Change in allocated costs						
(Purchased) roughage	-	(-)		(+)		
Concentrates				(+)		-
Animals						
Crop	-	+	-	-	±	+
Change in non-allocated costs						
Contractor						
Machines and installations						
Ground and buildings						
Water and energy						
Manure disposal	+		+			
Remaining						
Total	Negative	Negative	Dependent*	Positive	Dependent*	Negative
Social						
Labour			-			-
Administrative burden						
Safety		-				
Overall	Unknown	Negative	Negative	Unknown	Unknown	Negative

* Economic impact of measure 2.2.3 depends on fertilizer prices and machinery prices

* Economic impact of measure 2.2.5 depends on prices for fertilizers with lower footprint

Data-analysis	2.4.1	2.4.4	2.4.6
Environmental model			
Pearson's Correlation	-0.009	0.119	-0.173
Significance	0.789	0.001***	0.057*
Conclusion	Not significant	Positive	Positive
Multiple measure model			
Beta-coefficient	-157	59	-149
Standard error	599	47	1348
T-statistic	-0.262	1.242	-0.110
Significance	0.793	0.215	0.912
Conclusion	Not significant	Not significant	Not significant
Single measure model			
Beta-coefficient	-167	20	-411
Standard error	168	12	343
T-statistic	-0.992	1.712	-1.198
Significance	0.321	0.087*	0.231
Conclusion	Not significant	Negative	Not significant
Social model			
Pearson's Correlation	-0.004	0.118	-0.046
Significance	0.900	0.001***	0.189
Conclusion	Not significant	Positive	Not significant

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Greenhouse gases – Energy

Literature review	2.5.1	2.5.2	2.5.3	2.5.4	2.5.5	2.5.6	2.5.7	2.5.8
Environment								
CO_2 equivalents emitted per kg milk	Average	High	Low	Low	Average	Low	Low	Low
Economy								
Change in revenues								
Milk								
Sales of animals								
Remaining	+	+						
Change in allocated costs								
(Purchased) roughage								
Concentrates								
Animals								
Crop								
Change in non-allocated costs								
Contractor								
Machines and installations	+	+	+	+	+			
Ground and buildings								
Water and energy	-		-	-	-	-		
Manure disposal								
Remaining							-	±
Total	Dependent*	Positive	Positive	Positive	Dependent*	Positive	Positive	Dependent*
Social								
Labour						-	-	
Administrative burden								
Safety	-							
Overall	Negative	Unknown	Unknown	Unknown	Unknown	Negative	Negative	Unknown

* Economic impact of measure 2.5.1 depends on installation of solar panels

* Economic impact of measure 2.5.5 depends on light schedules, size of stable and longevity of LED-lightning

* Economic impact of measure 2.5.8 depends on biodiesel prices compared to conventional diesel prices

Data-analysis	2.5.1	2.5.6	2.5.7
Environmental model			
Pearson's Correlation	-0.117	-0.067	-0.071
Significance	0.001***	0.057*	0.043**
Conclusion	Positive	Negative	Negative
Multiple measure model			
Beta-coefficient	-11842	-	-236
Standard error	6623	-	24
T-statistic	-1.788	-	-10.001
Significance	0.074*	-	0.000***
Conclusion	Negative	Positive	Positive
Single measure model			
Beta-coefficient	4341	-3	15
Standard error	2310	4	2
T-statistic	1.879	-0.757	6.258
Significance	0.060	0.449	0.000***
Conclusion	Positive	Not significant	Negative
Social model			
Pearson's Correlation	0.020	0.123	0.076
Significance	0.577	0.000***	0.025**
Conclusion	Not significant	Negative	Negative

Greenhouse gases – Land

Literature review	2.6.1	2.6.2	2.6.3	2.6.4	2.6.5	2.6.6
Environment						
CO_2 equivalents emitted per kg milk	Dependent*	Average	Low	Dependent*	Unknown	Unknown
Economy						
Change in revenues						
Milk						
Sales of animals						
Remaining						
Change in allocated costs						
(Purchased) roughage	±	±		-		
Concentrates						-
Animals						
Crop			+		-	+
Change in non-allocated costs						
Contractor	(-)	(-)	-			-
Machines and installations				+		
Ground and buildings						
Water and energy						
Manure disposal						
Remaining					-	
Total	Dependent*	Positive	Dependent*	Break-even	Positive	Break-even
Social						
Labour	+	+	-	-	+	+
Administrative burden						
Safety						
Overall	Positive	Positive	Negative	Negative	Positive	Negative

* Environmental impact of measure 2.6.1 depends on weather after ploughing, time of ploughing, frequency of sowing, and others

* Economic impact of measure 2.6.1 depends on soil type and grassland management

* Economic impact of measure 2.6.3 depends on moment of sowing

* Environmental impact of measure 2.6.4 depends on magnitude of implementation and ditch level

Data-analysis	2.6.2
Environmental model	
Pearson's Correlation	-0.020
Significance	0.579
Conclusion	Not significant
Multiple measure model	
Beta-coefficient	282
Standard error	196
T-statistic	1.442
Significance	0.150
Conclusion	Not significant
Single measure model	
Beta-coefficient	38
Standard error	77
T-statistic	0.490
Significance	0.624
Conclusion	Not significant
Social model	
Pearson's Correlation	0.097
Significance	0.006***
Conclusion	Positive

Appendix III – Outcomes single measure models

Reduction of young cattle

Essential information

Independent variable	# of heifers per 10 milking cows
Dependent variable	Income per annual work unit
Outliers independent variable	< 5 and > 10
Outliers dependent variable	< -120000 and >200000
N	1846
Adjusted R²	0.059

Coefficients

	B	Standard error	t	Sig.
(Constant)	61453	6395	9.608	0.000***
# of heifers per 10 milking cows	-1282	786	-1.631	0.103
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	1143	2087	0.548	0.584
Soil type: peat	513	2698	0.190	0.849
Soil type: loess	-4749	4197	-1.131	0.258
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-14174	3114	-4.551	0.000***
Year: 2013	-747	3089	-0.242	0.809
Year: 2014	-3005	3145	-0.955	0.340
Year: 2015	-15961	3085	-5.174	0.000***
Year: 2016	-27080	3072	-8.814	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.841E+11	9	2.046E+10	13.817	0.000
Residual	2.718E+11	1836	1480441468		
Total	2.902E+12	1845			

Longevity of dairy cows

Essential information

Independent variable	Replacement rate
Dependent variable	Income per annual work unit
Outliers independent variable	< 5% and > 50%
Outliers dependent variable	< - 120000 and > 200000
N	2144
Adjusted R²	0.066

