Impact of ammonia reduction measures on farmer income, governmental costs and ammonia reduction

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Abstract

This thesis investigates the multifaceted effects of ammonia reduction measures in the Netherlands. Hereby aiming to help address the pressing issue of high ammonia emissions in the agricultural sector of the Netherlands. Beforehand, an overview of the historical context of ammonia emissions and the surrounding policy is given. Thereafter, some potential measures are examined on their effects on farmer income, governmental costs and ammonia reduction. This was done for a reference farm which was based on the characteristics of an average size dairy farm.

The effects on farmer income were calculated through a partial budgeting approach, where for the buyout option a cashflow analysis was done pre-emptively. The costs for the government consisted of the subsidies they gave combined with the purchasing of production rights, varying for each measure. The reduction in ammonia was given as a percentage from baseline, based on the decrease in the number of cows or on innovation. Lastly, a group-based optimization of 15 farmers was done, to showcase the potential effects of the combination of all the measures.

The results showed that subsidizing innovative stable systems was the most promising of the measures examined in this research, which calls for further research into the actual effectiveness of these innovative stable systems and research into new disruptive innovations to reduce the emissions of the agricultural sector. Additionally, it showed that with a high enough budget buying out farmers can be a successful measure, as it then decreases a lot of ammonia emission, while still leaving room in the budget for other measures.

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1. Introduction

Dairy cows do not efficiently use their dietary nitrogen. Of all the nitrogen they consume, about one-third is either used by the cow herself or is secreted in the milk (Weis, 2005). The rest is excreted in urine and feces. While cows don't excrete much ammonia through their feces and urine, when feces and urine are combined (manure), the nitrogen in the manure is converted into ammonia through bacterial degradation (Ishler, 2016). Between 60 and 80 percent of the nitrogen in urine is in the form of urea. Urease, an enzyme produced by microorganisms in feces and soil, reacts with urea and converts it to ammonia. Ammonia is a volatile gas that can escape into the atmosphere and when an abundance of ammonia deposits in natural areas, it can potentially lead to changes in the soil and vegetation of these areas (Loubet et al., 2006).

The Netherlands has many Natura 2000 areas and one of the main goals of Natura 2000 areas is preserving nature. High nitrogen deposition complicates the preservation of Nature, especially for areas that are sensitive to nitrogen like heath- and woodlands (Kros et al, 2008). To protect these areas the government wants to lower nitrogen emissions in the Netherlands. Nitrogen emission comes in two main forms: Ammonia (NH3) and Nitrogen oxide (NOx) (RIVM, n.d.), where ammonia is mostly emitted by animals in agriculture and nitrogen oxides are mainly emitted by traffic and the industry. This thesis exclusively addresses the issue of Nitrogen emission through Ammonia, which means that Nitrogen reduction measures are actually ammonia reduction measures in this context, which they will also be called in this thesis. Ammonia emissions in the Netherlands have already decreased notably. In 1982, there was an emission of 240 kilotons of ammonia, this decreased to 150 kilotons in 2000 and 124 in 2020 (CBS, 2022). The reduction in the last 20 years remains modest and as highlighted by Kros et al, back in 2008, further reduction is needed to ensure the long-term health of these habitats.

For the Dutch government, it has been a challenge to formulate suitable legislation to achieve a reduction in ammonia deposition while concurrently facilitating a stable operational environment for their (farm) businesses. Already in 2011, there were complications in granting permits for farm expansions and the construction of new infrastructure close to protected nature reserves (Julen, 2022). In the following years, the Nitrogen Action Programme (PAS) was launched to remediate this problem. This legislation was inadequate, because in 2019 the State Council (Raad van State; the highest legislative body in the Netherlands) decided that the PAS could not be used anymore to authorize activities that cause additional nitrogen deposition on Natura 2000 areas (Raad van State, 2019). This decision necessitates that the Dutch government provides new legislation to address nitrogen deposition in nature reserves.

In a letter to the parliament the Ministry of Agriculture, Nature and Food Quality (Ministry of LNV) proposed several measures, consisting of a voluntary buy-up arrangement to make room for new activities in the short term and other possible solutions like innovation, less protein in feed and nature inclusive farming to lower the ammonia emissions in the long term (Ministry of LNV, 2022a). These long-term changes will change farm business operations and thus also their income. What is unclear, however, is the impact of these measures. More specifically, the impact of these measures on farmer income, costs for the government and ammonia reduction. When examining the individual measures on their own the focus primarily lies on which measures are the most effective, while a combination of measures might be the most effective. Therefore this thesis also examines the measures on a group basis, to explore the combined effects.

1.1 Study objective:

The objective of this study is to assess the multifaceted effects of ammonia reduction measures within the agricultural sector. Specifically, the effects on the income of the farmer, the reduction in ammonia and the costs for the government. Additionally, the differences between an individual and a group-based approach for these measures will be evaluated. To reach this objective the following research questions will be answered:

- What are the potential ammonia reduction measures and how might they impact farmer practices?
- What are the individual effects of these measures on farmer income, governmental costs and ammonia reduction?
- What are the collective effects of ammonia reduction measures, when optimizing a group of farmers choices depending on varying constraints?

2. Background

This background will first introduce the nitrogen crisis and give an overview of how it originated and developed. It will discuss the European directives and the Natura 2000 network, which this thesis uses as the start of the crisis. Thereafter, we elaborate on the reactions of the Dutch government to these directives. This will show various legislation that was accepted and later invalidated throughout the years 2006 to 2019 and the current situation. The second part of the background delves into how the economic effects of changes in farmer practices have been measured over the years.

2.1.1 Habitats and birds directive

In 1992, the European Union accepted the Habitats Directive, which this thesis takes as the start of the beginning of the Dutch nitrogen crisis (Eur-lex, 1992). The Birds Directive dating from 1979 is also of importance, as the assigned protected areas of this directive were also included in the Habitats Directive. However, most protected areas come from the Habitats Directive. The Habitats Directive was established to conserve, protect and improve the quality of the environment. With the goal of contributing to sustainable development of the protected areas and hereby conserving and improving biodiversity (European Commission, N. D., a).

The Habitats Directive identifies certain habitat types and animal- and plant species that must be protected. Examples of habitat types are dunes, forests or heathlands. Next to the protection of certain habitat types, natural habitats of animal- and plant species can also be designated for protection, to ensure the protection of these species.

2.1.2 Natura 2000 network

The main component of the Habitats Directive is the Natura 2000 network which has grown into the largest coordinated network of protected areas in the world with almost 28,000 sites in Europe (European Commission, 2020). The network takes up around 18% of Europe's land area and around 10% of the surrounding seas. For the Netherlands, 14.7% of the total land area is part of the Natura 2000 network (European Environment Agency, 2018). This means that for the Netherlands the area is slightly less than average, which could be explained by the higher population density in the Netherlands leaving less space for nature.

A Natura 2000 site is an area that is appointed to protect a certain habitat, plant or animal following the Habitats Directive. The choice of whether a certain area will be classified as a Natura 2000 site is based on the scientific criteria stated in the Habitats Directive (European Commission, N. D., b). The responsibility for assigning these sites lies with the member states themselves. They had to carry out extensive assessments for all habitats and species present in their country and then submit a list of "proposed Sites of Community Importance". This list had to include information such as the location, size and types of species/habitats. The European Environment Agency then assisted the European Commission in analyzing these proposals. When a site becomes a designated Natura 2000 area, the member states are duty-bound to prevent further deterioration. Additionally, they must introduce positive conservation measures to improve the conditions of these Natura 2000 sites to a favorable conservation status (European Commission, 2020).

2.1.3 Assigning Natura 2000 sites and goals

The years following the introduction of the Habitats Directive were about assigning Natura 2000 sites and drawing up the goals the Netherlands has for their Natura 2000 sites. This took up a considerable amount of time, because only in 2003 and 2004 were the proposed sites submitted to the European Commission and later accepted (Ministry of LNV, 2006).

In the Netherlands, there are 162 Natura 2000 sites, which were all designated back in 2003 and 2004. The provincial authorities are responsible for implementing conservation policies for these sites (Ministry of General Affairs, 2022). The provinces were required to formulate a governance plan for each site that resides within their jurisdiction. The provinces often collaborate with other involved parties of the Natura 2000 site to develop the governance plan. These plans describe the area, including all habitats and species within the site, and provide an overview of current activities and initial conditions. Additionally, they outline a vision for the future to address the core tasks of the area, such as implementing measures and monitoring progress. For instance, a governance plan might describe how to protect a particular bird species or restore a certain habitat.

2.1.4 Permits in and around Natura 2000 areas

According to European agreements, as implemented in Dutch legislation, The Netherlands must prevent further deterioration of Natura 2000 areas. This means that when starting a new activity, for example expanding a stable or building a new road, one must show that the nitrogen emission caused by this activity does not affect a Natura 2000 area. If an activity is deemed to have a negative effect on a Natura 2000 area it will not get a permit, unless the expected nitrogen deposition will be offset internally or externally. (BIJ12, 2022)

The first regulation for permits was introduced in 2007 and called: the ammonia and Natura 2000 assessment framework. With this framework, there were still many ways to get a permit to expand your farm.

1. If a farm was still soil-bound after expansion it would get a permit.
2. If a farm's ammonia deposition on the closest Natura 2000 area is lower than 5% of the critical threshold value, it gets a permit.
3. If the new ammonia deposition is lower than before the expansion, it gets a permit, even if the deposition is higher than the critical threshold value of 5%
4. If the farm after expansion goes beyond the critical threshold value of 5%, but in the Natura 2000 area the total deposition is lower than the critical deposition the farm can also get a permit (Ministry of LNV, 2007)

This framework was not supported by environmental and nature organizations, and it was meant as a temporary measure (Trojan, 2008). In December of 2007, two environmental organizations objected to a permit that was given through the assessment framework, following this case the Raad van state (the highest governing body in the Netherlands) decided to suspend the permit (Ministry of LNV., 2008). This was because the chair of the administrative law department had serious doubt whether the assessment framework delivered a sufficient guarantee that the expansion of this case would not result in significant effects on a Natura 2000 area. This led to the conclusion that the ammonia and Natura 2000 assessment framework was not legally tenable.

