Shaping the vision for the sustainable future of Dutch agriculture:

targets, pathways and measures to reduce greenhouse gas emissions

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Shaping the vision for the sustainable future of Dutch agriculture: targets, pathways and measures to reduce GHG emissions

MSc Thesis Plant Production Systems

Name:	*Annet Lindhout*
Registration number:	*950722521060*
Study:	*MSc Plant Sciences – Specialization Crop Sciences*
Chair group:	*Plant Production Systems (PPS)*
Code Number:	*PPS-80436*
Date:	*November, 2018*
Supervisors:	*Dr Pytrik Reidsma*
	Juliana Dias Bernardes Gil PhD
Examiner:	*Dr Gerrie van de Ven*

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Abstract

The Netherlands committed themselves to the Paris Climate Agreement as well as to the Sustainable Development Goals (SDGs). That has also consequences for the agricultural sector, which is central to SDG-2 and is a major emitter of greenhouse gases (GHG). Current agricultural practices are under pressure due to their large impact on the environment and are not tenable towards the future. Therefore, this thesis aimed at setting targets for Dutch agriculture regarding future GHG emissions. This was done in a backcasting framework, by first identifying future targets and then working backwards to identify measures to reach those targets. The targets were set based on identified stakeholders' desires. Moreover, literature was explored to discover measures to reach the targets. The measures were quantified for their mitigation potential in Dutch agriculture. Measures were found to reduce the emissions from enteric fermentation, manure management and agricultural soils. Emissions from enteric fermentation can potentially be reduced by, for example, changing livestock diet or by using the methane for biogas production. The mitigation potentials of measures in enteric fermentation range from 0.24 to 4.45 tonnes CO_2-equivalent per hectare. Mitigation measures for manure management, including manure digestion for bioenergy or decreasing manure storage temperature can potentially reduce emissions with 0.36 to 2.6 tonnes CO_2 equivalent per hectare. Emissions of agricultural soils can be decreased by 0.3 to 6.4 tonnes CO_2 equivalent per hectare by measures like precision agriculture and cover cropping. The stakeholders' target for 2050, reducing emissions by 10.3 tonnes CO_2 equivalent per hectare can be reached by implementation of the quantified technical mitigation strategies. However, that requires full adoption of the strategies by all farmers on all fields, which is difficult to achieve as large financing, knowledge and changes in management are needed. Alternatively, emissions will also decrease by reducing production intensity along with a decrease in consumption, for example by reducing meat consumption or decreasing food waste. Reaching the targets will require large changes, but the Netherlands has the potential and the responsibility to decrease GHG emissions from agriculture

1. Introduction

In 2016, the United Nations (UN) established a collective policy agenda with goals and targets, the Sustainable Development Goals (SDGs)(UN, 2015). The SDGs, like their predecessor the Millennial Development Goals (MDGs), mark a method to globally achieve targets related to economic and social issues and reflect concerns on for example poverty and hunger (Biermann et al., 2017). The MDGs mainly concerned developing countries, using assistance of developed countries (Lucas et al., 2016; Sachs, 2012). Contrastingly, the SDGs broaden the scope of the MDGs and address the developed countries as well, since sustainable development involves the entire planet (Allen et al., 2016; Lucas et al., 2016; Sachs, 2012). The three pillars of sustainable development, economic, social, and environmental, are integrated in the SDGs in 17 aspirational goals (Biermann et al., 2017; Dobermann, 2016; UN, 2015). This resulted in a challenging agenda for all countries to transform to a sustainable world (Allen et al., 2016; Biermann et al., 2017; Lucas et al., 2016).

Food production and agriculture are important to consider when adopting the SDGs, as more than half of the SDGs are related to food production and agriculture in a direct or indirect fashion (Dobermann, 2016; Kanter et al., 2016; Sachs, 2012). The goals comprising decoupling of production growth and environmental effects, decreasing climate change and protecting biodiversity are related to agriculture. Agriculture is central to the second goal to eradicate hunger through sustainable agriculture. In addition, the second goal comprises for agriculture: 1) a viable income for farmers and business related to food production; 2) production of sufficient food to feed the whole world a balanced diet; 3) resilience to climate change; 4) reduction of greenhouse gas emissions and deforestation; 5) reduction of environmental harms; 6) sustainment of landscapes and culture (Dobermann, 2016; UN, 2015). To meet those SDGs is very challenging and requires a clear vision and targets that differ among countries, as the challenges varies between countries (Biermann et al., 2017; Dobermann, 2016; Eding et al., 2016; UN, 2015).

The Netherlands score well on economic, juridical, education and health related SDGs, but remains behind on climate, environment and sustainable food production, which concern agriculture (Delahaye et al., 2018; Eding et al., 2016; Lucas et al., 2016). This seems contrasting with the Netherlands being the second exporter of agricultural products worldwide after the US. In addition, National Geographic published an article on Dutch agriculture called “This tiny country feeds the world” and the status of Dutch agriculture is famous around the world (Viviano and Locatelli, 2017). However, the high productivity of the intensive Dutch agriculture does come with a great cost for the environment, natural ecosystems and biodiversity (Bos et al., 2013). Therefore, changes in current agricultural practices are required to reach the SDGs in 2030.

According to Gil *et al*. (2018), Dutch agriculture should especially change on nitrogen (N) surplus, Nitrogen Use Efficiency (NUE), pesticide use, genetic biodiversity and greenhouse gas (GHG) emissions to reach the SDGs. Currently, Dutch agriculture has a large contribution to the national GHG emissions (RIVM, 2017). Moreover, its highly intensive production, marked by high input use, results in the highest emissions per hectare in Europe (Dace and Blumberga, 2016). To reach SDG-2 as well as meet the Paris Climate Agreement, which is reflected in SDG-13, those agricultural emissions need to be reduced (United Nations, 2018). Moreover, GHG emissions are tightly related to both N-surplus and NUE, as most GHG emissions derive from manure and fertilizers (RIVM, 2017). The SDGs and the Paris Climate Agreement only have general and even vague targets (Biermann et al., 2017; Hák et al., 2016). Therefore, targets for agricultural GHG emissions were proposed, commissioned by the Dutch government (Rijksoverheid, 2018a). However, the implications of those targets on farm management and how to achieve those targets are still unknown (Klimaatakkoord, 2018). As agriculture occupies the largest part of land and other natural resources, they are also the main sector responsible for ensuring nature conservation, handling natural resources and protecting those societal goods (Vink and Boezeman, 2018). That also means agricultural practices impact the whole society, resulting in pressure on agriculture from outside the sector. Therefore, the vision for Dutch agriculture and the targets to be met should be shared, not only by the agricultural sector itself, but society as a whole.

The predicted changes required to reach a sustainable agriculture still need to be specified. Usually, realistic futures are determined based on forecasting approaches (Dreborg, 1996). Forecasting predicts future states based on historical changes and current trends. However, the large changes required for sustainability are not stimulated using forecasting, as forecasting depends on extrapolating current trends and practices towards the future (Dreborg, 1996). Alternatively, backcasting can be used. The main idea of backcasting is not about "likely futures" but on how to attain "desirable futures" (Robinson et al., 2011; Svenfelt et al., 2011). The future can be influenced as it depends on previous decisions (Robinson, 1988). Backcasting involves the design of a desirable future and, after that, the determination of the feasibility, trade-offs and measures required to reach that future (Höjer and Mattsson, 2000; Quist and Vergragt, 2006). This is especially applicable to problems that are complex, involve many different stakeholders and need major changes (Dreborg, 1996). Those characteristics are associated with moving to a sustainable agriculture, as well as investigating what changes are necessary to reach a sustainable future for Dutch agriculture.