Coefficients

	B	Standard error	t	Sig.
(Constant)	64533	3428	18.825	0.000***
Replacement rate	-609	103	-5.924	0.000***
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	1566	1937	0.808	0.419
Soil type: peat	1400	2448	0.572	0.567
Soil type: loess	-6385	3698	-1.727	0.084
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-14470	2845	-5.086	0.000***
Year: 2013	-467	2871	-0.163	0.871
Year: 2014	-2103	2888	-0.728	0.467
Year: 2015	-17034	2891	-5.892	0.000***
Year: 2016	-24153	2841	-8.502	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	2.366E+11	9	2.629E+10	17.907	0.000
Residual	3.133E+12	2134	1468070720		
Total	3.369E+12	2143			

MILK PRODUCTION PER COW

Essential information

Independent variable	Milk production per cow (100 kg)
Dependent variable	Income per annual work unit
Outliers independent variable	< 35 and > 120
Outliers dependent variable	< - 120000 and > 200000
N	2190
Adjusted R^2	0.069

Coefficients

	B	Standard error	t	Sig.
(Constant)	15121	5618	2.692	0.007***
Milk production per cow (100 kg)	406	64	6.312	0.000***
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	1622	1929	0.841	0.401
Soil type: peat	3705	2468	1.502	0.133
Soil type: loess	-3836	3580	-1.072	0.284
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12241	2821	-4.339	0.000***
Year: 2013	2112	2833	0.745	0.456
Year: 2014	-1149	2855	-0.402	0.678
Year: 2015	-14294	2824	-5.062	0.000***
Year: 2016	-24969	2810	-8.886	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	2.543E+11	9	2.826E+10	19.134	0.000
Residual	3.220E+12	2180	1476850481		
Total	3.474E+12	2189			

FEED MORE MAIZE AND LESS GRASS

Essential information

Independent variable	Kg dry matter maize / kg dry matter total
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< -120000 and > 200000
N	1082
Adjusted R²	0.084

Coefficients

	B	Standard error	t	Sig.
(Constant)	58402	4811	12.138	0.000***
Kg maize / kg total	-113	74	-1.522	0.128
Soil type: sand		Dummy variable taken out of analysis		
Soil type: clay	-3356	3103	-1.082	0.280
Soil type: peat	727	4794	0.152	0.880
Soil type: loess	-7087	5316	-1.333	0.183
Year: 2011		Dummy variable taken out of analysis		
Year: 2012	-10549	4684	-2.252	0.025**
Year: 2013	4867	4605	1.057	0.291
Year: 2014	-2929	4520	-0.648	0.517
Year: 2015	-18069	4448	-4.062	0.000***
Year: 2016	-30761	4402	-6.989	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.763E+11	9	1.959E+10	11.969	0.000
Residual	1.755E+12	1072	1636684698		
Total	1.931E+12	1081			

LESS CRUDE PROTEIN IN GRASS SILAGE

Essential information

Independent variable	Percentage crude protein in grass silage
Dependent variable	Income per annual work units
Outliers independent variable	< 10% and > 25%
Outliers dependent variable	< -120000 and > 200000
N	1111
Adjusted R²	0.079

Coefficients

	B	Standard error	t	Sig.
(Constant)	44351	12220	3.629	0.000***
% CU in grass silage	499	707	0.706	0.480
Soil type: sand		Dummy variable taken out of analysis		
Soil type: clay	-2242	3046	-0.736	0.462
Soil type: peat	1860	4712	0.395	0.639
Soil type: loess	-8198	5094	-1.609	0.108
Year: 2011		Dummy variable taken out of analysis		
Year: 2012	-9144	4636	-1.972	0.049**
Year: 2013	5163	4559	1.133	0.258
Year: 2014	-1738	4477	-0.388	0.698
Year: 2015	-16595	4396	-3.775	0.000***
Year: 2016	-29538	4339	-6.807	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.725E+11	9	1.917E+10	11.560	0.000
Residual	1.826E+12	1101	1658084932		
Total	1.998E+12	1110			

LESS CRUDE PROTEIN IN FRESH GRASS

Essential information

Independent variable	Percentage crude protein in fresh grass
Dependent variable	Income per annual work unit
Outliers independent variable	< 10 and > 29
Outliers dependent variable	< - 120000 and > 200000
N	799
Adjusted R^2	0.096

Coefficients

	B	Standard error	t	Sig.
(Constant)	69767	15932	4.379	0.000***
% CP in fresh grass	-807	787	-1.026	0.305
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-7339	3526	-2.082	0.038**
Soil type: peat	1391	4996	0.278	0.781
Soil type: loess	-10964	5300	-2.069	0.039**
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-7229	5167	-1.399	0.162
Year: 2013	7838	5041	1.155	0.120
Year: 2014	3685	4983	0.740	0.460
Year: 2015	-11901	4928	-2.415	0.016**
Year: 2016	-28571	4846	-5.895	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.364E+11	9	1.516E+10	10.343	0.000
Residual	1.143E+12	780	1465337627		
Total	1.279E+12	789			

Less crude protein in concentrates

Essential information

Independent variable	Percentage of crude protein in concentrates
Dependent variable	Income per annual work unit
Outliers independent variable	< 5 and > 45
Outliers dependent variable	< -120000 and > 200000
N	1116
Adjusted R^2	0.079

Coefficients

	B	Standard error	t	Sig.
(Constant)	66911	8415	7.948	0.000***
% CP in concentrates	-606	327	-1.853	0.064*
Soil type: sand		Dummy variable taken out of analysis		
Soil type: clay	-2958	3029	-0.977	0.329
Soil type: peat	432	4771	0.091	0.928
Soil type: loess	-8202	5047	-1.625	0.104
Year: 2011		Dummy variable taken out of analysis		
Year: 2012	-8804	4593	-1.917	0.056*
Year: 2013	5032	4507	-1.117	0.264
Year: 2014	-1511	4430	-0.341	0.733
Year: 2015	-16750	4360	-3.841	0.000***
Year: 2016	-29650	4319	-6.865	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.729E+11	9	1.921E+10	11.697	0.000
Residual	1.817E+12	1106	1642483989		
Total	1.989E+12	1115			

Grazing by dairy cows

Essential information

Independent variable	Grazing (yes/no)
Dependent variable	Income per annual work units
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R^2	0.053

Coefficients

	B	Standard error	t	Sig.
(Constant)	45692	2619	17.448	0.000***
Grazing: yes/no	3044	1949	1.562	0.119
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	874	1949	0.449	0.654
Soil type: peat	895	2475	0.362	0.718
Soil type: loess	-5720	3621	-1.597	0.111
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12509	2849	-4.391	0.000***
Year: 2013	1737	2865	0.606	0.554
Year: 2014	-998	2889	-0.346	0.730
Year: 2015	-13535	2856	-4.738	0.000***
Year: 2016	-23976	2837	-8.450	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.984E+11	9	2.205E+10	14.569	0.000
Residual	3.305E+12	2184	1513171517		
Total	3.503E+12	2193			