After the retraction of the assessment framework, it was still possible to get a permit through the Nature Protection Law 1998. However, this method was also suspended temporarily in April 2009, after the Raad van state suspended a permit that was granted through the Nature Protection Law 1998 (Broekmeyer et al., 2012). This all occurred at the same time as the economic crisis, which prompted the introduction of new legislation: the Crisis and Recovery Act. The Crisis and Recovery Act made it possible to speed up the projects in their spatial plans, for example, building projects could start faster (Ministry of Infrastructure and Water Management, 2020). It also brought a new framework to make binding agreements between the government, provinces, and other authorities about the reduction of nitrogen emissions (Broekmeyer et al., 2012). This framework would evolve into the Nitrogen Action Program (PAS).

2.1.5 Nitrogen Action Program (PAS)

PAS was created as a solution to make room for economic development in and around Natura 2000 areas and to stop the deterioration of nitrogen-sensitive habitats (Broekmeyer et al., 2012). Although the implementation of the crisis and recovery law in 2010 marked the inception of PAS, the program was not officially accepted and put into effect until 2015.

PAS was meant to be a cohesive action plan involving all authorities, at local and national levels, in addressing the issue of nitrogen (Drahmann & Sietses, 2015). There were two main approaches to mitigate the nitrogen pressure on the Natura 2000 areas: source-oriented measures and recovery measures. The source-oriented measures were meant to reduce the nitrogen deposition in nature areas by creating measures to lower the ammonia emission from the agricultural sector near Natura 2000 areas. These measures were specific for the agricultural sector, as other regulations already required other sectors to lower their nitrogen deposition in Natura 2000 areas. The recovery measures were meant to improve the resilience of the nitrogen-sensitive areas to nitrogen deposition, for example by improving water management in the areas.

These measures were meant to make sure there is a decrease in nitrogen deposition in the nitrogen-sensitive areas, creating room for new activities. This was called economic development space. This economic development space would thus come from a decrease in nitrogen deposition in Natura 2000 areas and it would be given out to new projects which would be of importance economically (Drahmann & Sietses, 2015). These projects would also have nitrogen deposition in the areas but could still receive a permit because the anticipated decrease in nitrogen deposition would serve as compensation.

This meant that PAS started with two conflicting goals: to reduce nitrogen deposition on Natura 2000 areas and on the other hand to issue permits for activities in and around these areas that would result in additional nitrogen deposition. Another point of conflict involved uncertainty regarding whether the proposed measures would achieve a practical reduction in nitrogen deposition comparable to the calculated estimates. The Commissie milieueffectenrapportage (Commission of Environmental Effects Reporting) was critical of the feasibility and effectiveness of the recovery measures and stated that the effects were uncertain and overly optimistic (Commissie MER, 2015).

Despite the criticism and the complex legal framework of the PAS, the secretary of state at the time was able to convince the parliament that it would be legally tenable (Julen, 2022). In 2019 however, the Raad van State ruled that PAS was untenable, just like they did with the ammonia and Natura 2000 assessment framework (Raad van State, 2019). The reasoning was that the positive effects upon which the economic development space relied were not predetermined, which was found to violate the Habitats Directive.

During the PAS, entrepreneurs and businesses that started an activity with a small amount of nitrogen deposition could proceed with just a notification of the calculated additional nitrogen deposition, following the law of nature protection (Ministry of LNV, 2023a). However, since the invalidation of the PAS, these entrepreneurs and businesses are now obliged to get a permit for these same activities that cause additional nitrogen deposition. The issue however is that there is no available nitrogen space to permit these businesses for their activities, making them partly illegal. It is not the fault of the entrepreneurs and businesses, which is why the government hopes to create a solution to make these businesses legal again. This takes a long time because the verdict was already years ago in 2019.

2.1.6 Current situation

The current situation of the Nitrogen crisis is in a way still similar to the years around 2010, with the issuance of permits in and around Natura 2000 areas in a difficult position. It is essential to implement new measures that reduce nitrogen deposition in nitrogen-sensitive areas, so that these areas reach a favorable conversion status. It is important that the effects of these measures are predictable and can be accurately measured, considering previous legislation was invalidated due to uncertainty in the effects of the measures. Previous policies seemed to prioritize the economic perspective, focusing on simplifying the permitting of new activities in and around the nitrogen-sensitive areas, while secondly trying to comply with the Habitats and Birds directives. This approach has led to insufficient legislation, which has led to an accumulating nitrogen problem.

To address this issue, both short-term and long-term solutions are required to bring the Natura 2000 areas to a favorable conversion status and create room for economic activities. Short-term solutions are also needed because numerous businesses need nitrogen space to legalize their businesses. For the mid- and long-term, measures that reduce nitrogen deposition in nitrogen-sensitive areas must be developed, creating room for new activities. These measures must be legally tenable to provide a sustainable long-term solution.

The government already set certain goals to improve the state of Natura 2000 areas. In the law nature protection, Article 1.12a states that at least 40% of the nitrogen-sensitive Natura 2000 areas must have a deposition lower than the amount of mol per hectare which would cause deterioration in 2025, 50% in 2030 and 74% in 2035 (Ministry of LNV, 2021). Additionally, a Nitrogen reduction and Nature improvement program was released. This program states that the government wants to achieve 74% of areas in a favorable conservation status already in 2030, instead of in 2035 (Ministry of LNV, 2022b). This means that in those areas the reduction must reflect the difference between the current state and the favorable conservation status, accounting for the additional deposition of new activities.

2.2 Economic background

Over the years, environmental legislation has had a significant economic impact on Dutch dairy farms. As a result, some literature has emerged concerning the economic effects of environmental regulations on Dutch dairy farms. An important piece of literature is the introduction of a deterministic static linear programming (LP) model of a dairy farm by Berentsen and Giesen (1995). The objective function of this model maximizes labor income, and the model can be used to determine the effects of technical and price changes on the farm plan, economic results and nutrient losses to the environment.

In the following years this LP model has served as a basis for various studies and has been continually adjusted for new scenarios over time. For instance, Berentsen and Tiessink (2003) used it to assess the consequences of two new environmental policies that were introduced at the time (MINAS and MFAS) on farm management, environment and farm economics. Following this study, Berentsen (2003) also investigated whether increasing animal productivity was an effective way of adhering to these new policies. A few years later it was used to calculate the costs and benefits of on farm nature conservation (Berentsen et al., 2007).

In 2013 The LP model underwent another update to define a typical Dutch dairy farm on sandy soils. The market prices of the time were updated in the model, together with new environmental policies (Van Middelaar et al., 2013). After the update the model was utilized to determine an optimal feeding strategy and, together with other calculations, to estimate the greenhouse gas emissions that the strategy would cause. A few years later the model was updated with the new Dairy Act, to examine the effects of the abolition of the milk quota and the introduction of a new manure policy based on a phosphate quota (Klootwijk et al., 2016). Recently the LP model was also adjusted to reflect an average peat soil farm, to examine the environmental and economic performance of peat soil farms (Van Boxmeer et al., 2021).

Earlier research on assessing farmers' income effects shows the use of the partial budgeting approach. For example, in 1994 Hady et al. examined the effects of management changes for a reproductive program through a partial budgeting analysis and in 1996 Van Schaik et al. showed that vaccination against paratuberculosis was profitable with partial budgeting. According to Rabin et al. (2007): "Partial budgeting is a useful tool to analyze the effects of expanding an enterprise, substituting crops, changing or adopting production practices, participating in a government program and when considering an alternative enterprise". The broad range of applications of partial budgeting means that it can be used for varying types of studies. For example, Tao et al. (2010) used partial budgeting to estimate the changes in net revenues associated with the implementation of manure nutrient management plans for dairy farms in Connecticut. More recently Clark, S. (2020) used partial budgeting to examine the economic effect of adding an on-farm store to an already existing farm.

In Dutch research partial budgeting was also used, for example, to estimate the economic benefits of a lactational treatment and an antibiotic treatment of mastitis (Swinkels et al., 2005a), (Swinkels et al., 2005b). Furthermore, Valeeva et al. (2007) used partial budgeting to calculate the costs of implementing various control measures in different stages of the dairy chain.

2.3 Conceptual framework

For this study, we focus on two main stakeholders: dairy farmers and the government. Other stakeholders may be impacted by the policies considered, such as the agrofeed industry, but these are out of the scope of this study.

For farmers, we examine the effects of the measures on their yearly income, as this is deemed the crucial factor in understanding the economic consequences the measures have on farmers. For the government, we calculate the cashflow, as the government will mostly engage in one-time investments which have to benefit the natura 2000 areas and will thus not have a monetary return on investment. It is, however, important to know the total investment the government will have to make to realize the measures, hence the choice to calculate the cashflow.

Figure 1 shows how this thesis can be divided into 3 parts. In the first part, the partial budgets of the measures are made. In the second part the effects of the measures on the income of the farmers, the ammonia reduction and the costs for the government are calculated. In the third part, the effects of a group of 15 farmers on farmer income, ammonia reduction and costs for the government are simulated through optimization and the results are shown on a group basis.