Developing a desired future for Dutch agriculture regarding GHG emissions involves many aspects. Stakeholder goals needed to be identified to be able to create broad support and underpin a shared vision. Measures to reach that future were explored, in which not only environmental, but also social and economic components were taken into account. Subsequently, feasibility, trade-offs and roadblocks became visible. Ultimately, guiding setting of targets and decision making would result in initiatives and collaborations to reach the SDGs and transform towards a sustainable Dutch agriculture.

The aim of this research was to develop a vision for the future of Dutch agriculture in which GHG emissions are reduced. Moreover, the vision was translated into targets regarding GHG emissions and reachability of the targets was analysed. The aim resulted in the following research questions:

1) Who are the stakeholders in sustainable agriculture regarding GHG emissions?
2) What is/are desired future(s) for agricultural GHG emissions according to the stakeholders?
3) How can the desired future(s) of the GHG emissions of Dutch agriculture be reached?
    a. What are historical trends in Dutch agricultural GHG emissions?
    b. What are the projected trends for GHG emissions?
    c. What measures are possible to reach the desired agricultural GHG emission level?

The thesis is structured in five sections. The methods used to answer the research questions are described in section two. The resulting findings on the research questions are presented in section three, the results section. Afterwards, the methods as well as the results are discussed in section four. The main findings and conclusions are highlighted in the last section.

2. Materials & Methods

2.1. Stakeholder identification

To identify the stakeholders involved in sustainable agriculture regarding GHG emissions, a stakeholder analysis was performed. Here, stakeholders were defined as "any identifiable group or individual who can affect the achievement of an organization's objectives or who is affected by the achievement of an organization's objectives"(Freeman and Reed, 1983). Using this as a criterion, the production chain from inputs to consumers was evaluated to identify stakeholders. In addition, governmental institutes and NGOs were checked for reports, visions and opinions on agricultural GHG emissions. It was not the goal of this thesis to perform an extensive stakeholder analysis, but to identify stakeholder goals for the future of agriculture. Therefore, broad groups of stakeholders were identified, like all consumers were combined, while in reality large variation exists in opinion about food production. Moreover, for governmental and NGO stakeholders, only the ones that have highest authority or are most engaged in and influencing the topic of agricultural GHG emissions were taken into account. The stakeholders were identified by a broad review of scientific and non-scientific literature (including Dutch news sources).

Knowing who the stakeholders are is important for several reasons. Firstly, it was necessary to determine the stakeholders' desired futures concerning the indicators. Secondly, it revealed conflicts and coherence between different stakeholders' desires. Thirdly, it resulted in the identification of trade-offs between indicators and socioeconomic aspects, such as effects on farm income and labour intensity. Fourthly, it helped determine realistic targets and supporting measures to obtain desired levels of the indicators.

2.2. Identifying stakeholder desired futures

After the stakeholders were identified, their aspirations for the future regarding agricultural GHG emissions were investigated. This was done using literature research. In addition, already existing questionnaires, websites, public statements, management reports, and reports on aims, missions, ambitions and visions of stakeholders were used to determine their aspirations for the future. The targets were quantified whenever possible, and total agricultural GHG emissions were expressed in Mton CO_2-equivalent but also in GHG emission intensity of agriculture (EIA_{ha}) (t CO_2-equivalent/ha) (Gil, 2018). Reduction percentages were given relative to emission levels in 1990 (RIVM, 2017). The individual stakeholders were grouped according to their aspiration for the future, taking stakeholders with similar quantitative goals together. This resulted in a summarized overview of the different desired future levels, whose feasibility was further analysed in this thesis.

2.3. Reaching the desired futures

It was investigated whether and how the desired futures of the stakeholders regarding agricultural GHG emissions can be attained. This was done by summarizing the historical GHG emission trends, estimating projected trends and identifying potential reduction strategies towards the future. In this thesis, agricultural emissions comprise arable farming and livestock farming, but not horticulture. Emissions were considered and calculated using the Intergovernmental Panel on Climate Change (IPCC) guidelines, which for example do not include energy-related emissions in agricultural emissions.

2.3.1. Historical trends

A literature study was performed to find out how the levels for GHG emissions have changed in the past for the Netherlands and what caused those changes. Information on Dutch agricultural GHG emissions was based on reports from governmental institutes, like the National Institute for Public Health and the Environment (RIVM), Centraal Bureau voor de Statistiek (CBS), Compendium voor de

Leefomgeving (CLO) and Planbureau voor de Leefomgeving (PBL). Data for calculations was as much as possible retrieved from the same source, to avoid uncertainty due to different calculation methods. Data on emissions from the three agricultural emissions categories listed by the IPCC, enteric fermentation, manure management and agricultural soils, as well as data on total emissions from 1990 until 2015 was retrieved from RIVM, (2017).

Emissions were also split between arable farming and livestock farming using data from RIVM (2017). Methane emissions as well as nitrous oxide emissions from manure storage and grazing were fully attributed to livestock farming. Nitrous oxide emission from fertilizers were fully attributed to arable farming. The emissions arising from manure application were divided over livestock and arable farming, based on the area of grassland and cropland and the average percentages of manure application to grassland and cropland (Compendium voor de Leefomgeving, 2016a; van Bruggen et al., 2017; Van Bruggen et al., 2015). Other minor emissions and CO_2 emissions could not be addressed to either arable or livestock farming. Therefore, they were left out the calculations on arable and livestock farming but were included in all other calculations.

2.3.2. Projected trends

The projected trends in agricultural GHG emissions were considered until 2030. This was done using literature research. Causes of variation in past emission were analysed to predict whether future emissions could vary further under similar conditions. Moreover, the effects of current and intended legislation and practices on agricultural GHG emissions were investigated. Reports of governmental institutes specifically for Dutch agriculture were used. The agricultural GHG emissions in the projected trends only include methane and nitrous oxide, thereby slightly varying from historical trends, which also included CO_2.

2.3.3. Mitigation strategies towards the future

Options to further reduce Dutch agricultural GHG emissions were explored through literature on the reduction of (i) methane emissions from enteric fermentation, (ii) nitrous oxide and methane emissions from manure management, (iii) nitrous oxide emissions from agricultural soils, as well as the increase of carbon sequestration in agricultural soils. Strategies were included only if the agricultural and climate conditions were comparable with Dutch ones, excluding measures studied in Africa, South-America, Asia, and Mediterranean countries. Moreover, only quantitative studies were included, leaving out the large body of qualitative studies.