Grazing by young cattle

Essential information

Independent variable	Young cattle grazing: yes/no
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R^2	0.052

Coefficients

	B	Standard error	t	Sig.
(Constant)	47461	2483	18.279	0.000***
Young cattle grazing: yes/no	830	1817	1.812	0.648
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	828	1950	0.422	0.671
Soil type: peat	1106	2472	0.405	0.655
Soil type: loess	-5581	3624	-1.736	0.124
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12565	2851	-4.417	0.000***
Year: 2013	1655	2867	0.590	0.564
Year: 2014	-1102	2890	-0.363	0.703
Year: 2015	-13662	2857	-4.750	0.000***
Year: 2016	-24022	2839	-8.430	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.950E+11	9	2.167E+10	14.307	0.000
Residual	3.308E+12	2184	1514716376		
Total	3.503E+12	2193			

Category 1 - RAV housing systems with < 10 kg NH_3 per animal place

Essential information

Independent variable	Low emission stable with < 10 NH_3: Yes/No
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R²	0.052

Coefficients

	B	Standard error	t	Sig.
(Constant)	48018	2151	22.323	0.000***
Low emission stable < 10 NH_3	-4135	5572	-0.742	0.458
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	826	1950	0.424	0.672
Soil type: peat	1250	2475	0.505	0.614
Soil type: loess	-5222	3633	-1.437	0.151
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12511	2850	-4.390	0.000***
Year: 2013	1703	2867	0.594	0.553
Year: 2014	-1015	2892	-0.351	0.726
Year: 2015	-13517	2864	-4.720	0.000***
Year: 2016	-23889	2845	-8.397	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.956E+11	9	2.173E+10	14.347	0.000
Residual	3.308E+12	2184	1514479266		
Total	3.503E+12	2193			

Category 2 - RAV housing systems with > 10 kg NH_3 per animal place

Essential information

Independent variable	Low emission stables > 10 NH_3: Yes/No
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R²	0.052

Coefficients

	B	Standard error	t	Sig.
(Constant)	48074	2155	22.305	0.000***
Low emission stable > 10 NH_3	-1157	3312	-0.349	0.727
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	827	1950	0.424	0.672
Soil type: peat	1142	2471	0.462	0.644
Soil type: loess	-5434	3619	-1.501	0.133
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12521	2851	-4.393	0.000***
Year: 2013	1689	2867	0.589	0.556
Year: 2014	-1059	2892	-0.366	0.714
Year: 2015	-13636	2858	-4.771	0.000***
Year: 2016	-23976	2843	-8.433	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.949E+11	9	2.166E+10	14.297	0.000
Residual	3.308E+12	2184	1514776502		
Total	3.503E+12	2193			

MANURE INJECTION

Essential information

Independent variable	% of arable land treated with manure injection
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R^2	0.055

Coefficients

	B	Standard error	t	Sig.
(Constant)	50857	2366	21.497	0.000***
Manure injection	-54	19	-2.850	0.004***
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-614	2010	-0.306	0.760
Soil type: peat	-1092	2588	-0.422	0.673
Soil type: loess	-5371	3611	-1.488	0.137
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12395	2846	-4.356	0.000***
Year: 2013	2677	2883	0.929	0.353
Year: 2014	120	2916	0.041	0.967
Year: 2015	-12257	2894	-4.235	0.000***
Year: 2016	-22488	2885	-7.795	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	2.070E+11	9	2.300E+10	15.238	0.000
Residual	3.296E+12	2184	1509248625		
Total	3.503E+12	2193			

IMPROVE FEED CONVERSION EFFICIENCY

Essential information

Independent variable	Kg dry matter / kg milk production
Dependent variable	Income per annual work unit
Outliers independent variable	< 50 and > 150
Outliers dependent variable	< - 120000 and > 200000
N	1036
Adjusted R²	0.076

Coefficients

	B	Standard error	t	Sig.
(Constant)	68754	13204	5.207	0.000***
Kg dry matter / kg milk prod.	-160	122	-1.305	0.192
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-2078	3066	-0.678	0.498
Soil type: peat	1839	4592	0.400	0.689
Soil type: loess	-9563	5073	-1.885	0.060*
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-10694	4728	-2.262	0.024**
Year: 2013	4481	4628	0.968	0.333
Year: 2014	-2932	4577	-0.641	0.522
Year: 2015	-16667	4501	-3.703	0.000***
Year: 2016	-29279	4456	-6.571	0.000***

ANOVA

	Sum of Square	Df	Mean Square	F	Sig.
Regression	1.496E+11	9	1.662E+10	10.445	0.000
Residual	1.633E+12	1026	1591187956		
Total	1.782E+12	1035			

FEED MORE FRESH GRASS

Essential information

Independent variable	Kg fresh grass / kg total grass
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	1081
Adjusted R²	0.095

Coefficients

	B	Standard error	t	Sig.
(Constant)	46942	3849	12.194	0.000***
Kg fresh grass / kg total grass	508	128	3.952	0.000***
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-1711	3035	-0.564	0.573
Soil type: peat	805	4644	0.173	0.862
Soil type: loess	-10542	5297	-1.990	0.047**
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-10552	4654	-2.267	0.024**
Year: 2013	4739	4575	1.036	0.301
Year: 2014	-2802	4489	-0.624	0.533
Year: 2015	-17579	4423	-3.974	0.000***
Year: 2016	-30511	4368	-6.986	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.927E+11	9	2.191E+10	13.554	0.000
Residual	1.731E+12	1071	1616247014		
Total	1.928E+12	1080			

USE OF WET BY-PRODUCTS

Essential information

Independent variable	% of dry matter by wet by-products
Dependent variable	Income per annual work unit
Outliers independent variable	< 25%
Outliers dependent variable	< - 120000 and > 200000
N	1080
Adjusted R^2	0.083

Coefficients

	B	Standard error	t	Sig.
(Constant)	51850	3697	14.026	0.000***
Wet by-products	434	299	1.451	0.147
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-2883	3078	-0.936	0.349
Soil type: peat	2601	4660	0.558	0.577
Soil type: loess	-7655	5297	-1.445	0.149
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-10768	4697	-2.293	0.022**
Year: 2013	4919	4617	1.065	0.287
Year: 2014	-2749	4531	-0.607	0.544
Year: 2015	-17933	4461	-4.020	0.000***
Year: 2016	-30394	4414	-6.886	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.757E+11	9	1.952E+10	11.906	0.000
Residual	1755E+12	1070	1639788303		
Total	1.930E+12	1079			