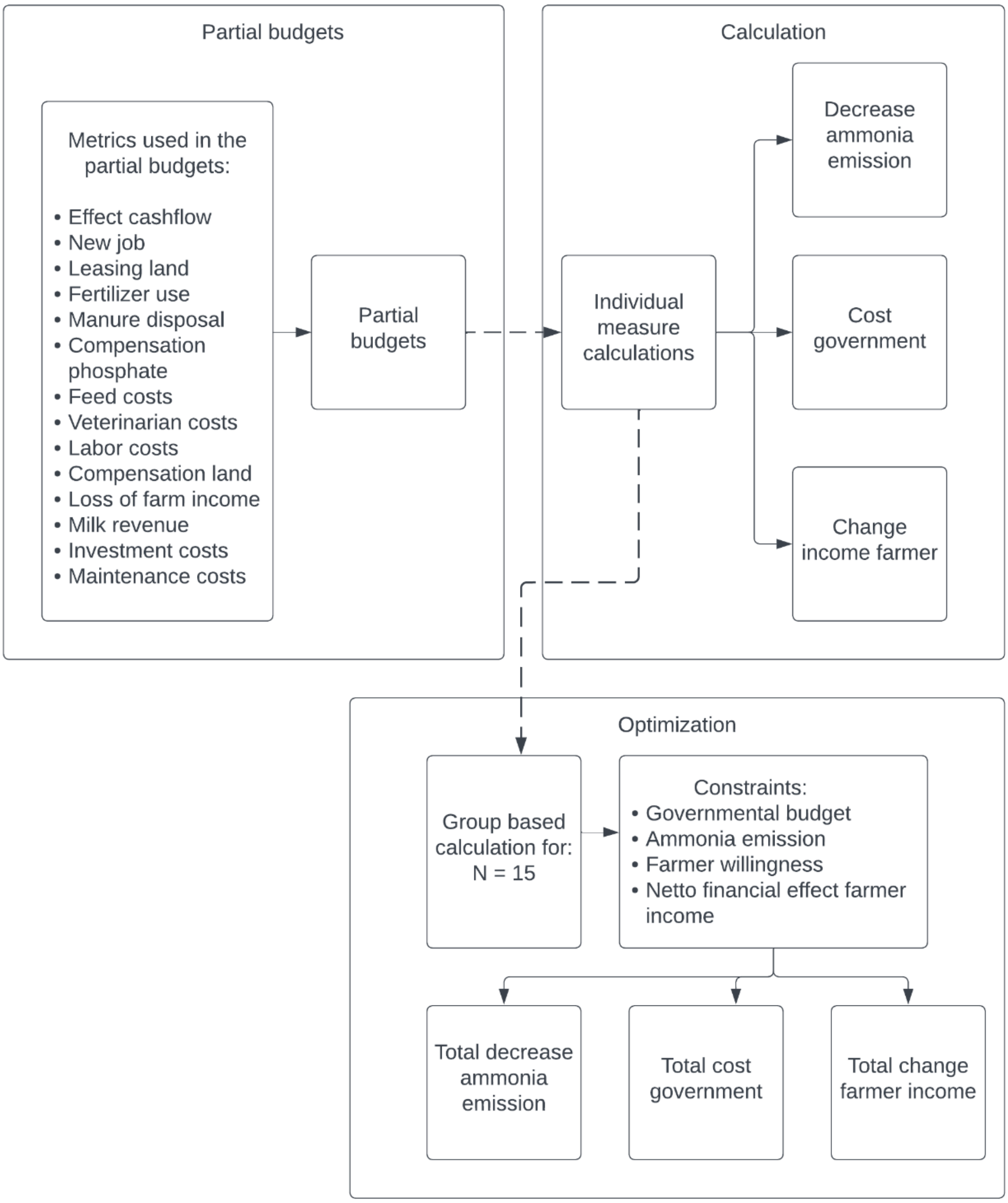

Figure 1 Conceptual framework showing 3 different parts of this research, partial budgets with the metrics that impact farmer income, calculation with the calculation of these effects and optimization where the outcomes of the calculation are optimizaed on a group level

In the first section, a partial budget was formulated for each measure. These partial budgets were approached from the perspective of the farmer. For every measure, different factors affect the partial budget, most notably the cashflow following a buyout and the calculation of the investment costs for the innovation measure using an amortization formula (Wittwer, J. 2020).

The partial budgets were then used in the calculation model, of which the results showcase the effects of the measures on an individual level. This will give the effects of income change, governmental costs and ammonia reduction for a reference farm.

In the last part of the research, the measures are simulated in a group context, with a group consisting of 15 farmers. This simulation mirrors real-world scenarios, shedding light on the collective impact of these decisions within a group setting. The goal is to find out which choices would be made considering certain constraints that would be logical for a group of 15 farmers, and what impact these choices would have on the collective income change of the farmers, costs for the government and ammonia reduction.

3. Materials and Methods

This section describes the approach to this study. First, it describes the parameters of the dairy farm and the fictional situation that was created to simulate the effects of these measures on a group basis. Secondly, it describes the process of selecting and defining ammonia reduction measures. Thirdly, the methods of determining the effects of these measures in terms of costs for the farmer, costs for the government and ammonia reduction are described. The last part describes the scenarios which were used to determine the group effects.

3.1 Fictional area

In my calculation, I assume a farming area consisting of 15 farms which are located near each other, each with their own characteristics. These characteristics are the same for every farm and are denoted by a lowercase i in the abbreviations. For example for the number of lactating cows (N_i^c), i stands for the farms and is similar for farm i1 to i15. The characteristics of the typical dairy farm were based on a sample of 276 farmers from BINternet [business information network], taken in 2021 (BINternet, 2022). For each of the 15 dairy farms, the following parameters were defined:

- 110 lactating cows (N_i^c)
- 33 young stock less than 1 year old $\left(N_i^{ysa}\right)$
- 30 young stock older than 1 year$\left(N_i^{ysb}\right)$
- 8.850 Kg milk per cow per year (N_i^{my})
- 60 hectares of land (N_i^{ha})
- 2,22 GVE per hectare (N_i^{gve})

3.2 Selecting and defining ammonia reduction measures

The government has defined a budget outlining the measures in which they aim to invest the available funds for realizing nitrogen, water and climate targets (Rijksoverheid, 2022). The measures that were discussed in this budget were used as a base for the construction of the ammonia reduction measures in this research. After having this base for the first measures, further research was done in (agricultural) newspapers and on Google, to get a better understanding of whether there were other options than the ones proposed by the government. This led to the inclusion of max GVE as another measure (Van Geest et al., 2023).

3.2.1 Buyout

The government has presented a measure with which they aim to buy out farmers (RVO, 2023a). This measure consists of a full buyout of the dairy farmer, meaning he has to cease his operations and sell his production rights. This ruling was called the landelijke beëindigingsregeling veehouderij (LBV) which is a national cessation scheme for livestock farming. The ruling makes a distinction with peek emitters, these peek emitters are located close to Natura-2000 areas and receive 120% compensation whereas non peek emitters receive 100%. The ruling for the peek emitters is called the LBV+. The government compensates the farmer in two ways. They pay for the production capacity (C_i^{pc}) and production rights(C_i^{pr}). Production capacity means the combined area of the stables, feed storage and manure storage in m^2 and production rights represent the phosphate rights. The compensation for production capacity is per m^2 and dependent on the age of the farm (A_i^f). The phosphate rights are bought for a standardized value of € 121 per phosphate right.

Only for the buyout measure we looked at the change in family income instead of the change of profit in the business itself.

The economic consequences of this measure are:

- Farmer receives compensation for his production capacity and production rights
- Farmer repays his loans with compensation from the government
- Farmer receives a standardized value of 5% a year on the money that remains after the loans are paid off.
- The income of the farmer changes from income through business practice to income from leasing out land combined with a new job
- Subsidy costs for the government

3.2.2 Innovation

With innovation in this study is meant the adoption of a circular system that separates the feces and urine of the cows. Some of the residual flows are turned into fertilizer, which can be used on the land instead of fertilizer that is purchased externally.

To determine the costs and ammonia reduction of innovation two innovations were examined, the Lely sphere (Lely, 2023) and the JOZ nitrogen cracker (JOZ, 2023). These results were compared to the PPP-Agro report (2022), which had also examined these or similar circular systems.

The economic consequences of this measure are:

- Farmer takes out a loan and invests in a circular system
- Farmer has yearly costs of loan repayment and interest payment and yearly maintenance costs
- Reduction of costs through a decrease of external manure disposition and lower purchasing costs of fertilizer
- Either no costs for the government or a cost through subsidizing a part of the purchase of the circular system

3.2.3 GVE measures

A GVE [grootvee-eenheid, livestock unit in Dutch] measure means a reduction in the number of cows per hectare. Farmers can have as many cows as they have hectares of land, multiplied with the limitation in GVE. This means that all farmers must adopt an extensive way of farming. We used a reduction to 1.7 (Van der Geest et al., 2023) and a reduction to 2.0 (about halfway the current GVE of 2.22 And the proposed 1.7). In this research, we assumed a decrease to the adequate GVE level by means of decreasing the number of cows and excluded the possibility to purchase extra land.

The economic consequences of this measure are:

- A decrease in income from milk yield for the farmer
- A decrease in costs through lower feed, veterinary, labor and manure disposal costs
- Government buys up phosphate rights

3.2.4 Nature inclusive

In the context of this research, the term “nature-inclusive measure” refers to a modification in the land-use plan for a segment of agricultural land. The agricultural land transitions in purpose to agricultural nature land. This was based on an already existing subsidy which addresses this transition (RVO, 2022). Based on the PPP-agro (2022) report, it was assumed that this transition to agricultural nature land results in a 50% decrease in the VEM [Voeder-eenheid melk, Feed-unit milk in Dutch] yield compared to agricultural land. Additionally, the quality of the grass is lower, resulting in a lower milk yield per cow. We opted to link the decrease in VEM yield to a reduction in the number of cows, meaning the farmer has to sell Phosphate rights associated with the decrease in VEM yield.

The economic consequences of this measure are:

- A singular influx of money for the farmer in the form of subsidy for land change and the sale of phosphate rights. This will be used for loan repayment
- A decrease in yearly costs for loan repayment and interest on loans
- A decrease in income from milk yield for the farmer
- A decrease in costs through lower feed, veterinarian, labor and manure disposal costs
- Subsidy costs for the government to compensate for the decrease in value of the land

3.3 Cost calculations of measures

In this section of the materials and methods, We elaborate on the calculation of costs for every measure. These cost computations show the annual financial impact on the farmer. Following the financial impact on income for the farmer the calculation for the governmental costs is shown. Lastly, we describe how the ammonia reduction of each measure was calculated.

3.3.1 Buyout

For the buyout an important intermediate step involved quantifying the impact of the buyout on the farmer's yearly income. This evaluation was conducted by executing a cashflow analysis on the buyout. This was an exception as only for this measure a cash flow analysis was executed before the calculation of the partial budget.