The measures were listed and quantified in the same unit, EIA_{ha} (t CO_2-equivalent/ha) for the total of Dutch agriculture, taking livestock and arable farming together. Additional data to convert the measures to EIA_{ha}, like grazing hours, emissions of urine and manure per animal type, and emissions from nitrogen inputs via organic and synthetic fertilizers was retrieved from RIVM (2017). In the calculations, the acreage of grassland was used of 1110000 ha and arable farming of 740000 ha, resulting in a total of 1750000 ha in 2015 (Compendium voor de Leefomgeving, 2016b). Mitigation potential was calculated at full potential, when the strategy is adopted on all farms and all acreage. Moreover, it was not taken into account whether a strategy was already partly adopted in the Netherlands. The measures were divided over enteric fermentation, manure management, and agricultural soils and afterwards listed from highest to lowest potential.

The uncertainty and costs of mitigation strategies were retrieved from the papers that quantified the mitigation potential of the strategies. Moreover, literature searches were used to find trade-offs of the strategies as well as willingness of adoption of the strategies by farmers. For willingness of adoption, also the strategies were submitted to farmers associations Land- en Tuinbouw Organisatie Nederland (LTO) and Nederlandse Akkerbouw Vakbond (NAV). They provided information and their opinions on the willingness and ease of adoption from a farmers perspective and also provided additional trade-offs, synergies and cost estimations. Moreover, the consequences of implementation were analysed in face of the goals of farmers, which was also used to estimate the willingness of adoption. The mitigation strategies were colour-coded according to level of innovation readiness and complexity, trade-offs and synergies, and willingness and ease of adoption based on the authors' interpretation. Literature was used to reflect on the mitigation strategies and to put attention to other options to reduce agricultural GHG emissions.

To reduce agricultural GHG emissions, measures can be taken both at the supply side, which comprises production measures, as well as at the demand side, which concerns consumption. To also give an indication of the effects of measures regarding consumption on GHG emissions, the effects of reduced meat consumption on emissions was calculated. Reduced meat consumption was chosen as it is a target of one of the stakeholders, Greenpeace. Greenpeace wants to reduce current meat consumption from 39 kg per person per year to 23 in 2030 and 17 in 2050 (Greenpeace, 2018b, 2018c). Those emissions were converted to absolute emissions by reducing the meat consumption but keeping the percentages share of pork (50%), beef (19%) and poultry (31%) in meat consumption in 2030 and 2050 similar to what they were in 2016. Emission values for pork, beef and poultry of respectively 4.5, 15.9 and 2.6 kg CO_2 equivalent per kg meat and population size estimates of 17020000 in 2016, 17934678 in 2030 and 18370350 in 2050 were used from CBS (2017) and Stichting Voedingscentrum Nederland (2018).

3. Results

3.1. Stakeholder identification

As the Netherlands is a democracy, defining a desired future regarding GHG emissions in Dutch agriculture should be based on the goals and desires of the Dutch people, or stakeholders. Stakeholders, who can affect changes or are affected by changes in GHG emissions of Dutch agriculture, are identified. Regarding GHG emissions of Dutch agriculture, stakeholders can mainly be found in the government, NGO's and in the entire food-chain.

3.1.1. Government

Governmental institutes that can affect changes in GHG emissions of Dutch agriculture are mainly the Dutch government and the European Union (EU). The Dutch government decides on the policy of the Netherlands and can create or change legislation on anything (Parlement & Politiek, n.d.). Everyone in the Netherlands has to adhere to the Dutch legislation. The Netherlands belongs to the EU and has agreed to comply with EU legislation. The EU has authority to set legislation on agriculture and environment and EU members are not allowed to make legislation that detracts from EU legislation (European Union, 1957). Therefore, both the Dutch government and the EU have high power regarding GHG emissions of Dutch agriculture.

Whether governmental institutes will use their power to affect changes in GHG emissions of Dutch agriculture depends on their interests in changes. The current Dutch government, "Rutte III", has "sustainability and reduction of GHG emissions" included as one of the four pillars of their coalition agreement and is forced by court to reduce GHG emissions (VVD et al., 2017; Rechtbank, 2015). Moreover, the Netherlands signed the Paris Climate Agreement together with 194 other countries to mitigate climate change by, among others, reduction of GHG emissions (European Union, 2015a; Rijksoverheid, n.d.). The EU also adopted this agreement for all member states (European Union, 2015b). This indicates that both the Dutch government and the EU have a high interest in mitigating climate change by reducing GHG emissions, also in Dutch agriculture.

3.1.2. NGOs

NGOs work in between the government and citizens on topics of assumed societal importance, among which environmental protection (NGO-community, n.d.). They reflect citizen concerns and interests on many different topics and try to put those on political agendas. Regarding GHG emissions and Dutch agriculture, some important NGOs active in the Netherlands are Greenpeace, Climate Action Network (CAN), Urgenda and Natuur & Milieu. As those NGOs are founded to cause societal and political change in terms of environment and climate change, the interests of these NGOs in GHG emissions of Dutch agriculture are high.

The NGOs vary in their strategies to work on achieving their goals. CAN is a coalition of more than 1700 NGOs with 150 member organisations and represents more than 40 million citizen in Europe (Climate Action Network Europe, 2018). They are actively influencing the UN climate negotiations and EU and EU member states' policy development on climate change. Greenpeace works worldwide on issues related to the environment by raising awareness through effective campaigns against large companies and sectors, political lobbying, and actions (Greenpeace, n.d.). For example, they are the founders of the prohibition of neonicotinoids and genetically modified crops in the EU. Urgenda works together with companies, governments and societal organizations on sustainable projects (Urgenda, n.d.). In a collaboration with 900 others, Urgenda won a court case against the government to force the government to do more on reduction of GHG emissions (Rechtbank, 2015). Natuur & Milieu works together with companies on sustainable projects that are attractive to consumers, help consumers with aspects related to sustainability and lobbies for 'green' laws (Natuur & Milieu, n.d.). Together these NGOs have much money to influence consumers, companies and governments on large scale, resulting in these NGOs being high in power (Ackermann et al., 2016).

3.1.3. Food-chain

Within the food-chain, farmers, the food processing industry, brokers, supermarkets and consumers are considered stakeholders in Dutch agricultural GHG emissions. Farmers are the primary producers of food. Although they have other main interests than reducing GHG emissions, most farmers do not want to harm the environment. The majority of the farmers wants to produce more sustainably, also to be more economically viable (Bouma and Marijnissen, 2018a). The gap between politics and consumers on one side and farmers on the other side becomes increasingly larger; farmers feel often offended and not heard (Bouma and Marijnissen, 2018b). In addition, farmers feel pressed by the industry, supermarkets and banks. To increase power, farmers collaborated in the Land en Tuinbouw Organisatie (LTO). LTO represents the interests of Dutch farmers for their economic and societal position by, for example joining political debates (LTO, 2018; LTO Nederland, n.d.). However, 77% of the farmers feels unrepresented by the LTO and 90% thinks LTO is unsuccessful in telling the right story (van Velzen, 2018).

The food processing industry and brokers come after the farmers in the food-chain. As there are a few companies that together have a large share in food production and trade, the power of those companies in product choice and production method requirements is high (PBL, 2012). Nowadays those companies put more attention and effort into sustainable production by making their own production system more sustainable and/or requiring sustainable production from their suppliers. The interest in sustainable production varies largely among companies. Some wish to be market leaders in sustainable production or are members of sustainability consortia, while other companies only meet the legislation (Cool Farm Alliance, n.d.; The Sustainability Consortium, n.d.). It must however be noted that in food production more attention is paid to organic production than to the reduction of GHG emissions.