USE OF GRASS CLOVER

Essential information

Independent variable	% of clover
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2193
Adjusted R^2	0.052

Coefficients

	B	Standard error	t	Sig.
(Constant)	48387	2181	22.187	0.000***
% of clover	-167	168	-0.992	0.321
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	1015	1963	0.517	0.605
Soil type: peat	1243	2473	0.503	0.615
Soil type: loess	-4677	3706	-1.262	0.207
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12529	2850	-4.395	0.000***
Year: 2013	1645	2867	0.574	0.566
Year: 2014	-1011	2894	-0.349	0.727
Year: 2015	-13551	2859	-4.739	0.000***
Year: 2016	-23885	2843	-8.403	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.960E+11	9	2.178E+10	14.375	0.000
Residual	3.307E+12	2183	1514821075		
Total	3.503E+12	2192			

LOWER FERTILIZER GIFT OF N

Essential information

Independent variable	Kg nitrogen fertilized per ha
Dependent variable	Income per annual work unit
Outliers independent variable	> 600 kg
Outliers dependent variable	< - 120000 and > 200000
N	1768
Adjusted R^2	0.055

Coefficients

	B	Standard error	t	Sig.
(Constant)	42662	4699	9.078	0.000***
Kg nitrogen fertilized per ha	20	12	1.712	0.087*
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-3015	2190	-1.377	0.169
Soil type: peat	-2664	2725	-0.978	0.328
Soil type: loess	-4280	4225	-1.013	0.311
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12973	3395	-3.821	0.000***
Year: 2013	830	3398	0.244	0.807
Year: 2014	-970	3239	-0.299	0.765
Year: 2015	-14108	3202	-4.405	0.000***
Year: 2016	-24176	3181	-7.601	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.674E+11	9	1.860E+10	12.397	0.000
Residual	2.638E+12	1758	1500570250		
Total	2.805E+12	1767			

CULTIVATION OF CONCENTRATE SUBSTITUTES

Essential information

Independent variable	% of hectares with concentrates substitutes
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R^2	0.052

Coefficients

	B	Standard error	t	Sig.
(Constant)	48327	2165	22.321	0.000***
% of hectares of concentrate substitutes	-411	343	-1.198	0.231
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	910	1951	0.466	0.641
Soil type: peat	928	2477	0.375	0.708
Soil type: loess	-4949	3643	-1.358	0.174
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12467	2850	-4.374	0.000***
Year: 2013	1568	2867	0.547	0.585
Year: 2014	-1217	2891	-0.421	0.674
Year: 2015	-13760	2857	-4.817	0.000***
Year: 2016	-24133	2839	-8.500	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.969E+11	9	2.188E+10	14.451	0.000
Residual	3.306E+12	2184	1513866927		
Total	3.503E+12	2193			

SOLAR PANELS

Essential information

Independent variable	Solarpanels: yes/no
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R²	0.053

Coefficients

	B	Standard error	t	Sig.
(Constant)	47747	2155	22.159	0.000***
Solar panels	4341	2310	1.879	0.060*
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	862	1948	0.442	0.658
Soil type: peat	1042	2470	0.422	0.673
Soil type: loess	-5157	3618	-1.425	0.154
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12681	2849	-4.451	0.000***
Year: 2013	1271	2872	0.443	0.658
Year: 2014	-1602	2900	-0.552	0.581
Year: 2015	-14387	2898	-4.996	0.000***
Year: 2016	-24850	2870	-8.659	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	2.001E+11	9	2.223E+10	14.698	0.000
Residual	3.303E+12	2184	1512415423		
Total	3.503E+12	2193			

OPTIMAL USAGE OF ELECTRICITY

Essential information

Independent variable	MJ electricity use (x1000 MJ)
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R²	0.052

Coefficients

	B	Standard error	t	Sig.
(Constant)	48609	2284	21.279	0.000***
MJ electricity use (x1000)	-3	4	-0.757	0.449
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	959	1959	0.490	0.624
Soil type: peat	1182	2471	0.478	0.632
Soil type: loess	-5583	3620	-1.542	0.123
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12528	2850	-4.396	0.000***
Year: 2013	1714	2867	0.598	0.550
Year: 2014	-1068	2890	-0.369	0.712
Year: 2015	-13610	2857	-4.763	0.000***
Year: 2016	-23940	2841	-8.427	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.956E+11	9	2.173E+10	14.350	0.000
Residual	3.308E+12	2184	1514464138		
Total	3.503E+12	2193			

REDUCE DIESEL CONSUMPTION

Essential information

Independent variable	MJ fuel and contract work (x1000)
Dependent variable	Income per annual work unit
Outliers independent variable	-
Outliers dependent variable	< - 120000 and > 200000
N	2194
Adjusted R²	0.068

Coefficients

	B	Standard error	t	Sig.
(Constant)	41626	2365	17.601	0.000***
MJ fuel and contract work (x1000)	15	2	6.258	0.000***
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	-223	1940	-0.115	0.909
Soil type: peat	2591	2459	1.025	0.305
Soil type: loess	-4309	3590	-1.200	0.230
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12639	2825	-4.474	0.000***
Year: 2013	1591	2841	0.560	0.576
Year: 2014	-1895	2867	-0.661	0.509
Year: 2015	-14444	2834	-5.097	0.000***
Year: 2016	-25193	2820	-8.934	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	2.530E+11	9	2.811E+10	18.890	0.000
Residual	3.250E+12	2184	1488173442		
Total	3.503E+12	2193			

REDUCE GRASSLAND RENEWAL

Essential information

Independent variable	Percentage of grassland renewed
Dependent variable	Income per annual work unit
Outliers independent variable	< 100%
Outliers dependent variable	< - 120000 and > 200000
N	2193
Adjusted R²	0.056

Coefficients

	B	Standard error	t	Sig.
(Constant)	48018	2152	22.315	0.000***
% of grassland renewed	38	77	0.490	0.624
Soil type: sand	Dummy variable taken out of analysis			
Soil type: clay	844	1951	0.433	0.665
Soil type: peat	1160	2472	0.469	0.639
Soil type: loess	-5507	3619	-1.522	0.128
Year: 2011	Dummy variable taken out of analysis			
Year: 2012	-12711	2876	-4.419	0.000***
Year: 2013	1472	2896	0.508	0.611
Year: 2014	-1342	2933	-0.458	0.647
Year: 2015	-13957	2916	-4.787	0.000***
Year: 2016	-24204	2861	-8.460	0.000***

ANOVA

	Sum of Square	df	Mean Square	F	Sig.
Regression	1.951E+11	9	2.167E+10	14.303	0.000
Residual	3.308E+12	2183	1515388122		
Total	3.503E+12	2192			

Appendix IV – Outliers and missing values

This appendix presents the information on the outliers and missing values in the data-analysis.