The farmer gets compensation for two things from the government, his production rights (C_i^{pr}) and his production capacity (C_i^{pc}). The compensation associated with his production rights was calculated in the following way:

$$C_i^{pr} = \left(N_i^c \cdot E^c + N_i^{ysa} \cdot E^{ysa} + N_i^{ysb} \cdot E^{ysb}\right) \cdot P^e.$$

E^c stands for the phosphate emission per cow in farm i and E^{ysa} and E^{ysb} stand for the phosphate emission per young stock less than 1 year old and older than 1 year respectively. P^e stands for the price of emission, which is the price per phosphate right. A phosphate right consists of 1 kg emission of phosphate.

For production capacity, a function was developed that would return the value per square meter production capacity depending on the age of the components included in the production capacity. This function was based on the corrected replacement value of livestock by the ministry of LNV (2023b). The function was called Value_per_m2(A_i^f).

This led to the following formula:

$$C_i^{pc} = CAP_i \cdot \text{Value\_per\_m2}(A^f)$$

Where CAP_i is the total production capacity of farm i in m^2.

Next to the compensation the farmer gets from the government, he will also receive money from selling his livestock (C_i^{ls}). This sums up to:

$$C_i^{ls} = N_i^c \cdot P^c + N_i^{ysa} \cdot P^{ysa} + N_i^{ysb} \cdot P^{ysb}$$

Where P^c, P^{ysa}, P^{ysb} stand for the price of a cow, price of young stock younger than 1 year and young stock older than one year respectively.

We assumed that the farmer must pay income tax on the cessation profit of his farm (C_i^{tax}). The tax rate for the initial €73,031 is 36.93%, while any amount exceeding this initial €73,031 is subject to a higher tax rate of 49.50% (Belastingdienst, 2023). This led to the following formula:

$$C_i^{tax} = (C_i^{pr} + C_i^{pc} - B^{cap} - 73031) * 0{,}495 + 73031 * 0{,}3693$$

Where B^{cap} is the book value of the production capacity.

With all previous formulas and some standalone values combined, the formula showing the end balance for the buyout (C_i^{buy}) was developed:

$$C_i^{buy} = C_i^{pr} + C_i^{pc} + C_i^{ls} + MCH - C_i^{tax} - MD - L$$

In this formula MCH stands for the value of sold machinery, MD stands for the costs of manure which would have to be disposed and L stands for the outstanding loans of the farmer.

3.3.2 Innovation

For innovation, the yearly costs for the farmer were calculated by combining an annual loan payment formula with the yearly maintenance costs and the reduced costs. This cost of innovation was denoted as (C_i^{inn}):

$$C_i^{inn} = \frac{r * PV}{1 - (1 + r)^{-n}} + C_i^{main} - Rmd_i - Rf_i$$

The annual interest rate expressed as a decimal is r. PV is the value of the loan which finances the investment and n is the number of years over which the payment is divided. The yearly maintenance costs were denoted as C_i^{main} and were based on the calculation of the economic effects of the JOZ nitrogen cracker by Countus (2022) and adjusted for the number of cows. The reduced costs consisted of reduced costs from manure disposal (Rmd_i) and reduced fertilizer use costs (Rf_i). The Rmd_i were also based on the calculation from Countus and adjusted for the number of cows and the Rf_i were based on the average fertilizer costs on the average of the years 2022 and 2021 (Binternet, 2023b). The present value of the investment costs (PV) for the installation of the innovation were not adjusted for the number of cows as we assumed there would be significant fixed costs and wanted to create a margin of safety. They were however valued a bit lower at € 250.000 instead of the € 275.000 from Countus (2022).

To determine the effects of a subsidy on the costs of innovation, we lowered the PV with € 100.000 while keeping all other parameters constant.

3.3.3 GVE measures

The GVE measure in this research would purely reduce the number of livestock. To calculate how much livestock had to be reduced we first calculated the percentage of reduction needed to comply to the proposed GVE-norm (DEC_{xi}).

$$DEC_{xi} = (x - N_i^{gve})/N_i^{gve},$$

In which x stands for the GVE-norm and N_i^{gve} reflects the number of GVE per hectare at farm i.

With the help of the integer function in Python, we then calculated the new number of cows at GVE level x (NN_{xi}^c):

$$NN_{xi}^{c} = INT(N_i^c * \left(1 + \frac{DEC_{xi}}{100}\right))$$

Subtracting NN_{xi}^{c} from N_i^c gives us the difference in the number of cows at GVE level x for farm i: DN_{xi}^{c}. The same calculations were done for the 2 groups of young stock, giving us DN_{xi}^{ysa} and DN_{xi}^{ysb}.

After having calculated the differences, their effects on other costs were calculated. We assumed there would be changes in the total VEM use ($Cvem_{xi}$), labor costs (C_{xi}^{l}), veterinarian costs (C_{xi}^{v}) and manure disposal costs (CM_{xi}).

For VEM use the calculation was the most extensive, first, it was examined how much VEM cows and young stock need on average based on the ruminant tables of the CVB (2022). These averages were then multiplied with the differences in cows and young stock. This led to a total change in VEM used for GVE level x which was multiplied by a specific price per VEM (WUR, 2023). This led to a change in costs denoted as ($Cvem_{xi}$), The calculation can be found in the appendix.

The change in costs for labor $\left(C_{xi}^{l}\right)$ and veterinarian costs (C_{xi}^{v}) were calculated by:

$$C_{xi}^{l} = DN_{xi}^{c} * N^{my} * C^{lbr}$$

$$C_{xi}^{v} = DN_{xi}^{c} * N^{my} * C^{vet}$$

Where C^{lbr} stands for the cost of labor per kg of milk and C^{vet} stands for the veterinarian costs per kg of milk. The milk yield in kg per cow is denoted as N^{my}.

The decrease in manure disposal costs (CM_{xi}), was calculated as follows:

$$CM_{xi} = \left(DN_{xi}^{c} * M^{c} + DN_{xi}^{ysa} * M^{ysa} + DN_{xi}^{ysb} * M^{ysb}\right) * C^{man}$$

Where M stands for the amount of manure in m^3 the cows or young stock produce per year and C^{man} stands for the cost of disposing one m^3 of manure.

The government buys up the phosphate rights the farmer is unable to utilize because of the GVE limit. This compensation is used to reduce the farmer's loans, causing for lower yearly loan repayment and lower yearly interest costs, combined in (C_{xi}^{comp}).

$$C_{xi}^{comp} = \left(DN_{xi}^{c} * E^{c} + DN_{xi}^{ysa} * E^{ysa} + DN_{xi}^{ysb} * E^{ysb}\right) * P^{e} * (L_i^r + L_i^i))$$

Where L_i^r and L_i^i represent the yearly loan repayment percentage and interest percentage respectively.

These changes in costs combined with the loss in milk revenue lead to a total change in costs for the GVE measure ($Cgve_{xi}$) of:

$$Cgve_{xi} = (DN_{xi}^{c} * N^{my} * P^{m}) + C_{xi}^{l} + C_{xi}^{v} + CM_{xi} + Cvem_{xi} + C_{xi}^{comp}$$

Where P^{m} is the milk price per kg of milk.

3.3.4 Nature-inclusive

For the nature-inclusive measure, we employed a formula similar to the GVE measure to determine the new number of cows (NN_{yi}^{c}). This formula differed in that it was now based on the percentual change of the grassland, denoted as y. If y% of the grassland transitioned to agricultural nature land, the number of cows would change with 0,5y%. This change in the number of cows was because we assumed that grassland that transforms into agricultural nature land only yields 50% of VEM regular grassland yields and we wanted to correlate the decrease in VEM yield to the number of cows. This gives the following formula which illustrates the new number of cows for the nature-inclusive measure (NN_{yi}^{c}):

$$NN_{yi}^{c} = INT(N_{yi}^{c} * \left(1 + \frac{0{,}5y}{100}\right))$$

Regular grassland has 2 times the yield of agricultural nature land. The feed intake from regular grassland (F_{y}^{gr}) is calculated as follows: $F_{y}^{gr} = \left(\frac{100-y}{100-0.5y}\right)$. Additionally, the quality of the roughage coming from agricultural nature land is lower, leading to a lower milk yield (PPP-Agro, 2022).

With the percentage of feed intake from regular grassland and the milk loss through the quality of roughage we calculated the change in the milk yield per cow (NN^{my}):

$$NN_{y}^{my} = N^{my} - \left(1 - F_{y}^{gr}\right) * 100 * N^{ml}$$

Where N^{ml} is the loss of milk yield in kg per percentage of feed derived from agricultural nature land.

Combined with the decrease in cows, this leads to a difference in the total revenue of milk (C_{yi}^{mr}), which is calculated by:

$$C_{yi}^{mr} = (NN_{yi}^{c} * \ NN_{y}^{my} - N_{i}^{c} * N^{my} -) * P^{m}$$

The difference in labor (C_{yi}^{l}) and veterinarian (C_{yi}^{v}) costs were calculated similarly as the GVE measure. The only difference is that they were also adjusted for the lower milk yield per cow.

$$C_{yi}^{l} = (N_{i}^{c} * N^{my} - NN_{yi}^{c} * \ NN_{y}^{my}) \ * C^{lbr}$$

$$C_{yi}^{v} = (N_{i}^{c} * N^{my} - NN_{yi}^{c} * \ NN_{y}^{my}) * C^{vet}$$

The farmer gets compensated for every hectare that is changed into agricultural nature land. To show the effects of this compensation on his yearly income we subtracted the compensation from his outstanding loans and calculated the effects on his yearly loan repayment and yearly interest costs (C_{yi}^{comp}):

$$C_{yi}^{comp} = \left(N_{yi}^{hc} * \ P^{comp}\right) * (L_{i}^{r} + L_{i}^{i})$$

The number of hectares changed is denoted by N_{yi}^{hc} and P^{comp} stands for the price of compensation per hectare transformed into agricultural nature land.