In the Netherlands, all food produced ends up in only five buying offices ,which buy food on behalf of the supermarkets (PBL, 2012). Because there are so few buying offices, the power of these offices and their supermarkets is high. Supermarkets offer their products largely depending on the consumer demands and desires. Therefore, supermarkets are not considered to have interest in GHG emissions in Dutch agriculture, unless the consumers have interest.

The consumers together have high power in GHG emissions in Dutch agriculture. They can act in NGOs as well as change the production offer in supermarkets by consciously buying food and thereby cause changes in the whole supply chain. Part of the consumers is however not interested in the GHG emissions of their food, others are interested but are not willing to pay the price required for more sustainable food (GfK, 2018). Another part of the consumers is interested in sustainable food, is willing to pay more and shift their diet. Although the interests in GHG emissions of Dutch agriculture is highly variable among consumers, the power is the largest in the end of the food-chain, at the supermarkets and consumers. Over the last few years, the share of sustainable food sold is increasing (Fernhout, 2017). However, most food marketed as sustainable food does not concern reduced GHG emissions, but organically produced food (Ecolabel Index, 2018).

Companies in the food-chain are often dependent on banks. Banks provide loans to finance expansion or innovation, but only when banks think the business ideas are viable. Moreover, banks have a strong societal responsibility and take that responsibility along in the business ideas they finance. Thereby, banks can stimulate sectors that need their financing to produce more sustainably.

3.2. Stakeholder's desired futures

The stakeholders' goals and targets for the future determine the endpoint of what is desired regarding GHG emissions of Dutch agriculture. During this study those goals and targets formed the starting point to investigate what measures are needed to reach the desired futures. The goals, aims or targets of the stakeholders described in the previous chapter regarding GHG emission of Dutch agriculture are listed to formulate the starting points for finding measures and mitigation strategies.

3.2.1. Government

The current Dutch government has set goals on reducing the Dutch GHG emissions and is currently working on fixing those goals in the climate law. Compared with baseline year 1990 (223.1 Mton CO_2-equivalent (RIVM, 2017)), the Dutch government aims to reduce the national GHG emissions by 20% in 2020 and 49% in 2030 (Rijksoverheid, 2018b). Agriculture was responsible for emissions of 25.3 Mton CO_2-equivalent in 1990 (RIVM, 2017). The coalition agreement of the Dutch government contains an indicative, non-equal allocation of GHG emission reductions. According to the coalition agreement, Dutch agriculture would contribute with a reduction of 3.5 Mton CO_2-equivalent to the 56 Mton CO_2-equivalent reduction required from 2017 onwards to reach a reduction of 49% in 2030 (Rijksoverheid, 2018b). Of this reduction of 3.5 Mton CO_2-equivalent, one Mton should be reduced in horticulture, which is not included in this thesis (Klimaatakkoord, 2018). This leaves 2.5 Mton CO_2-equivalent that needs to be reduced in Dutch agriculture in 2030.

The EU also set targets regarding reduction of GHG emissions. By 2030, the whole EU should have reduced GHG emissions by 30% compared with 1990 in the non-Emissions Trading System (ETS) sectors, in which agriculture is included (European Union, 2018). For every EU member state, the share has been determined by the national gross domestic product per capita and cost-effectiveness. The Netherlands should thereby reduce GHG emissions in non-ETS sectors by 36% (European Union, 2018). When equally sharing those 36% among all non-ETS sectors, Dutch agriculture should reduce GHG emissions by 36%, although some flexibility is allowed (European Commission, 2018). This is a reduction from 25.3 Mton CO_2-equivalent in 1990 to 16.2 Mton CO_2-equivalent in 2030.

3.2.2. NGOs

CAN does not have a quantitative target regarding GHG emissions in agriculture. However, the organization does want to reduce agricultural GHG emissions while also ensuring food security. CAN aims at mitigation actions to achieve the Paris Climate Agreement targets and limit global warming to 1.5^{o}C. However, mitigation actions should avoid trade-offs, most importantly with food security, gender equality, indigenous peoples' rights and animal wellbeing (Climate Action Network, 2016).

Greenpeace has, like CAN, no quantitative targets regarding GHG emissions in agriculture. The NGO does support the Paris Climate Agreement to keep global warming within the 1.5^{o}C increase by the end of this century (Greenpeace, 2018c). In agriculture, Greenpeace aims to do this by decreasing the amount of livestock production and meat consumption. In the Netherlands, the average meat consumption is 39 kg meat per person per year and Greenpeace wants to decrease that consumption to 23 kg in 2030 and 17 kg in 2050 (Greenpeace, 2018a).

Urgenda is focussing on 100% sustainable energy that has no CO_2 emissions in 2030 and aims at a 20% reduction in energy use in Dutch agriculture, mainly in horticulture (Urgenda and Minnesma, n.d.). Moreover, Urgenda pleads for shifting consumption to more plant proteins instead of meat proteins.

Natuur & Milieu aims to achieve the Paris Climate Agreement in 2030. The organization wants to do that by reducing Dutch agricultural GHG emissions with 47% in 2030 and 95% in 2050 (Natuur & Milieu, 2017). The main reduction in GHG emissions should come from a decrease in livestock numbers and meat consumption. Land use should shift to more vegetable and nuts production and less livestock production, while soils should store more carbon.

3.2.3. Food-chain

There are about 65,000 farmers in the Netherlands (PBL, 2012) and because they are so many, large variation in aims, goals and targets is likely to occur. There is also large diversification in farm type, from dairy to arable farming, organic to conventional, causing even more variation in aims related to sustainability and in aspects considered important. While in poultry, farmers are actively working on reducing emissions (Jimmink et al., 2017; Kip in Nederland, 2016), many arable farmers are unaware of their emissions and even think they are only sequestering carbon in their soils (Nederlandse Akkerbouw Vakbond, 2018). Still, more than 80% of the farmers want to produce more sustainably and more than half of the farmers want to do that within ten years (Bouma and Marijnissen, 2018a). LTO, that represents almost 50,000 farmers, aims to produce better with less to become more sustainable (LTO Nederland, n.d.). The Nederlandse Akkerbouw Vakbond (NAV) aims at societal sustainable agriculture with prevention of harmful emission levels (Nederlandse Akkerbouw Vakbond, n.d.). Despite these aspirations and aims, for most farmers it is more important to get better prices for their products, improvement of their image and a reduction of legislation and rules (Agripeilingen, 2017).

Also in the food processing industry, companies' strategies to reduce GHG emissions vary largely. Some companies, like Unilever, FrieslandCampina and Royal Cosun signed a sustainability manifest and are actively working on aims concerning sustainability and reducing emissions. Unilever has the goal to be carbon positive, which is a negative net emission level, in 2030 (Unilever, n.d.), FrieslandCampina aims at climate-neutral growth (FrieslandCampina, 2018) and Royal Cosun supports farmers in cultivating more sustainably (Royal Cosun, n.d.). It should be noted that these are the leading companies in sustainability and reducing emissions while many other companies lack aims on emissions.