The following table presents all the outlier boundaries that were set for this research.

Measure	Variable	Upper bound	Lower bound
	Independent variables		
1.1.1/2.1.1 Reduction of young cattle	# of heifers per 10 dairy cows	10	5
1.1.2/2.1.2 Longevity of dairy cows	Replacement rate	50%	5%
1.1.3/2.1.3 Increase milk production per cow per year	Milk production per cow per year (100 kg)	120(00) litres	35(00) litres
1.2.1/2.2.2 Feed more maize and less grass	Kg dry matter grass / kg dry matter total	-	-
1.2.2 Less crude protein in grass silage	% CP in grass silage	25%	10%
1.2.3 Less crude protein in fresh grass	% CP in fresh grass	29%	15%
1.2.4 Less crude protein in concentrates	% CP in concentrates	45%	5%
1.3.1 Grazing by dairy cows	Grazing: yes/no	-	-
1.3.2 Grazing by young cattle	Young cattle grazing: yes/no	-	-
1.4.1 Category 1 – RAV housing systems with < 10 kg NH3 per animal place	Yes/no	-	-
1.4.2 Category 2 – RAV housing systems with > 10 kg NH3 per animal place	Yes/no	-	-
1.7.2 Manure injection	% of land injected	-	-
2.2.1 Improve feed conversion efficiency	Kg dry matter total / milk production	50 kg	150 kg
2.2.3 Feed more fresh grass	Fresh grass / grass total	-	-
2.2.7 Use of wet by-products	Kg dry matter wet by-products / kg dry matter total	25%	
2.4.1 Use of grass-clover	% of clover	-	-
2.4.4 Lower fertilizer gift of N	N gift per hectare in kg	600 kg	-
2.4.6 Cultivation of concentrate substitutes	% of hectares with concentrate substitutes	-	-
2.5.1 Solar panels	Solar panels: yes/no	-	-
2.5.5 Optimal usage of electricity	MJ use other energy (1000 MJ)		
2.5.6 Optimal usage of diesel	MJ use fuel machinery and contractors (1000 MJ)		
2.6.2 Reduce grassland renewal	% of grassland renewed	100%	
	Dependent variables		
Income (single measure model)	Margin per aje in €	€200,000	€ - 120,000
Income (multiple measure model)	Margin in €	€500,000	€ - 200,000

The following table shows how many samples were taken out due the outlier restrictions or because of missing values.

Measure	Variable	N	Outliers	Missing values	Total
Independent variables					
1.1.1/2.1.1 Reduction of young cattle	# of heifers per 10 dairy cows	1846	358	0	2204
1.1.2/2.1.2 Longevity of dairy cows	Replacement rate	2144	60	0	2204
1.1.3/2.1.3 Increase milk production per cow per year	Milk production per cow per year (100 kg)	2190	14	0	2204
1.2.1/2.2.2 Feed more maize and less grass	Kg dry matter grass / kg dry matter total	1092	10	1182	2204
1.2.2 Less crude protein in grass silage	% CP in grass silage	1111	12	1091	2204
1.2.3 Less crude protein in fresh grass	% CP in fresh grass	799	324	1091	2204
1.2.4 Less crude protein in concentrates	% CP in concentrates	1116	8	1080	2204
1.3.1 Grazing by dairy cows	Grazing: yes/no	2204	0	0	2204
1.3.2 Grazing by young cattle	Young cattle grazing: yes/no	2204	0	0	2204
1.4.1 Category 1 – RAV housing systems with < 10 kg NH3 per animal place	Yes/no	2204	0	0	2204
1.4.2 Category 2 – RAV housing systems with > 10 kg NH3 per animal place	Yes/no	2204	0	0	2204
1.7.2 Manure injection	% of land injected	2204	0	0	2204
2.2.1 Improve feed conversion efficiency	Kg dry matter total / milk production	1046	1158	0	2204
2.2.3 Feed more fresh grass	Fresh grass / grass total	1102	9	1112	2204
2.2.7 Use of wet by-products	Kg dry matter wet by-products / kg dry matter total	1090	6	1108	2204
2.4.1 Use of grass-clover	% of clover	2203	0	1	2204
2.4.4 Lower fertilizer gift of N	N gift per hectare in kg	1768	13	423	2204
2.4.6 Cultivation of concentrate substitutes	% of hectares with concentrate substitutes	2204	0	0	2204
2.5.1 Solar panels	Solar panels: yes/no	2204	0	0	2204

2.5.5 Optimal usage of electricity	MJ use other energy (1000 MJ)	2204	0	0	2204
2.5.6 Optimal usage of diesel	MJ use fuel machinery and contractors (1000 MJ)	2204	0	0	2204
2.6.2 Reduce grassland renewal	% of grassland renewed	2204	0	0	2204
Dependent variables					
Income (single measure model)	Margin per aje in €	2204	10	0	2204
Income (multiple measure model)	Margin in €	2204	12	0	2204

APPENDIX V – FIGURES RAV HOUSING SYSTEMS

When the costs per square meter cannot be exactly determined, the costs have been estimated with the use of the costs of comparable systems. When 100- is indicated, costs per square meter are estimated to be above €100, when 100+ is indicated it is estimated that the costs per square meter are below €100.

RAV housing system	Emission factor (kg NH3 emission per animal place)	Costs per square meters	Category
A 1.1	5.7	100-	1
A 1.2	10.2	100-	2
A 1.3	10.2	100-	2
A 1.4	9.2	100-	1
A 1.5	11.8	100-	2
A 1.6	11.0	65	2
A 1.7	11.0	110	2
A 1.8	11.8	100-	2
A 1.9	6.0	100+	1
A 1.10	7.0	130	1
A 1.11	11.8	100+	2
A 1.12	12.2	129	2
A 1.13	7.0	100+	1
A 1.14	7.0	64 – 120	1
A 1.15	10.3	67 – 77	2
A 1.16	11.7	100-	2
A 1.17	5.1	113	3
A 1.18	8.0	65	1
A 1.19	11.0	105 – 155	2
A 1.20	10.1	70	2
A 1.21	7.0	65 – 95	1
A 1.22	11.0	80	2
A 1.23	6.0	80	1
A 1.24	9.1	60 – 80	1
A 1.25	10.3	125 – 140	2
A 1.26	8.0	120	1
A 1.27	10.3	110	2
A 1.28	7.7	115	1
A 1.29	9.9	65	1
A 1.30	9.4	75	1

Appendix VI – Conclusion per mitigation measure

This appendix presents an overview of the conclusions for all the mitigation measures that were investigated in this research.