Additionally, the farmer gets a compensation for the phosphate rights he must cease using because of the new number of cows being correlated to the decrease in VEM yield (C_{yi}^{pr}). This compensation is similar to the compensation for phosphate rights in the GVE measure:

$$C_{yi}^{pr} = \left(\left(DN_{yi}^{c} \cdot E^{c} + DN_{yi}^{ysa} \cdot E^{ysa} + DN_{yi}^{ysb} \cdot E^{ysb}\right) \cdot P^{e}\right) * (L_{i}^{r} + L_{i}^{i})$$

Combining these costs with the changes in veterinarian costs and labor costs and the change in VEM costs leads to the following change in costs for nature transition with y as the percentage of land changed (Cna_{yi}).

$$Cna_{yi} = C_{yi}^{mr} + C_{yi}^{l} + C_{yi}^{v} + C_{yi}^{comp} + C_{yi}^{pr}$$

3.4 Costs government

For the government, the costs consist of either subsidies or the acquisition of phosphate rights. For buyout, both are applicable as they buy out the farmer by buying up his production rights and subsidizing his loss of production capacity. For innovation, there only is a potential subsidy, while for GVE measures there only is an acquisition of phosphate rights. For nature-inclusive, there is a subsidy for the transition of land and also there is an acquisition of phosphate rights.

3.5 Ammonia reduction

Ammonia reduction was calculated as a percentage of total base of ammonia emission. For all measures, except innovation, The calculation was based on the reduction of the number of cows on the farm.

For innovation, the reduction depends on the circular housing system. We examined the Lely Sphere, the JOZ nitrogen cracker and the PPP-agro report (2022) and came to an emission factor of 5 kg ammonia per cow per year, whereas a regular housing system has an emission factor of 13 kg per year (Kenniscentrum InfoMil, 2023). We assumed that young stock would not be included in this housing system, so their emissions would not lower. We also adjusted for outdoor grazing, where we assumed that cows are outside for half the year for 12 hours a day, leading to a decrease in effectiveness of 25%.

For Nature inclusive, next to the reduction of the amount of cows, the reduction through the cease of manure application on the nature land was also taken into account, together with the lower emission through a lower milk yield. The amount of reduction by stopping manure application was based on the ratio of emissions through manure application compared to the total ammonia emissions (Agrimatie, 2022)

3.6 Cost price

We calculated the effect of cost price per measure by dividing the calculated income effect by the amount of milk produced after the implementation of the measure. In the following formula, the example is given for the GVE measure, but $Cgve_{xi}$ could be exchanged for the total cost change of other measures.

$$CCP = (Cgve_{xi})/(NN_{y}^{my} * NN_{yi}^{c})$$

Where CCP is the change in cost price per kilogram of milk in eurocents.

3.7 Parameterisation

Table 1 Explanation of all abbreviations used in the materials and methods, with their value, unit and source

Factor	Abbreviation	Value	Unit	Source
Dairy cows	N^{c}	110		Binternet (2022)
Young stock <1 year old	N^{ysa}	33		Binternet (2022)
Young stock >1 year old	N^{ysb}	30		Binternet (2022)
Kg milk per cow per year	N^{my}	8.850	Kg milk	Binternet (2022)
GVE per hectare	N^{gve}	2,22	GVE	

Price cow	P^c	1600	Euros	Own expertise and Nieuwe oogst (2023)
Price young stock <1 year	P^{ysa}	400	Euros	Own expertise and Nieuw oogst (2023)
Price young stock >1 year	P^{ysb}	1000	Euros	Own expertise
Phosphate emission cows	E^c	42,7	Kg phosphate	RVO (2023b)
Phosphate emission young stock <1 year	E^{ysa}	9,6	Kg phosphate	RVO (2023c)
Phosphate emission young stock >1 year old	E^{ysb}	21,9	Kg phosphate	RVO (2023c)
Price per phosphate right to emit 1 Kg of phosphate	P^e	121	Euros	RVO (2023a)
Land in hectares	N^{ha}	60	Hectares	Binternet (2022)
Land price per ha	P^{ha}	70.000	Euros	Kadaster (2023)
Percentage Land owned by the farmer	LO	0,63	Percentage	Binternet (2022)
Outstanding loans	L	1.400.000	Euros	Binternet (2023a)
Age of the farm	A^f	26	years	Binternet (2023a)
Production capacity	CAP	2750	M^2	Wout de Bruin
Bookvalue production capacity	B^{cap}	400.000	Euros	Binternet (2023a)
Machinery	MCH	134.000	Euros	Binternet (2023a)
Manure disposal	MD	18.000	Euros	Own expertise
Milk price	P^m	0,45	Euros	Own expertise and ZuivelNL (2023)
VEM price	P^{vem}	0,00022	Euros	Own expertise and WUR (2023)
Veterinarian costs per kg milk	C^{vet}	0,02	Euros	Own expertise and Stevens, R. (2020)
Labor costs per kg milk	C^{lbr}	0,012	Euros	Own expertise and Binternet (2023b)
Manure costs per m^3	C^{man}	18	Euros	Countus (2022)
Manure output cows	M^C	29,5	m^3 Manure	RVO (2023b), RVO (2019)
Manure output young stock <1 year	M^{ysa}	8	m^3 Manure	RVO (2023c), RVO (2019)
Manure output young stock >1 year	M^{ysb}	16,5	m^3 Manure	RVO (2023c), RVO (2019)
Compensation for the transition agricultural land to nature land per hectare	P^{comp}	35.000	Euros	Kadaster (2023)

Milk loss per hectare of land converted to nature	N^{ml}	20	Kg milk	Own expertise and PPP-agro advies (2022)
Repayment percentage of loan	L^{r}	3	percentage	Own expertise
Interest on loan	L^{i}	2	percentage	Own expertise

There were a few sources on which the assumptions of this research was build. For farm-specific characteristics we first examined all the information from BINternet and If the needed knowledge was not available in this source, the data of the CBS was consulted and otherwise the assumptions were based on personal experience. For emission outputs, for example, manure output or phosphate emissions, we based our information on governmental sources. Next, we provide some more specific explanations:

The prices of cows and young stock were estimated by combining the values for cows from Nieuwe oogst (2023) with anecdotal experiences.

The production capacity was determined through discussions with Wout de Bruin, assessing the production capacity of his farm which is similar to the dairy farm profile used in this research.

For manure disposal we assumed that there would be some manure left in the manure storage which the farmer would have to dispose of. A percentage of the yearly manure output was multiplied by the average price for manure disposal.

The milk price was determined by estimating an average from the price for milk from the previous years, more specifically on the price from January 2022 till June 2023. Based on the prices from ZuivelNL (2023).

The VEM price is picked as an average of the months December 2022 to June 2023 from WUR (2022). The price is normally depicted as the Kvem price, but in this case, it was easier to calculate with the price for an individual VEM, which is why the VEM price was chosen.

As the source of veterinarian costs was from 2020, the costs were adjusted upwards to better represent the actual costs.

The labor costs were calculated by dividing the costs assigned by Binternet (2023b) to external labor, which amounts to €11,800, by the total milk yield from all cows.

The Manure output was calculated by dividing the nitrogen output of cows and young stock, obtained from RVO (2023b) and RVO (2023c), by 4. Because in one m^3 of manure, there is on average 4 kg nitrogen (RVO, 2019).

Based on the market prices of Kadaster (2023), the price of agricultural nature land was determined at € 35.000, which is half of the € 70.000 at which regular agricultural land is valued in this thesis. Based on the PPP-agro (2022) report, it was assumed that on average, agricultural nature land has half the VEM yield compared to regular agricultural land. Additionally, the quality of the feed was lower than that of agricultural land, leading to a lower milk yield per cow.

The Milk loss was based on the PPP-Agro report by comparing their calculated milk yield of a nature inclusive farm to their calculated milk yield of their reference farm. It was then assumed to be lower and adjusted to reflect a number that decreases per percentage of feed coming from nature land.

3.8 Optimization

After all the previous costs of measures were calculated using Python and Excel, the results were grouped together in an Excel sheet. These combined results were optimized using the Excel solver function. We optimized for all 3 components, ammonia reduction, governmental costs and farmer income. We took a group of 15 farmers with the reference farm discussed earlier who all had the same options available.

3.8.1 Maximizing ammonia reduction

The first optimization focused on maximizing ammonia reduction and showed the possibilities with increasing budget levels of € 500.000, starting at € 500,000 to € 5,000,000. Leading to the following objective function:

$$max \sum_{i=1}^{15} \sum_{j=1}^{9} (x_{ij} r_{ij})$$

Where x_{ij} is a binary variable indicating whether farm i chooses measure j or not and j = 1 stands for buyout LBV, j = 2 for buyout LBV+, j = 3 for innovation with subsidy, j = 4 for GVE at 1,7, j = 5 for GVE at 2,0, j = 6 for Nature inclusive at 10%, j = 7 for Nature inclusive at 20%, j = 8 for Nature inclusive at 40%, and j = 9 for doing nothing.

r_{ij} is the percentage reduction of ammonia from baseline for farm i and measure j.

Subject to the following constraints:

$$\sum_{j=1}^{9} x_{ij} = 1 \ \ \forall i \in \{1, \ldots, 15\}$$

$$\sum_{i=1}^{15} \sum_{j=1}^{9} (x_{ij} c_{ij}) \leq B$$

Where c_{ij} is the cost of implementing measure j for farm i for the government and B stands for the budget level.

We also did this same optimization, only excluding the option for innovation.

3.8.2 Minimizing governmental costs

In the second optimization, we examined the effects on governmental costs, with the constraint that an ammonia reduction of at least 30% would have to be realized. This led to the following objective function:

$$min \sum_{i=1}^{15} \sum_{j=1}^{9} (x_{ij} c_{ij})$$

Subject to the following constraints:

$$\sum_{j=1}^{9} x_{ij} = 1 \ \ \forall i \in \{1, \ldots, 15\}$$

$$\sum_{i=1}^{15} x_{ij} r_{ij} \geq 15R$$

R here stands for the percentage of reduction.