Within the Centraal Bureau Levensmiddelen, supermarkets are working on a more sustainable food chain (Centaal Bureau Levensmiddelenhandel, 2018). Separate supermarket chains have set goals. Albert Heijn, for example, wants all supermarkets to be CO_2-neutral in 2025 and aims at an equal share of plant- and animal proteins in our diets in 2025. For their products, supermarkets mainly have requirements on less pesticides but not on reduction of GHG emissions (Albert Heijn, 2018, 2017; Jumbo, 2017; Lidl, 2018). Nevertheless, Jumbo wants their suppliers to feed livestock with feed from Europe to decrease the carbon footprint (Menkveld, 2018). Consumption of sustainably labelled food is increasing in the Netherlands (Logatcheva, 2017). However, the labels mainly concern other aspects of "sustainability", like organically produced or fair-trade, suggesting consumers have other priorities in "sustainable consumption" than reducing GHG emissions.

Banks are dependent on their image and therefore want to take the lead in societal important aspects. Rabobank is the largest bank in the Netherlands in the food and agricultural sector ("Rabobank | Banken.nl," n.d.). Rabobank wants to take up the challenge to make the sector CO_2-neutral (Rabobank, 2018). A large role needs to be played by precision agriculture, innovation, big-data and modern breeding techniques, according to the bank.

3.2.4. Targets for a desired future

Stakeholders' targets regarding GHG emissions in Dutch agriculture were quantified and converted into targets for emissions per hectare (Table 1). The EU and some NGOs want to keep temperature rise during this century at 1.5°C and have the same sectoral reduction share. As they all have the same quantitative targets for agricultural GHG emission reduction, they are grouped into the desired future "Paris agreement". To reach the maximum 1.5°C temperature rise, the Netherlands has to reduce the emissions by 95% in 2050. As already described in section 4.2.1, the Dutch government proposed a climate law to reduce GHG emissions and indicated what the emission reduction of each sector should be to achieve a total reduction of 49% in 2030. Arable and livestock farming should reduce their emission levels after 2017 with 2.5 Mton to 16.5 Mton to reach the reduction of 49% in 2030 according to the sectoral distribution. The Dutch climate law also set a target of a reduction of total Dutch GHG emissions of 95%. However, it was not further specified what share all sectors would have of those 95%. Therefore, a reduction of 95% was set as 2050 target of the Dutch government for agricultural GHG emissions, assuming equally sharing reductions among sectors. Natuur & Milieu aims to achieve a reduction in agricultural GHG emissions of 47% in 2030 and 95% in 2050. The target for 2050 is the same for the NGO's and governments. However, the path towards that reduction differs among the stakeholders. The stakeholders in the food chain have no quantitative aims, but are willing to reduce emissions as long as it does not affect their income. Together, stakeholders have three different desired futures that will be used as targets. Strategies could be defined to reach those targets in which also the qualitative stakeholder aims are taken along, which was derived from a backcasting approach.

Table 1: Stakeholders' desired futures regarding GHG emissions of Dutch agriculture for 2030 and 2050, the baseline values from 1990, and measured values from 2015. *The EU and NGOs, who had as main target to reach goals of the Paris Climate Agreement with a similar sectoral share, were merged into "Paris Agreement" as they all had the same target. The Dutch government represents targets based on the Dutch climate law and its indication for further reductions of agricultural emissions after 2017. The food-chain represents all stakeholders present in the food-chain, except for consumers.* ***A)*** *Targets for Dutch agricultural GHG emissions in Mton CO_2-equivalent and* ***B)*** *in ton CO_2-equivalent per hectare.*

A	*1990*	*2015*	*2030*	*2050*
Paris Agreement	25.3	19.2	16.2	1.3
Dutch Government	25.3	19.2	16.5	1.3
Natuur & Milieu	25.3	19.2	13.4	1.3
Food-chain	Any reduction is fine if the income is not negatively affected			

B	*1990*	*2015*	*2030*	*2050*
Paris Agreement	12.7	11.0	8.1	0.7
Dutch Government	12.7	11.0	9.4	0.7
Natuur & Milieu	12.7	11.0	6.7	0.7
Food-chain	Any reduction is fine if the income is not negatively affected			

3.3. Reaching the desired futures

3.3.1. Historical trends

Dutch agriculture is, and has been, an important emitter of GHG. The sector contributes even more than industry to the national GHG emissions. In 2015, agriculture emitted 9.8% of the national emissions, compared to 11.3% in 1990 (RIVM, 2017).In that same time period, the sector reduced its GHG emissions from 25.3 to 19.2 Mton CO_2-equivalent, which is a reduction of 24% (RIVM, 2017). Agriculture is only a minor emitter of CO_2, but has comparably large CH_4 and N_2O emissions that have a larger global warming potential than CO_2 (Kramer et al., 1999; Moerkerken and Smit, 2016; Working Group I: The Physical Science Basis, 2007). Those agricultural emissions mainly arise from enteric fermentation, manure management and agricultural soils (Kramer et al., 1999; O'Mara, 2011).

3.3.1.1. Enteric fermentation

Enteric fermentation accounted for 44% of the Dutch agricultural GHG emissions in 2015 (RIVM, 2017). It results in methane emissions as a by-product of the fermentative digestion by gut micro-organisms (Gerber et al., 2013). Factors affecting total emissions through enteric fermentation are the amount of livestock, livestock breed, rumen pH, amount of feed intake, type and quality of feed and temperature of the environment (AgriHolland, 2015; Sejian et al., 2011; Shibata and Terada, 2010). When emissions are expressed on a product basis, the animal productivity also influences emission intensity.

Methane emissions resulting from enteric fermentation were reduced by 8%, from 9.2 Mton CO_2-equivalent in 1990 to 8.5 Mton CO_2-equivalent in 2015 (RIVM, 2017). This reduction was caused by a decrease in livestock numbers and especially by the decrease of dairy cattle (Moerkerken and Smit, 2016). Better breeds and increases in feed intake and feed digestibility caused an increase in milk production per cow. This resulted in a decrease of dairy cattle as milk production was not allowed to increase above the milk quota. The milk quota is a system in which milk production was coupled to production rights to ensure a stable milk price and prevent overproduction of milk. However, the milk quota was abolished in 2015, which resulted in an increase of 8% of dairy cattle numbers (Agrimatie, 2017a). To prevent further increases in livestock numbers, the government established a phosphate ceiling and a stopping bonus that together caused a reduction in cattle in 2017 (Agrimatie, 2017a). Reduction in historical emissions due to enteric fermentation were mainly dependent on cattle number, which was highly influenced by management and governmental legislation.