Category 1.1 – Productivity

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.1.1 Reduce young cattle		Average	Positive	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Not significant	Not significant	Not significant
	Written conclusion	Previous studies show that this measure is profitable, has a positive social impact and an average mitigation potential. However, this was not confirmed by the data-analysis.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.1.2 Increase longevity of dairy cows		Average	Positive	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Positive	Positive	Not significant
	Written conclusion	This measure is linked to measure 1.1.2, therefore, previous studies hypothesized the same result. The data-analysis showed a significant positive economic result.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.1.3 Increase milk production per cow		High	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Positive	Positive	Not significant
	Written conclusion	The literature stated that increasing the milk production per cow would lead to a significant environmental and economic benefit, but a negative social impact due to management changes and required capabilities. The data-analysis could only confirm an average positive economic impact.			

Category 1.2 – Low protein feed

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.2.1 Feed more maize and less grass		Average	Break-even	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Positive	Not significant	Positive
	Written conclusion	This measure has an average environmental and positive social benefit to farmers, according to literature. In the data-analysis all the indicators had a significant positive result, except for the second economic model, which is of lesser importance than the first one. Overall, this measure can be considered as a very positive one.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.2.2 Less crude protein in grass silage		Average	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Not significant	Positive
	Written conclusion	Previous studies concluded that this feeding strategy is economically and environmentally advantageous, whereas in the data-analysis the environmental and social impact had a significant positive result. Therefore it can only be concluded that the environmental impact is very positive.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.2.3 Less crude protein in pasture grass		Dependent	Unknown	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Not significant	Positive
	Written conclusion	This measure is not been covered in literature on a large scale, the only information found in literature is that the environmental impact depends on the grazing time and the ratio. The data-analysis showed that the environmental and social impact is positive, whereas the economic impact was not significant. This means that there is no end conclusion on the economic impact of this measure.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.2.4 Less crude protein in concentrates		Average	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Negative	Positive	Positive	Not significant
	Written conclusion	Because concentrates make up a smaller part in the ratio, the environmental impact is expected to be smaller as the previous measures, whereas the economic impact is positive and the social impact unknown. Strangely, the correlation between crude protein content and ammonia emissions was negative. The average economic impact is positive and the social impact had an insignificant outcome.			

Category 1.3 – Grazing

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.3.1 Grazing by dairy cows		High	Positive	Dependent	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Negative	Not significant	Not significant
	Written conclusion	Grazing has a very high ammonia mitigation potential and literature states that it has a positive economic impact. This was however not confirmed by the data-analysis, the reason behind this is explained in chapter 6, discussion. According to literature, the social impact is dependent on the system that is practiced and the data-analysis did not show a significant correlation.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.3.2 Grazing by young cattle		High	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Positive	Not significant	Positive
	Written conclusion	The environmental and economic impact was expected to be similar to the impact of dairy cows that graze, although revenues from grazing are different. The data-analysis showed a positive impact on all the three elements, which means that this measure is very positive to both farmers and environment.			

Category 1.4 – Low emission housing systems

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.4.1 Category 1 - RAV housing systems with < 10 KG NH_3 per animal place		High	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Negative	Not significant	Not significant	Negative
	Written conclusion	Due to categorization, a well-based literature review was not possible. The hypotheses is based on assumptions. The data-analysis showed a negative environmental and social impact. It should however be considered that every farmer has to replace or renovate his or hers stable at some point, and only RAV housing systems are allowed to be built.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.4.2 Category 2 - RAV housing systems with > 10 KG NH_3 per animal place		High	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Not significant	Not significant	Not significant
	Written conclusion	The artificial categorization of RAV housing systems led to an assessment that is based on assumptions. All the results in the data-analysis were not significant. This means that no conclusions can be drawn for this measure in this research.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.4.3 Category 3 – Mechanical ventilated system		High	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The assumptions do also hold for this single housing system. It could not be investigated in the data-analysis because there were too few samples that implemented this housing system.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.4.4 Category 4 – Natural ventilated system		High	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data analysis			
	Written conclusion	This is an old RAV-system which cannot be newly built anymore, but is still used among farmers. The same assumptions were used as in the previous measures. It could not be investigated in the data-analysis because the amount of samples that implemented this measure was too low.			

Category 1.5 – Existing stables

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.5.1 Roof insulation		Low	Unknown	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	In literature it is stated that this measure has just a tiny environmental benefit and the social impact for farmers is negative. Therefore, it should not be a measure to focus a lot on in the future. It was not possible to conduct a data-analysis, since the data was not available in the BIN-dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.5.2 ACNV		Average	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Whereas the environmental impact is assessed as average by literature, the economic impact to the farmer is negative. This measure was not suitable for data-analysis because the data was not present in BIN.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.5.3 Manure dilution in manure cellar		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	This measure has a high ammonia mitigation potential, but the impacts to the farmer are negative. This conclusion is based on literature, it was not possible to investigate this measure because the data was not present in the BIN database.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.5.4 Manure dilution on walking floors		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The conclusions based on the literature review are the same as for the previous measure, since the measure is similar. The BIN database does not contain data on this measure, therefore this measure was not investigated.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.5.5 Manure sliding		Unknown	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	There is not much scientific information available on this measure, except that is expected that the economic outcome is negative. The measure was not investigated in the data-analysis because it was not quantifiable.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.5.6 Manure acidification		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	This measure, that has a high ammonia mitigation potential, still needs development because the economic and social impacts to the farmer are still negative. It was not suitable for data-analysis because the data was not present in the BIN database.			

Category 1.6 – Manure application grassland

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.6.1 Manure dilution before application		High	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Previous studies concluded that this measure is environmental and economic beneficial, whereas the social impact remained unknown. It was not suitable for data-analysis because data was not present in the BIN database			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.6.2 Accurate manure disposal		Average	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Scientific literature stated that more accurate manure disposal leads to an average ammonia emission mitigation and a positive economic result. It was not suitable for data-analysis because it was not quantifiable.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.6.3 Manure disposal under favourable weather conditions		Average	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	This measure is related to the previous one, since both promote a better uptake of minerals by the soil and crop. It is not taken into account for the data-analysis because it was not quantifiable.			

Category 1.7 – Manure application arable land

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.7.1 Incorporation in two rounds		Average	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	This measure has an average mitigation potential, but it has a negative economic result. This has been stated by scientific literature, it was not possible to investigate it during the data-analysis, since it there was no data available.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
1.7.2 Manure injection		High	Unknown	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Negative	Not significant
	Written conclusion	It is scientifically concluded that this measure has high ammonia emission mitigation potential. This was confirmed by the data-analysis. Furthermore, only the second economic model gave a significant result, which was negative. However, this was not found in the first model in which many more variables were included.			