After generating this first optimization, a constraint was added to limit the number of farmers being allowed to choose innovation as a measure.

$$\sum_{i=1}^{15} x_{i3} \leq 5$$

3.8.3 Maximizing farmer income

Similarly to the second optimization, we also examined the effect on farmer income, with the same constraint that an ammonia reduction of at least 30% had to be realized. Maximizing farmer income gave the following objective function:

$$max \sum_{i=1}^{15} \sum_{j=1}^{9} (x_{ij} \pi_{ij})$$

Where π_{ij} stands for the profit for farmer i choosing measure j.

Subject to the same constraints as the second optimization, namely:

$$\sum_{j=1}^{9} x_{ij} = 1 \;\; \forall i \in \{1, \ldots, 15\}$$

$$\sum_{i=1}^{15} x_{ij} r_{ij} \geq 15R$$

After generating a first optimization with these constraints, the following constraint was added to limit the number of buyouts to 1.

$$\sum_{i=1}^{15} x_{i1} + \sum_{i=1}^{15} x_{i2} \leq 1$$

4. Results

In this chapter, the results are presented. First, the cashflow of the buyout measure is shown, after which the partial budgets of all the measures are shown. Secondly, the costs for the government and the ammonia reduction are showcased together with the effect on farmer income from the partial budgets. Thirdly, the results from the optimization models are shown

4.1 Buyout

This cashflow analysis showcases the effects of a buyout following an LBV or LBV+ structure. This serves as a crucial preliminary calculation to the partial budgets. Table 2 gives all in and out streams and also shows the differences between the peek emitters who can participate in the LBV+ and the other farmers who can only participate in the less profitable ruling.

*Table 2 Cashflow (*1,000 euro) of a farm participating in a cessation scheme of the Landelijke beëindigingsregling veehouderij (LBV) for regular farmers and peek emitters (LBV+)*

Cashflow	**Buyout LBV**		**Buyout LBV+**	
(In € x1000)	**In**	**Out**	**In**	**Out**
Production rights	686	-	823	-
Production capacity	1.102	-	1.322	-
Selling livestock	219	-	219	-
Tax payment	-	678	-	855
Payoff loans	-	1.400	-	1.400
Machinery	134	-	134	-
Manure disposal	-	18	-	18
Total	**2.141**	**2.096**	**2.499**	**2.273**

In both buyout rulings, the loans are completely paid off. In the case of the regular LBV ruling the farmer is left with € 45.000, and in the case of the LBV+ the farmer is left with € 226.000. The difference between LBV and LBV+ is € 181.000. This cashflow will be shown later in the partial budgets as "Effect cashflow". In the partial budgets, 5% of the cashflow is shown as a yearly payout.

4.2 Partial budgets

In Table 3 the partial budgets show that only one measure, the buyout, yields a positive effect on the annual budget of the farmer. This is because the farmer has two major new income streams replacing his income from farming. Innovation with subsidy is the closest to break-even, primarily because of the lower investment costs than regular innovation. The reduction in other expenses can nearly offset the investment and maintenance costs. For the nature inclusive and GVE measures, the small positive effects are not able to compensate for the loss in milk revenue.

Table 3 Partial budgets of potential ammonia reducing measures showcasing the metrics that change in yearly farmer income for the reference farm

Economical metrics	**Buyout**	**Buyout LBV+**	**Innovation**	**Innovation with subsidy**	**GVE 2.0**	**GVE 1.7**	**Nature inclusive 10%**	**Nature inclusive 20%**	**Nature inclusive 40%**
Effect cashflow	2.275	11.307	-	-	-	-	-	-	-
New job	58.700	58.700	-	-	-	-	-	-	-
Leasing land	53.760	53.760	-	-	-	-	-	-	-
Fertilizer use	-	-	15.400	15.400	-	-	-	-	-

Manure disposal	-	-	26.730	26.730	7.308	17.037	-	-	-
Comp phosphate	-	-	-	-	8.109	8.109	1.715	3.430	6.860
Feed costs	-	-	-	-	18.083	42.290	3.479	5.015	9.755
Veterinarian costs	-	-	-	-	1.947	4.602	1.280	2.387	4.774
Labor costs	-	-	-	-	1.168	2.761	768	1.432	2.864
Comp land	-	-	-	-	-	-	10.500	21.000	42.000
Loss of farm income	-91.000	-91.000	-	-	-	-	-	-	-
Milk revenue	-	-	-	-	-43.807	-103.545	-28.821	-53.707	-107.415
Investment costs	-	-	-32.376	-19.425	-	-	-	-	-
Maintenance costs	-	-	-25.631	-25.631	-	-	-	-	-
Net effect	**23.735**	**32.767**	**-15.877**	**-2.926**	**-11.830**	**-28.746**	**-11.079**	**-20.433**	**-41.162**

4.3 Costs government and ammonia reduction

The governmental costs vary significantly across measures, mostly dependent on the type and scale of the subsidy granted. In all measures except for innovation, the government buys up phosphate rights. For a buyout, they also subsidize the loss of production capacity and for nature inclusive measures they subsidize the transition of the land, leading to higher costs.

In Table 4, we present the costs for the government and the ammonia reduction of the measures. Additionally, the income effects of the farmer, which are the same as in Table 3, are present to show the cost for the farmer per 1% reduction in ammonia. Unsurprisingly, buyout is the highest in ammonia reduction, given the farm and its ammonia-producing livestock cease to exist entirely. This also incurs the highest costs for the government, reflecting the high costs associated with farm buyouts. Notably, the second highest ammonia reduction comes from innovation, higher even than the strictest GVE or Nature inclusive measures, while the governmental costs are amongst the lowest for this measure.

Table 4 Overview of all measures with their respective costs, income effects and reduction of ammonia, and the costs and income effects per 1% reduction.

Measure	Costs govern - ment in €	Ammonia reduction in %	Effect income farmer in €	Cost gov per 1% reduction in €	Effect income farmer per 1% reduction in €
Buyout	1.788.369	100	23.735	17.884	237
Buyout LBV+	2.146.040	100	32.767	21.460	328
Innovation	0	51	-15.877	0	-311
Innovation with subsidy	100.000	51	-2.926	1.961	-57
GVE 2.0	69.430	8,4	-11.830	8.265	-1.408
GVE 1.7	164.830	22,2	-27.770	7.425	-1.251
Nature inclusive 10%	244.300	7,9	-11.077	30.924	-1.402
Nature inclusive 20%	488.600	15,8	-20.442	30.924	-1.294
Nature inclusive 40%	977.200	31,6	-41.161	30.904	-1.302

In Figures 2 and 3 we represent the costs for the government and the effect on farmer income in relation to ammonia reduction. Figure 2 unsurprisingly shows that on average a higher cost for the government results in higher ammonia reduction. Figure 3 shows that on average measures with a higher ammonia reduction have a more positive effect on farmer income.