3.3.1.2. Manure management

During manure management, which involves everything concerning handling and storage of livestock manure, CH_4 and N_2O are emitted. Factors affecting emissions through manure management are the housing and management systems, temperature, storage time, diet and livestock type (Chadwick et al., 2011; Hristov et al., 2013; Sejian et al., 2015; Smith et al., 2008). Between 1990 and 2015, CH_4 and N_2O from manure were reduced with 23% and 15% respectively (RIVM, 2017). These reductions were caused by decreasing livestock numbers and lower N excretions per animal (Moerkerken and Smit, 2016; RIVM, 2017). Other effects on emission of GHG of manure management were increases for dairy cattle due to shifts from grazing to confinement systems (Van Bruggen et al., 2012; Van Bruggen and Faqiri, 2015). This resulted in an increased liquid manure proportion with higher emissions (Hongmin Dong et al., 2006) Moreover, changes in housing systems for poultry resulted in an 84% reduction of poultry methane emissions (RIVM, 2017; Van Bruggen et al., 2012). The livestock numbers decreased for dairy cattle due to higher milk production per cow. The sheep population more than halved due to both the foot-and-mouth disease and a governmental lowering and stopping of the bonus per owe (Centraal Bureau voor de Statistiek, 2018a; Compendium voor de Leefomgeving, 2016c). Contrastingly, other livestock numbers increased but that did not compensate the reduction in emissions due to the decreasing dairy and sheep numbers. The amounts of goats kept increasing as their milk was not under the milk quota and served as a replacement for cow milk (Centraal Bureau voor de Statistiek, 2018a; Compendium voor de Leefomgeving, 2016c; van der Meulen, n.d.). Poultry numbers fluctuate due to diseases and the same holds for swine. In addition, governmental regulation on manure and phosphate caused a reduction in swine numbers (Compendium voor de Leefomgeving, 2016c; RIVM, 2017). Changes in historical emissions from manure management were mainly dependent on decreasing livestock and thereby a reduction in total manure management and on the housing systems applied.

3.3.1.3. Agricultural soils

In agricultural soils, emission of N_2O takes place via application of synthetic and organic fertilizers, grazing, crop residues and cultivation of organic soils. In addition, indirect emissions occur due to atmospheric deposition, nitrogen leaching and run-off. Emissions of N_2O from agricultural soils comprised 28% of the Dutch agricultural GHG emissions in 2015. These emissions reduced with 40% when compared with 1990 (Moerkerken and Smit, 2016; RIVM, 2017). The reduction was caused by a large decrease in nitrogen inputs from both organic and synthetic fertilizers. This is also the main cause of the reduction in total Dutch agricultural GHG emissions (Moerkerken and Smit, 2016). The reduction of N-inputs and subsequently reduced GHG emissions was mainly caused by tightening of European and Dutch legislation (Moerkerken and Smit, 2016) (Figure 1). In addition, less grazing hours of dairy cows decreased the amount of manure production during grazing and subsequently reduced agricultural soil emissions by 4% (Van Bruggen and Faqiri, 2015). However, legislation aimed at reducing ammonia emissions by injecting manure in the soil resulted in an increase of N_2O emissions from agricultural soils (de Haan et al., 2009; Rijksdienst voor Ondernemend Nederland, n.d.). The reduction of historical GHG emissions from agricultural soils is mainly caused by decreases in fertilizer inputs and regulated by the Dutch and EU governments.

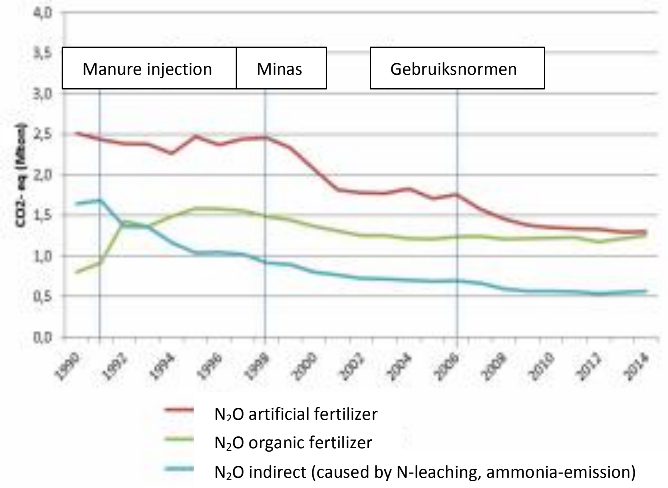

Figure 1: Historical GHG emissions of Dutch agricultural soils and the effects of legislation measures on direct and indirect N_2O emissions from artificial and organic fertilizers. *"Manure injection" indicates a law that obliged manure injection in the soil instead of surface spreading. "Minas" required farmers to keep track of incoming and outgoing minerals and a mineral surplus was restricted. Minas was replaced by "gebruiksnormen" that restricted maximum supply of manure and minerals based on acreage, soil type and crop type. Adapted from Moerkerken and Smit, (2016).*

3.3.1.4. Overview historical trends

The historical GHG emissions of Dutch agriculture have for both arable and livestock farming decreased compared to the emissions in 1990 (Figure 2A & 2B). The reduction was also observed when splitting emissions based on their source, enteric fermentation, manure management and agricultural soils (Figure 2D). However, the last few years, emissions started increasing again. This was mainly due to increasing numbers of dairy cows caused by abolishment of the milk quota system. GHG emissions were in total 19.2 Mton CO_2-equivalent in 2015 (RIVM, 2017). This is about 11.0 ton CO_2-equivalent/ha (Calculations based on Compendium voor de leefomgeving, (2016); RIVM, (2017)). Livestock accounts for the largest share of the Dutch agricultural GHG emissions (about 85%). Moreover, the emissions of livestock on a per hectare basis are four to six times larger than arable farming, with 15.2 and 3.0 ton

CO_2-equivalent/ha respectively in 2015 (Figure 2C) (Calculations based on Compendium voor de leefomgeving, (2016); van Bruggen et al., (2017)).