Category 2.1 – Productivity

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.1.1 Reduce young cattle		Average	Positive	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Not significant	Not significant
	Written conclusion	The only conclusion that differs from the same measure in the ammonia mitigation measures is that the environmental is significantly positive. Furthermore there were no differences between this measure in the ammonia model and the greenhouse gas model.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.1.2 Increase longevity of dairy cows		Average	Positive	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Positive	Positive	Not significant
	Written conclusion	The conclusion from this measure in the ammonia and greenhouse gas measure models is similar. This means that compared to the other measures, both models show that this measure is, on average, significantly economically beneficial. The environmental and social impact is however not significant.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.1.3 Increase milk production per cow		Dependent	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Positive	Positive	Not significant
	Written conclusion	According to literature, the impact on greenhouse gas emissions depends on the extra feed that is required. The outcome of the data-analysis differs compared to the similar measure 1.1.3, the environmental impact on greenhouse gases is positive.			

Category 2.2 – Feed

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.1 Improve feed conversion efficiency		Average	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Not significant	Not significant
	Written conclusion	Improving the feed conversion efficiency leads to an average environmental impact, positive economic impact and negative social impact, according to literature. Only the environmental impact was confirmed by data-analysis, since the other impacts did not show a significant result. The strongest conclusion possible from this research comes therefore from the literature review.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.2 Feed more maize and less grass		Average	Break-even	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Not significant	Not significant
	Written conclusion	This measure was also investigated in the ammonia mitigation categories, the environmental impact was hypothesized to be lower for the greenhouse gas mitigation measures. In the data-analysis this measure showed a significant positive result for the economic impact in the ammonia mitigation measures model, which was not there in the greenhouse gas mitigation measures model. The only significant result was a positive environmental impact.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.3 Feed more fresh grass and less grass silage		Average	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Negative	Positive	Positive	Positive
	Written conclusion	The hypothesis based on the literature review was not proven for both the environmental and social impact. It was expected that the environmental impact would be positive, and the social impact positive, but this was the other way around. For the economic impact it can be clearly concluded from this research that this measure is significantly positive.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.4 Improve digestibility of grass		Average	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The hypotheses before the data-analysis was that, according to literature, this measure would lead to an average environmental impact, positive economic impact due to the more efficient use of grass and negative social impact because of the extra management capabilities required. This measure was not investigated in the data-analysis because it was not available in the BIN-data set.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.5 Feed additives		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Whereas the mitigation potential is very high, the other impacts on the farmers' life were hypothesized to be negative. Therefore this is a measure which requires further development the improve the economic and social impacts. Unfortunately it was not investigated in the data-analysis because the data was not present.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.6 Concentrates with lower footprint		High	Dependent	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The greenhouse gas mitigation potential is very high, as concentrates are responsible for a large portion of the total emissions. The economic impact is however dependent on the prices of regular concentrates. The social impact is unknown but will be minimal since it requires a different order at the feed company. It was not possible to research this measure because it was not available in the dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.2.7 Use of wet by-products		Low	Dependent	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Not significant	Not significant	Positive
	Written conclusion	The use of wet by-products leads to a low environmental impact and a negative social impact. The economic impact depends on the sort wet by-products that is fed to the cows. These hypotheses were tested in the data-analysis and only the social impact showed a significant result. However, this result was not in line with the expectation based on the literature review. Therefore, no conclusion can be drawn from this research for the social impact of this measure.			

Category 2.3 – Manure storage

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.3.1 Methane oxidation		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The mitigation potential of this measure is high, but the direct impacts to the farmer are negative. Therefore this measure will need more development before successful implementation can be reached. It was not suitable for data-analysis because the data was not present in the database.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.3.2 Manure acidification		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The same measure as measure 1.5.6. Although the environmental impact after implementation is high, the economic and social impact are negative. It was not investigated in the data-analysis because the data was not present in the BIN-dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.3.3 Manure fermentation		High	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The mitigation potential of manure fermentation is high, but the consequences after implementation to the farmer are negative. This means further research and development is still required to make this a viable mitigation measure. It was not investigated during the data-analysis because the data was not present in the dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.3.4 Manure separation		Average	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The literature review showed that this measure has an average environmental impact, whereas the economic impact is positive and the social impact is negative. This was however not investigated during the research because the data was not present in the dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.3.5 Decrease manure temperature		Average	Unknown	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The environmental impact was hypothesized to be average, whereas it was expected that the social impact is negative. The economic impact remained unknown because there was not scientific information available on this. It was not possible to investigate this in the data-analysis because the data was not available.			

Category 2.4 – Crop and fertilization

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.4.1 Use of grass-clover		Average	Negative	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not significant	Not significant	Not significant	Not significant
	Written conclusion	It was hypothesized during the literature review that the potential mitigation of greenhouse gases is average, while the economic impact after increasing the grass-clover percentage will be negative. The social impact remained unknown. All the results in the data-analysis were insignificant.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.4.2 Nitrification inhibitors		Average	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Nitrification inhibitors have an average environmental mitigation potential, but the economic and social impacts to the farmers are negative. This means more development is required to make it a viable measure for all impacts. Data-analysis was not possible because the data was not available in the dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.4.3 Precision application of fertilizer		Average	Break-even	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Based on literature it was concluded that this measure has an average environmental impact and a negative social impact. The economic impact can break-even, or a small positive or small negative result can be expected. It was not possible to analyse this measure in the data-analysis because the data was not present in the BIN-dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.4.4 Lower fertilizer gift of N		High	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Negative	Positive
	Written conclusion	Lowering the fertilizer gift of N was hypothesized to have a high mitigation potential and a positive economic impact. The social impact remained unknown because there is no scientific information available. In the data-analysis the environmental and social impact showed a significant positive result. The second economic model showed a significant, average, negative result, but this conclusion is not very strong since the first model did not have a significant result. The first model is more complete and gives therefore a stronger conclusion.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.4.5 Footprint chemical fertilizer		Average	Dependent	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	Reducing the footprint of chemical fertilizer has an average environmental impact, since the production of chemicals only represent a few percentages. The economic impact depends on the prices for fertilizers with a lower footprint. The social impact remained unknown, but the measure will not have a large impact on the social indicators. It was not suitable for data-analysis since the data was not present in the database.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.4.6 Cultivation of concentrate substitutes		Unknown	Negative	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Not significant	Not significant	Negative
	Written conclusion	It was not possible to find reliable information on the mitigation potential of this measure, but the economic and social impact was hypothesized to be negative. In the data-analysis, the environmental impact was positive. The economic impact was not significant, so the hypothesis could not be tested by the data-analysis. The social impact was the same compared to the literature review.			