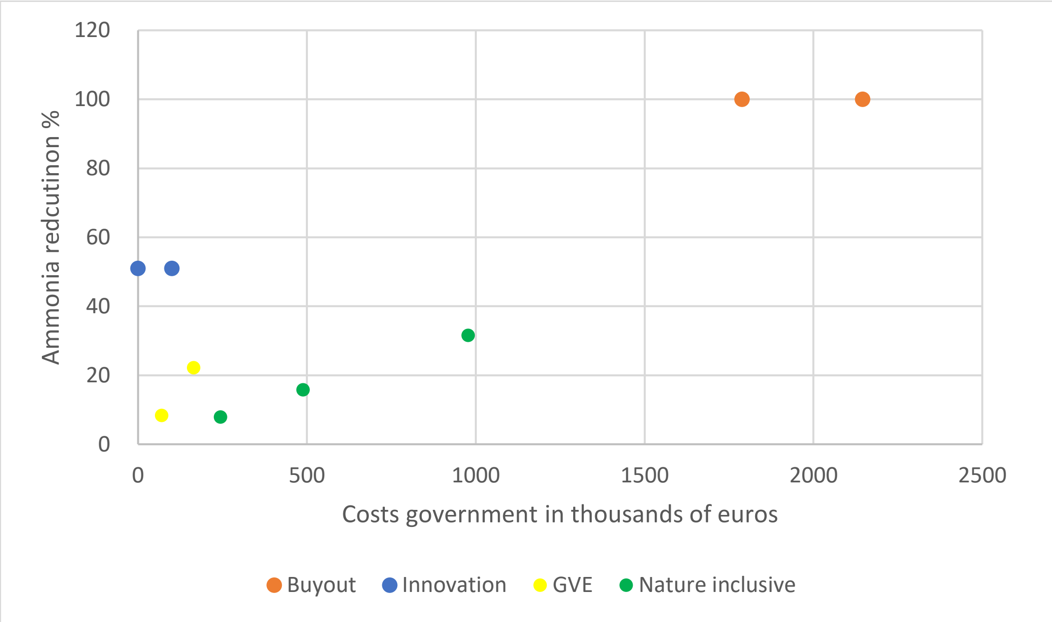

Figure 2 Costs government in relation to ammonia reduction

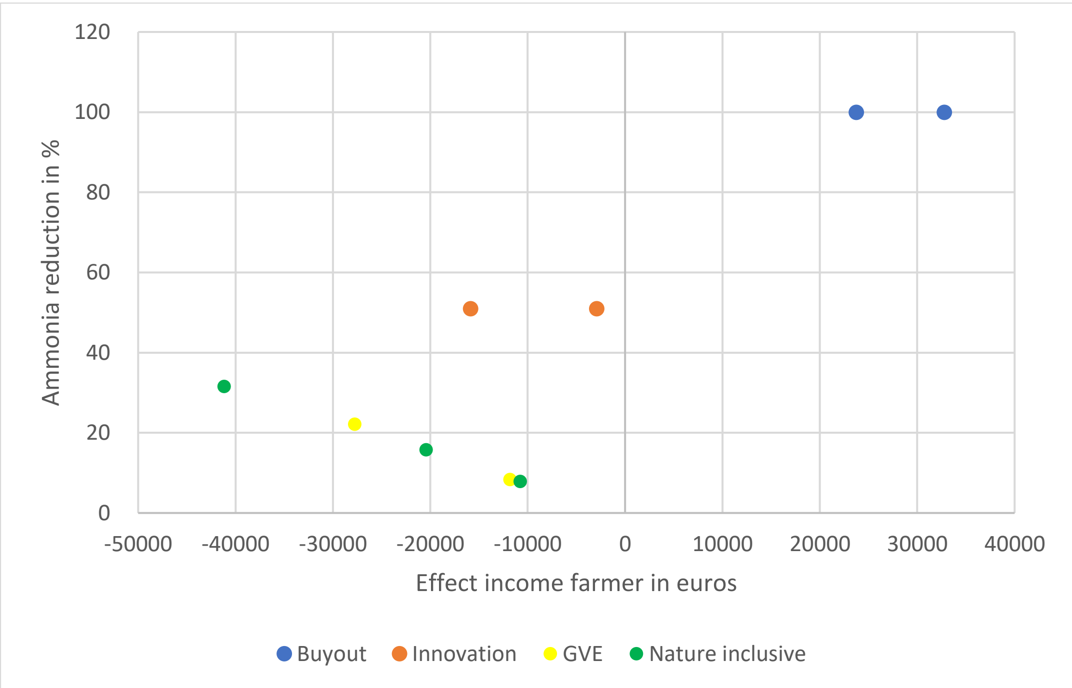

Figure 3 Effect income farmer in relation to ammonia reduction

In Figure 4 we see that GVE and Nature inclusive measures have far worse effects on farmer income per reduction percentage than innovation and buyout. We also see that Nature inclusive has the same effect on the farmer, but it costs the government far more money per percentage reduction in ammonia.

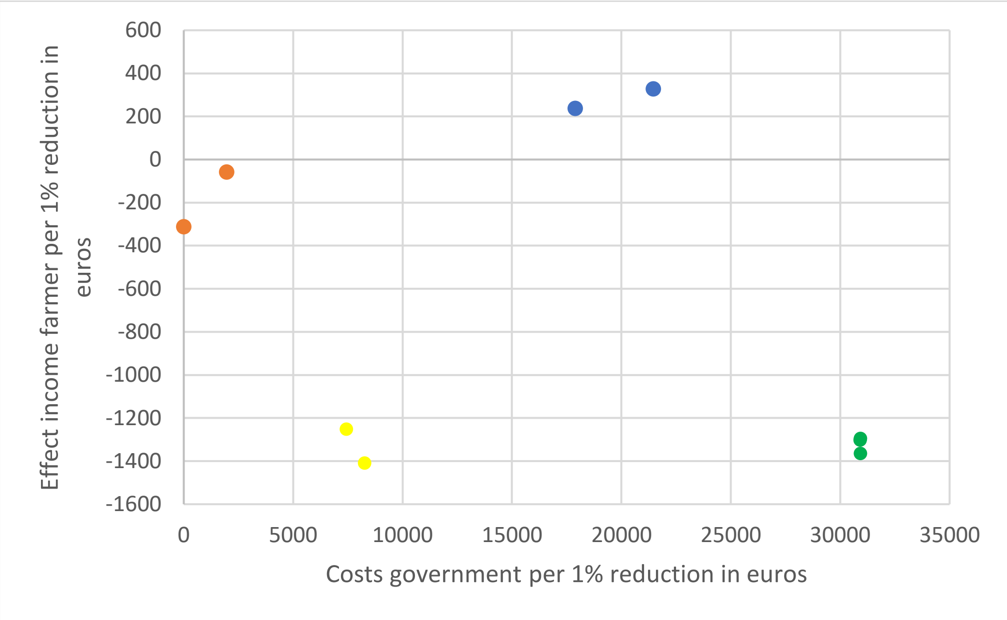

Figure 4 Costs government in relation to the effect on income for farmers both per 1% ammonia reduction

4.4 Cost price

Table 5 showcases the increase in the cost price for the varying measures that have a negative effect on the income of the farmer. As the cost price is calculated over the new number of cows and their milk yield, we see that the effect of an increase from 20% to 40% nature inclusive results in around double the income effect, but more than double the effect on the cost price, as there are less cows to divide the costs over.

Table 5 Increase in cost price needed to compensate for the negative effects of ammonia reduction measures to reach the same profit as before the measure

Measure	Effects income in euros	Increase cost price in euro cents per KG milk
Innovate	-15877	1,6
Innovation with subsidy	-2926	0,3
GVE 2,0	-11830	1,4
GVE 1,7	-27770	3,1
Nature inclusive 10%	-11077	1,2
Nature inclusive 20%	-20442	2,4
Nature inclusive 40%	-41161	5,6

4.5 Optimization

4.5.1 Maximizing ammonia reduction

In table 6 we see the results of the optimization of ammonia reduction dependant on a budget of the government. There are two separate optimizations in this table, one where innovation is a possible measure and one where optimization is not a possible measure. It should be noted that all other measures, excluding innovation without subsidy, were included in the optimization. The results in the table exclusively showcase those measures that yielded tangible outcomes. Innovation without subsidy was excluded as there is no cost to this measure.

We see that the difference between the reduction of ammonia with the possibility of innovation is at least double that of the optimization without innovation in all budget categories. We also see that even though a buyout is possible at a budget of € 2 million, it is only used at a budget of € 3,5 million in the optimization with subsidy and at € 4 million in the optimization without subsidy. This shows that it is more cost-effective to have all farmers contribute a small amount instead of buying out 1 farmer, even if innovation is not a possible measure.

Table 6 Optimizing ammonia reduction constraint by a governmental budget, with the differentiation of whether innovation is a possible measure

	With Innovation			**Without innovation**				
Budget in euros	**Innovation with subsidy**	**Buyout**	**Ammonia reduction**	**GVE 1,7**	**Buyout**	**Nature inclusive 40%**	**Do nothing**	**Ammonia reduction**
500.000	5	0	17%	3	0	0	0	4%
1.000.000	10	0	34%	6	0	0	0	9%
1.500.000	15	0	51%	9	0	0	0	13%
2.000.000	15	0	51%	12	0	0	0	18%
2.500.000	15	0	51%	15	0	0	0	22%
3.000.000	15	0	51%	15	0	0	0	22%
3.500.000	14	1	54%	14	0	1	0	23%
4.000.000	14	0	54%	13	1	0	1	26%
4.500.000	14	0	54%	14	1	0	0	27%
5.000.000	13	2	58%	13	1	1	0	28%

4.5.2 Minimizing governmental costs and maximizing farmer profit

The second optimization was done with the intent of reducing ammonia by at least 30%, and then examining the objectives of minimizing the costs for the government and maximizing profit for the farmers given this level of reduction. Table 7 gives the optimization results of minimizing governmental costs and maximizing farmer income under the constraint of 30% reduction of ammonia.

Table 7 shows that for the government it’s most beneficial to realize a 30% reduction utilizing innovation. When constraining the number of farmers willing to use innovation to 5, it would be most beneficial to subject the farmers to a maximum GVE measure. When optimizing for farmer profit they would all choose to be bought out, realizing 100% ammonia reduction. When constrained to only 1 buyout maximum, the farmers choose innovation as well. Not all farmers choose subsidized innovation, just enough to realize the 30% ammonia reduction.

Table 7 Optimization results of measures chosen when minimizing governmental costs or maximizing farmer profit

	Min costs government		**Max profit farmer**	
	30% reduction	**30% + max 5 inn**	**30% reduction**	**30% + max 1 buyout**
Do nothing	6	1	-	7
Innovation with subsidy	9	5	-	7
Buyout	-	-	-	-
Buyout LBV+	-	-	15	1
Nature inclusive 20%	-	-	-	-
Nature inclusive 10%	-	-	-	-
Nature inclusive 40%	-	-	-	-
GVE 2,0	-	-	-	-
GVE 1,7	-	9	-	-
Total costs Gov in €	900,000	1,983,470	32,190,600	2,846,040
Total change farmer income in €	-130,680	-322,530	378,900	12,285
ammonia reduction %	30	30	100	30

5. Discussion

In this discussion we will first discuss the limitations of the research, thereafter we discuss the results of each individual measure and later the group-based effects of the measures. We also discuss the connection of recent governmental policy with the results of this thesis.

5.1 limitations

The research in this thesis is based on a broad number of assumptions, which causes low certainty on the exact results of the calculations and optimizations done in this thesis. Some of this uncertainty could have been lowered by enacting a sensitivity analysis on some of the most uncertain variables, but due to time constraints, this was not done. The thesis also only looked at several measures, giving results of only these measures.

5.1.1 Buyout

The results of a buyout depend on the current situation of the farm. In this thesis, we only looked at the results of buying out a reference farm, but in reality, the actual outcomes for farmers can be very different from reference farm in this study. The compensation by means of buying up phosphate rights is likely quite representable for all farms, as it only depends on the number of cows and young stock. The compensation for production capacity, however, can be highly variable. The age of the stable and the area size of the stables, feed storage and manure storage in square meters can differ substantially per farm, resulting in completely different compensations per farm. It would have been ideal to have done a sensitivity analysis on some of these variables and to compare the implications on bigger or smaller farms, but due to time constraints this was not possible.

5.1.2 Innovation

Innovation has the highest amount of uncertainty of all the measures, as previous innovative measures have turned out to be less effective than they claimed to be (Ministry of LNV, 2024a). These innovations will have to be tested thoroughly for their effectiveness and when in place might have to be checked on whether they are used in the way they are supposed to be used. A major limitation of our study lies in the absence of adjusting for the associated extra costs and uncertainties. This could potentially skew the perception of innovation in a more positive light than its actual impact, highlighting the need for caution in interpreting the study's findings. The only adjustments we did make were picking the lowest reduction percentages provided and assuming no effect on the emission of young stock.

5.1.3 GVE

GVE measures would in reality be imposed on all farmers at the same time, but in the optimization model, GVE counted as an individual measure. This could result in outcomes where only a part of the 15 farmers would have to reduce their number of cows.