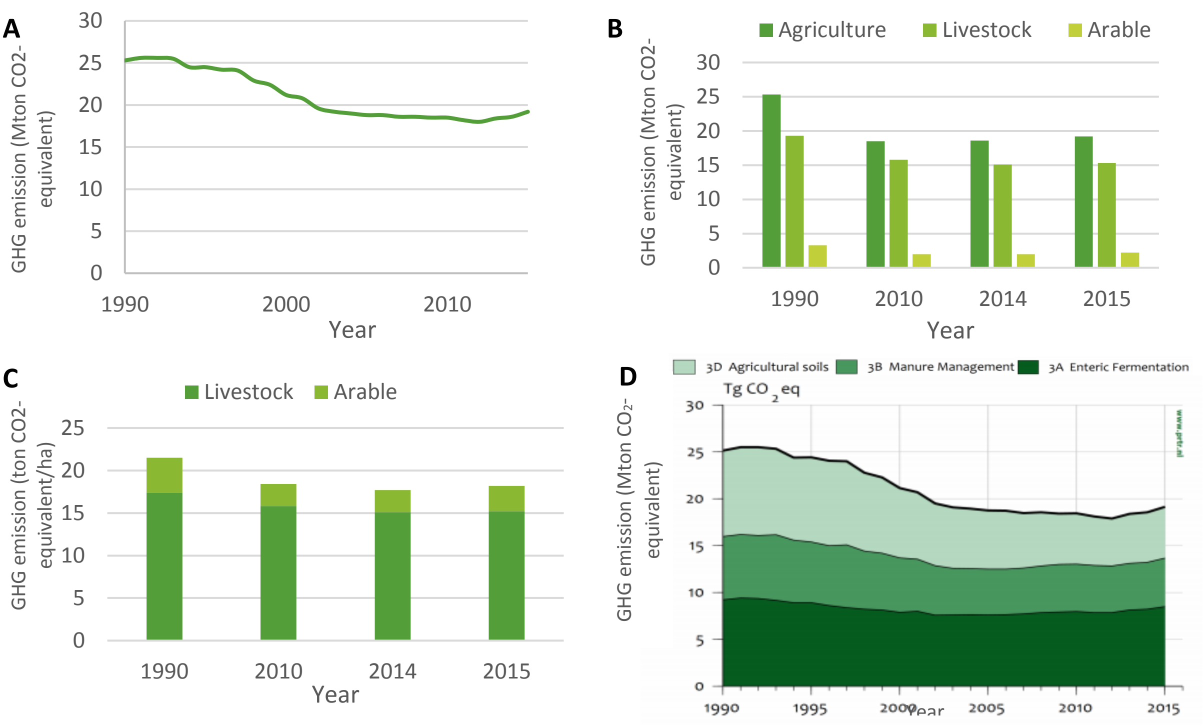

***Figure 2: Historical GHG emissions of Dutch agriculture**. **A)** GHG from 1990-2015 in Mton CO_2-equivalent **B)** divided in GHG emissions of total Dutch agriculture, livestock farming and arable farming **C)** GHG emissions of livestock and arable farming per hectare **D)** divided over the processes enteric fermentation, manure management and agricultural soils. Figures 1.A-1.C were created based on data from Compendium voor de Leefomgeving, (2016b); National Institute for Public Health and the Environment (RIVM),(2017); van Bruggen et al., (2017); Van Bruggen et al., (2015). Figure 1.D was retrieved from RIVM, (2017).*

3.3.2. Projected trends

Historical trends in GHG emissions and current emissions might change towards the future. Changes can be caused by legislation, societal pressure, technological advances and economic forces. These factors cannot be predicted for the future. However, what can be done is translating current trends and practices and currently applied and intended legislation into future agricultural GHG emissions.

Based on current applied and intended legislation and trends, future agricultural GHG emissions were estimated by Velthof *et al*, (2016) until 2030. Their projected trends are together with historical trends and future targets of the stakeholders shown in figure 3. The large decrease in historical GHG emissions is expected not to continue in the future. Instead, even a small increase is estimated. Methane emissions are expected to increase due to larger numbers of dairy cows and more milk production per cow (Velthof et al., 2016). This results in more methane emissions from enteric fermentation and manure management. Nitrous oxide emissions are estimated to have only minor changes in the future. The projected future trends do not account for agricultural CO_2 emissions, unlike the calculations from historical trends. As can be seen in figure 3 the projected future trends will not result in achievement of the targets.

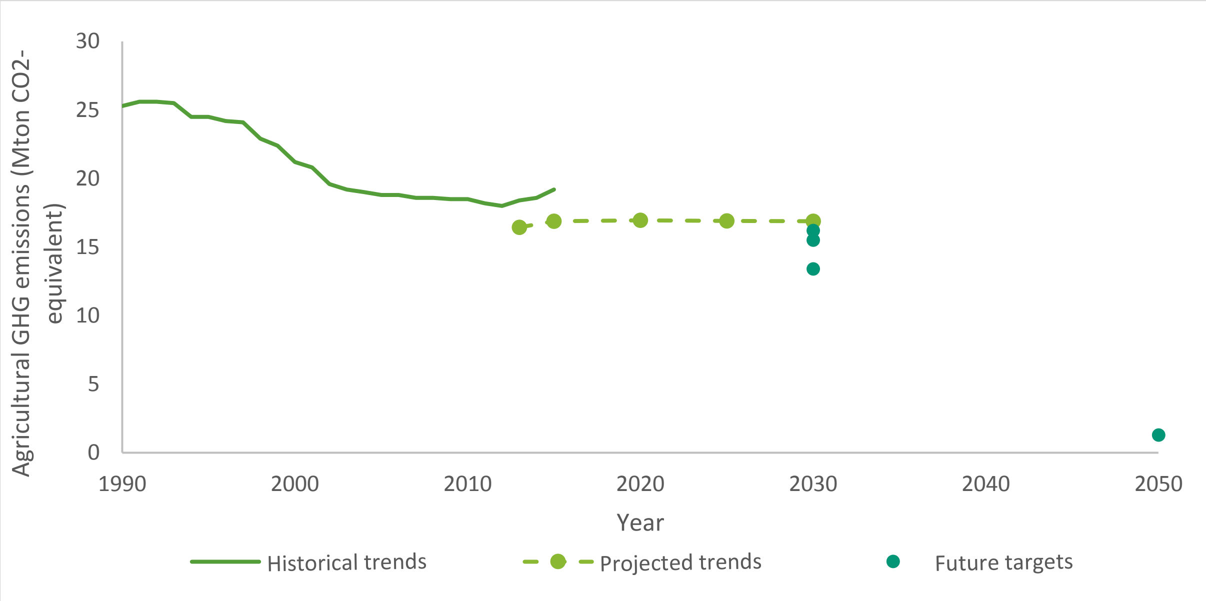

Figure 3: Historical trends, projected trends and future targets regarding Dutch agricultural GHG emissions*. Historical GHG emissions were calculated based on data on CO_2, CH_4 and N_2O emissions from RIVM, (2017). Projected trends were calculated based on estimations for future CH_4 and N_2O emission retrieved from Velthof et al., (2016). Future targets for 2030 and 2050 were set, based on a variety of stakeholder aims as described in chapter 3.2.*

After historical trends of decreasing emissions, GHG emissions shortly increased and are projected to merely stabilize in the future (Velthof et al., 2016). Historically, the emissions were reduced by an increased milk production per cow and a subsequent decrease in dairy cows due to the milk quota (RIVM, 2017). However, the milk quota was abolished in 2015, which resulted in an increasing herd size and consequently higher GHG emissions (RIVM, 2017). To limit the following expansion in dairy cow herd size, the Dutch government set new rules in which growth is related to land ownership, phosphate production and manure processing (Rijksdienst voor Ondernemend Nederland, 2018a, 2018b, 2018c, 2018d). These measures limit further growth and subsequent GHG emissions but will not result in a future reduction in GHG emissions (Velthof et al., 2016). Most measures regarding manure management, application of manure on agricultural soils and animal housings are related to reduce ammonia and fine dust emissions and do not consider a reduction in GHG emissions.

The largest contributor to the historical reduction in agricultural GHG emissions was the decrease in manure and artificial fertilizer application on agricultural soils (Moerkerken and Smit, 2016). This was caused by legislation that restricted the amount of organic fertilizer and the total fertilizer application (Velthof et al., 2017). Under currently applied and intended legislation, the fertilizer application will not reduce further (Velthof et al., 2016). Although legislation successfully aims at reducing ammonia emission upon application, the application methods used for that result in an increased nitrous oxide emission (RIVM, 2017). This will be counteracted by an expected continuation of an already occuring trend of decreasing farming acreage, which will reduce GHG emissions due to less total fertilizer application (Velthof et al., 2016). The historical trends and legislation causing a reduction in GHG emissions are expected not to cause a similar reduction towards the future. Instead, GHG emissions are projected to merely stabilize and the stakeholders' targets will not be reached when continuing business as usual (figure 3). Therefore, to reach the targets, more needs to be done than the continuation of current practices and currently applied and intended legislation.