CATEGORY 2.5 – ENERGY

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.1 Solar panels		Average	Dependent	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Positive	Negative	Positive	Not significant
	Written conclusion	Solar panels have an average mitigation potential according to literature, but it is all dependent, similar to the economic impact, on the way the solar panels are installed. The social impact was hypothesized to be negative. The data-analysis on the environmental impact was positive, while the social impact was not significant. The economic impact remains complicated, the first model was negative and the second model was positive. Therefore, there it is hard to align a conclusion to the economic impact.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.2 Windmills		High	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The generation potential of wind turbines is high, and the installations pay themselves back financially. The social impact of wind turbines on farmers' lives is not mentioned in the literature. It should be considered that there is a social impact on the surroundings of the location where the wind turbine is placed. Data-analysis was not possible because the number of farmers that implemented this measure was too low.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.3 Heat recovery		Low	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The mitigation potential of this measure is just very small, but the savings on energy pay back the initial investment. The social impact is unknown but it is safe to assume that this is just minimal. It was not suitable for data-analysis because the information was not available in the dataset.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.4 Pre-cooler		Low	Positive	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The same principles apply for this measure as to measure 2.6.3, the mitigation potential is just low but the initial investment is paid back by the savings. The social impact is expected to be minimal. It was not taken into account during the data-analysis because the data was not available.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.5 LED-lightning		Average	Dependent	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The environmental impact is greater compared to other electricity reduction measures. The economic impact is dependent on many variables such as lightning schedules. The social impact remained unknown. This measure was not suitable for data-analysis since the data was not available.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.6 Optimal usage of electricity		Low	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Negative	Positive	Not significant	Negative
	Written conclusion	It is possible to gain from this financially, but the mitigation impact is just low and the social impact is negative. These were the hypotheses before the data-analysis. The data-analysis showed that it has a negative environmental impact, but this is not true. It only says that farms that use less electricity emit more greenhouse gases in general. The data-analysis showed that the conclusions on the economic and social impact are the same as in the literature review.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.7 Reduce diesel consumption		Low	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Negative	Positive	Negative	Negative
	Written conclusion	Reducing the diesel consumption has a low environmental impact because electricity only makes up a small part of the total GHG emissions. There are significant costs savings that can be made, but this takes some work to reach this. The data-analysis showed a negative correlation between reducing the diesel usage and GHG emissions. This has possibly to due with the fact that the direct impact is just low. The other two elements were comparable with the literature review.				

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.5.8 Biodiesel		Low	Dependent	Unknown	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The environmental impact is low because diesel usage only takes up a small part of the total GHG emissions. The economic impact depends on the prices of conventional diesel and biodiesel. The social impact remained unknown, but it can be assumed that this is minimal. It was not possible to investigate this measure in the data-analysis since the information was not available in the dataset.			

CATEGORY 2.6 – LAND

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.6.1 Not ploughing permanent grassland		Dependent	Dependent	Positive	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The environmental impact of this measure depends on, among others, the weather after ploughing and time of ploughing, if the grassland is ploughed. The economic impact depends on the soil type of the grassland and the grassland management. The social impact is positive because less labour is required. It was not suitable for data-analysis because the data was lacking in the dataset.			

<table>
<tr><td>Measure</td><td rowspan="2">Literature review</td><td>Environmental impact</td><td>Economic impact</td><td>Social impact</td><td></td></tr>
<tr><td rowspan="4">2.6.2 Reduce grassland renewal</td><td>Average</td><td>Positive</td><td>Positive</td><td></td></tr>
<tr><td rowspan="2">Data-analysis</td><td>Environmental impact</td><td>Economic impact (model 1)</td><td>Economic impact (model 2)</td><td>Social impact</td></tr>
<tr><td>Not significant</td><td>Not significant</td><td>Not significant</td><td>Positive</td></tr>
<tr><td>Written conclusion</td><td colspan="4">It was hypothesized that the environmental impact is average and that the economic and social impacts are positive. In the data-analysis it could only be confirmed that the social impact was positive, the rest of the results were not significant.</td></tr>
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<table>
<tr><td>Measure</td><td rowspan="2">Literature review</td><td>Environmental impact</td><td>Economic impact</td><td>Social impact</td><td></td></tr>
<tr><td rowspan="4">2.6.3 Catch crops and green manures</td><td>Low</td><td>Dependent</td><td>Negative</td><td></td></tr>
<tr><td rowspan="2">Data-analysis</td><td>Environmental impact</td><td>Economic impact (model 1)</td><td>Economic impact (model 2)</td><td>Social impact</td></tr>
<tr><td colspan="4">Not suitable for data-analysis</td></tr>
<tr><td>Written conclusion</td><td colspan="4">The environmental impact of this measure is low, and the social impact is negative. The economic impact depends on the moment of sowing the catch crops. Therefore, this measure is one of the least important measures to implement on practical level. It was not investigated in the data-analysis because the data was not present.</td></tr>
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<table>
<tr><td>Measure</td><td rowspan="2">Literature review</td><td>Environmental impact</td><td>Economic impact</td><td>Social impact</td><td></td></tr>
<tr><td rowspan="4">2.6.4 Drainage in peat areas</td><td>Dependent</td><td>Break-even</td><td>Negative</td><td></td></tr>
<tr><td rowspan="2">Data-analysis</td><td>Environmental impact</td><td>Economic impact (model 1)</td><td>Economic impact (model 2)</td><td>Social impact</td></tr>
<tr><td colspan="4">Not suitable for data-analysis</td></tr>
<tr><td>Written conclusion</td><td colspan="4">The environmental impact depends on the magnitude of implementation and on the level on which the ditches are installed. The measure will not result in a large profit or large loss. The social impact is negative due to the extra work that is required. It was not suitable for data-analysis because the data was not available in the dataset.</td></tr>
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Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.6.5 Non-inversion tillage		Unknown	Positive	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The environmental impact remained unanswered by the scientific literature. The economic impact is hypothesized to be positive, while the social impact is negative. The data-analysis was not possible to perform because of unavailability of the data.			

Measure	Literature review	Environmental impact	Economic impact	Social impact	
2.6.6 More grass in crop rotation plan		Unknown	Break-even	Negative	
	Data-analysis	Environmental impact	Economic impact (model 1)	Economic impact (model 2)	Social impact
		Not suitable for data-analysis			
	Written conclusion	The environmental impact is unknown by literature, because most literature is focused on increasing the maize on the cultivated area. The economic impact will be minimal and the social impact is negative due to the extra work required. The measure could not be investigated in the data-analysis due to the fact that the data was not present.			