5.1.4 Nature inclusive

For this study, we excluded the possibility of intensifying farmer practices on the land which was not transformed to Nature land. This negatively skewed the economic results of the transition to nature inclusive farming and resulted in it barely seeming like a possibility. In reality, one could intensify farming practices on the land still used for farming and thereby generate a higher milk revenue, which could improve the results. It would, however, be strange to transition this way, as nature inclusive farming is usually associated with a more extensive way of farming

5.1.5 Other potential measures

In this study, only a limited number of measures that could be impactful in the reduction of ammonia were included, but there are other measures which could play a role in the reduction of ammonia. Generally, these are less impactful innovative measures or management changes. Examples are regularly spraying the stable floor with water, adding additives to manure and influencing the microbiome of cows (CLM & Aeres hogeschool, 2023). Then there are also options like feeding the cows a diet with a lower amount of protein resulting in less ammonia emission (Sebek et al. 2015)

The research from CLM and Aeres hogeschool revealed that regularly spraying water on stable floors was the most well-liked measure by current farmers, financial investors and advisors in the sector. This preference was attributed to its perceived low cost and ease of implementation. Notably, this practice could be viewed as a lower budget alternative to the innovative measures depicted in this study. The water spraying does not generate any income, so to compare it with the innovative measure from this study it would have to be subsidized to create a similar income effect for the farmer. In further research, a comparison of both measures in terms of ammonia reduction in relation to costs could show which option has the best cost-effectiveness for the government.

5.2 Implications

5.2.1 Buyout

The buyout measure was the only measure with a positive impact on the annual income of the farmer. This was highly dependent on the compensation the farmers would receive following the LBV buyout ruling, for farmers that can participate in the LBV+ ruling it resulted in an extra yearly income of € 9.000, but also requires the farmer to find another job after being bought out.

In the example of this study, the loans of the farmer could be completely repaid with the cashflow following the buyout, without having to sell any owned land. This could be different for other farmers, resulting in a different situation where the farmer has to sell a portion of his land to pay off the loans. In reality, the farmers that will participate in a voluntary buyout are likely older farmers, who likely have lower loans, but also older stables. This could very well compensate for each other, leading to a roughly similar outcome. In a further study, research could be done to find out for which farmers taking part in a buyout is the most beneficial and on which variables this depends.

It is still reasonable to assume that for almost all farmers it is beneficial to stop farming and find another job or retire. Meaning that, based on economic reasons one would expect a lot of farmers would choose to participate in a buyout. Still, at the end of 2023, only 336 dairy farmers have made themselves available for a buyout following the LBV or LBV+ ruling (RVO, 2023d). This only accounts for roughly 2.5% of all dairy farmers in the Netherlands, which means that the vast majority of farmers are not interested in being bought out, even though it is profitable. They likely want to continue their way of life and give that a higher meaning than a fuller bank account.

5.2.2 Innovation

In terms of income effects, with a subsidy of 40%, the measure came close to break-even for the farmer. The initial investment costs pose a heavy burden in terms of costs, but for farmers with around 200 cows, this burden is comparatively lighter and can be more easily distributed. This could lead to a situation where for a lot of bigger farmers it could be financially viable to purchase an innovative stable system and not for small farmers. This could indirectly stimulate bigger farms that do not let their cows graze outside, which is why environmental organizations caution against innovative stable systems (CLM & Aeres hogeschool, 2023). This is a legitimate concern because for the innovation to be effective the cows must stay in the stable. For ammonia emissions, it is not problematic to keep outdoor grazing as a business practice, but as the farmer earns back his investment by turning manure into fertilizer, it might decrease his profitability if he would take part in outdoor grazing.

Furthermore, it is important to realize that ammonia is just one facet of the environmental problems in the Netherlands. There is also the leaching of nitrogen into water and the emission of other greenhouse gasses like methane (Erisman, J. W. et al., 2021). Although the JOZ nitrogen cracker also claims to lower methane emission (JOZ, 2023), innovative stable systems will not help in reducing greenhouse gas emissions as reducing the number of cows does.

5.2.3 GVE

If a GVE measure would come into effect, it could work if every farmer would have the average amount of cows per hectare. In reality, this is not the case, which would lead to cases where a farmer who has 4 cows per hectare would have to eliminate half his livestock if the max GVE would be set at 2 cows per hectare. So while on average, the results might be representable, on an individual level the implications might differ immensely.

GVE is also a measure where the costs will be recurring every year and the farmers will have to be compensated somehow, as the cost price per kg of milk is increased. This could be done by governmental subsidization, which would increase the costs for the government, or by increasing the price, which might have other implications.

5.2.4 Nature inclusive

The transition from regular farming to nature inclusive farming is difficult, it brings up significant costs without necessarily generating additional income. This transition would have to be heavily funded by the government, for which in return it receives more nature. The benefit of this influx of nature in terms of value is something that is beyond this research, but it could be worthwhile to subject this to a cost-benefit analysis as done by Hanley et al. (2009). Such an analysis could determine whether subsidizing these transitions would be justified.

Nature inclusive farming is also something that the farmer must be interested in himself, in this case, the farmer would likely already be implementing some practices close to this type of farming and could potentially make the transition easier than for the average dairy farm.

5.3 Effects on farmer income

The results of this thesis showed that participating in a buyout leads to a higher income per year than continuing with the farming practices for the representative dairy farm in this study. While this might seem like a reason to participate, previous cessation schemes have shown that only if the economic situation of farmers is dire, are they interested in the financial benefits of the cessation scheme (Boezeman, & Vink, 2022). If farmers are not in financial trouble, the participants of a cessation scheme mostly consist of farmers that were planning to cease farming already.

The negative effects of the other measures therefore are more interesting, all other measures ended up having a negative effect. Innovation with subsidy was close to break-even and if the subsidy would be higher the effect on the income for the farmer would be break-even. Further research could be done into what the best structure for subsidy on innovative stable systems could be, if the government decides that it wants to use it as a way to tackle ammonia emission.

5.4 Costs government

Innovation is by far the most cost-effective if it works, which leads to a difficult situation for the government in deciding how to proceed with innovation. If they work out the right testing of innovations and create the right legislation then they should make sure that as many farmers as needed are subsidized to purchase an innovative stable system.

5.5 Reduction of ammonia emission

The supposed reduction of Ammonia is highly dependent on the implementation of innovative stable systems. As shown in Table 6, the difference between ammonia reduction with the possibility of innovative stable systems as a possible solution results in more than double the reduction in emissions at similar governmental budget levels. This shows the importance of further research into how effective the stable systems are, and if they seem to be effective the government should subsidize the innovative stable systems.

Ammonia emissions should not only be addressed by large-scale measures, which this study researched, but also with countrywide management changes, as this could possibly reduce ammonia emissions by 15% (Wemmenhove, & Šebek, 2021). Moreover, implementing these changes would incur minimal costs, only potentially for educational purposes and auditing.

5.6 Optimization

The observation that a buyout only becomes a viable option at a budget of € 3,5 million with the possibility of innovation and € 4 million when excluding innovation underscores the cost-effectiveness of having all farmers contribute a nominal amount, as opposed to a buyout strategy for a single farmer. Remarkably, this holds true even in scenarios where innovation is not considered a feasible measure, as a GVE measure for all farmers is more cost-effective.

This however does not mean that there is no place for buyout as a measure, if we multiply the € 3,5 million by 1000, which would roughly give us the budget needed to use these measures on all dairy farms in the Netherlands, this would give us a total budget of € 3,5 billion. The budget which was proposed by the government consisted of € 25 billion (Rijksoverheid, 2022). This budget would not be fully intended for the dairy sector, but there would surely be more than € 3,5 billion available for the reduction of emissions in the dairy sector. This leads to the justification of using voluntary buyout as a measure.

When optimizing for a minimum in governmental costs and a maximum in farmer income, in both cases innovation comes out as the measure which should be chosen, unless all farmers would want to be bought out in which case they should all choose to participate in a voluntary buyout. This underlines the importance of finding a way to safeguard the effectiveness of these innovations, as this seems the major obstacle in the way of implementing these innovative stable systems.

5.7 Governmental policy regarding innovation

In a recent update on the progress of the nitrogen approach the government showed that they are currently working on subsidies for innovative stable systems (Ministry of LNV, 2024a), (Ministry of LNV, 2024b). To realize these measures they are also focusing on better ways of measuring ammonia emissions on individual farms. A group named “Accelerating innovation emission reduction sustainable livestock farming” has been mobilized to speed up the process in evaluating whether the available measures actually have their claimed effects and secondly they are seeking new innovations that could bring about a disruptive change and outperform the currently available options.

The government has stated that they are aiming to subsidize these innovative measures for 80% of the purchase price. This is double the percentage chosen in this research and would very likely make partaking in this subsidy economically viable for almost every farmer.

As a recommendation, I would advise the government to continue their efforts to realize innovative measures. With the subsidization of 80% of the purchase price they would likely attract a large number of dairy farmers to use this subsidy. While this subsidization percentage is high, innovation is the most cost-effective, therefore the government could reach its goals of reducing ammonia emissions while staying within the once proposed budget.

6. Conclusion

This study aimed to examine the multifaceted effects of possible ammonia reduction measures in the agricultural sector. The study examined a voluntary buyout, the implementation of an innovative stable system, a GVE measure, and a transition to nature inclusive farming. The study used a partial budgeting approach to calculate the income effects of these measures on farmer income and the governmental costs needed to realize these measures. Based on the number of cows and other effects, the reduction in ammonia was calculated.

At an individual level, the subsidization of innovation proved to be the most effective measure, achieving the highest reduction in ammonia per governmental costs and approaching a break-even effect on farmer income. For the farmers participating in a buyout is the most beneficial option economically.

In terms of the collective effects, at a budget level of € 3,5 million per 15 farmers, buyout starts to be an effective measure to decrease ammonia reduction, where it would supplement the other farmers taking on innovative stable systems subsidized by the government. This means that if the overall budget is around € 3,5 billion, the government should indeed buy out farmers to reduce ammonia emissions the most.

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