3.3.3. Strategies to reach the desired futures

In 2030, the Dutch agriculture needs to have the GHG emission of 2015 further reduced by 3-5.8 Mton CO_2-equivalent to achieve the targets of 13.4-6.5 Mton CO_2-equivalent. This is a reduction between 16-30% to 2.9-4.3 tonnes CO_2-equivalent per hectare. For 2050, the reduction needs to be 17.9 Mton CO_2-equivalent, which is 10.3 tonnes CO_2-equivalent per hectare. Based on historical and projected trends, Dutch agricultural GHG emissions will stabilize at around 16.9 Mton CO_2-equivalent. This is not sufficient to reach the stakeholders' aims and therefore, more needs to be done to reduce Dutch agricultural GHG emissions.

Currently known agricultural mitigation measures to further reduce GHG emissions are listed and quantified in table 2. Their mitigation potential is calculated at full potential, meaning the strategy is adopted by all farmers and applied by the whole agricultural sector. Further mitigation of GHG emissions is possible for all main emission categories, namely enteric fermentation, manure management and agricultural soils. The strategies differ, not only in their mitigation potential, but also in innovation readiness, complexity, trade-offs and synergies. Some strategies are already applicable while other strategies have never been applied in practice and demand further research or technological improvements, which is reflected in "innovation readiness". Mitigation strategies might require large changes in farm management, require education or changes on stables, manure storage or machinery, which is reflected in "complexity". Strategies that aim to reduce GHG emissions can have trade-offs as well as synergies with other aspects of sustainability, like N-surplus, pesticide use or biodiversity, but also with for example, economic aspects. The mitigation potential is important with regard to reaching the targets for GHG emission reduction. But the implementation of mitigation strategies also largely depends on their innovation readiness, complexity, trade-offs and synergies. Many of the listed strategies require large investments or great transformations in farming. This reduces the likelihood that farmers will adopt mitigation strategies that have no benefits for them without compensation or legal restrictions.

__Table 2: Mitigation strategies to reduce GHG emissions of Dutch agriculture.__ The mitigation strategies are divided over enteric fermentation, manure management and agricultural soils. Their mitigation potential (MP) is quantified for Dutch agriculture in reductions per hectare for the full Dutch agricultural acreage. The mitigation strategies are listed from the highest mitigation potential to the lowest potential for the three categories, enteric fermentation, manure management and agricultural soils. The area in which the mitigation strategy was studied and quantified is given. Trade-offs and synergies are explored based on literature and the author's ideas. The uncertainty of the mitigation potential was derived as much as possible based on information from the papers quantifying the strategy, but also based on other literature sources. Costs of implementation of the strategy and incentives were given as provided in the papers that quantified the mitigation potential, as well as other literature. The farmers' willingness/ease to adopt the strategies is derived from information of a Dutch farmer's trade union NAV, literature and the authors' perception. The colour classification was proposed by the author to divide the innovation readiness and complexity of mitigation strategies from ready/easy implementation to very complex/not ready; trade-offs & synergies from many synergies/few trade-offs to few synergies/many trade-offs; willingness/ease to adopt from willing to adopt to not willing to adopt in respectively the colours green – yellow – orange – red. Absence of colours in willingness/ease to adopt is when those strategies are currently not yet applied in the Netherlands and the attitude of farmers to that strategy is unknown.

Mitigation strategy Innovation readiness /complexity	MP (t CO_2-eq/ha)	Study type	Area	Trade-offs & synergies	Uncertainty	Costs	Willingness/ease to adopt	Incentives	Remarks	Source
Enteric fermentation										
Several innovative technologies to catch in methane	-4.45	Review, experimental and feasibility studies	World-wide, mainly New-Zealand	Might be expensive.	Technologies are not yet applied for this purpose. All methane of confined livestock should be caught to reach the mitigation potential, which is not realistic			For some revenue, methane can be sold for biogas or bioplastics	New technologies might take some time to become ready for application. Full conversion of CH_4 results in CO_2, so there will be no full reduction GHG emission.	(Pratt and Tate, 2018)
Shift to organic dairy farming	-1.7	Modelling of 8 organic model farms and 6 conventional model farms	The Netherlands	Reduced milk production. Maybe less farm profit if all farms shift to organic farming	-63% - +18% plus not investigated uncertainty in model inputs	Higher costs for inputs and grazing land	Farmer might be reluctant to the large required changes in farm management		Reduction is mainly due to lower production intensity, the emissions were not lower per unit product	(Bos et al., 2007)
Breeding for higher animal productivity	-1% EIA_{dm}/ year	Modelling per animal type	United Kingdom	For poultry and beef cattle, the reduction is due to faster weight gain and thereby earlier slaughter and shorter life, which is not desired by animal rights groups.	Under current situation, the projection will hold for 15 years. -1% is average over all livestock. Beef and sheep are lower as there the adaptation of new technology is low.	No additional costs, Except when farmers have to buy new animals instead of using their own bred young animals.	The farmer sees an economic incentive to adopt the technology and can exploit the improvements without needing any significant training or changed practice.		For absolute decreases in GHG emissions, an increase in production needs to be balanced with a decrease in herd.	(Genesis-Faraday Partnership, 2008; Gill et al., 2010; Jones et al., 2008)

Dairy cattle diet change: more fat (6%), less fibre	-0.24	Quantitative research	Netherlands / North-West-Europe / Globally	Fat-quality of milk might be affected. Less grazing is not desired for animal rights and culture. Milk production slightly increases	Results might differ in grazing systems	Costs of buying some differences in feed	Depends whether whole grazing regime or farm management needs to be changed		Includes reduced direct and indirect emissions from enteric fermentation and manure management	(Caro et al., 2016)
Manure management										
Several innovative technologies to catch methane	-2.6	Review, experimental and feasibility studies	World-wide, mainly New-Zealand	Might be expensive	Technologies are not yet applied for this purpose. All methane of manure should be caught to reach the mitigation potential, which is not realistic.			For some revenue, methane can be sold for biogas or bioplastics	New technologies take some time to become ready for application. Full conversion of CH_4 results in CO_2, not fully reducing emission.	(Pratt and Tate, 2018)
Shift from liquid to separation pig manure systems	-1.95	Quantitative research	China, the Netherlands	More labour required. Might be difficult to create in existing housings	-3 - -4 Mton reduction		System requires daily labour, might make farmers reluctant. No revenue of this measure.			(Wang et al., 2017)
Anaerobic manure digestion for energy capture combined with daily flushing of cattle manure and cooling of pig manure	-1.7	Modelling	Temperate regions	New equipment needed Current manure digesters are highly dependent on subsidies Will reduce manure surplus	-33 - +6% for slurry cooling	Costs for a mono-digester are between €150,000 and €600,000 depending on the size. Yearly costs are estimated at €55,000	Highly expensive digesters, little revenue and other benefits apart from reducing emissions, makes farmers reluctant.	Change legislation to label digested products not anymore as animal manure		(Sommer et al., 2004; van der Bas, 2018; Velghe and Wierinck, 2013)
Nitrification inhibitors	-1.3 - +0.15	Quantitative research Review	UK, globally	Financially Reduced N-leakage Increased NUE Increased grass yields	-1.3- +0.15 t/ha	€506/ t CO_2-eq	Besides from the costs, it has many advantages. Part of the farmers might be willing to pay for that		Decreases in N_2O can increase NH_3, and thereby increase indirect N_2O emissions	(Lam et al., 2017; O'Brien et al., 2014; Winiwarter et al., 2018)
Cooling pig storage manure to 10ºC	-0.37	Modelling	Temperate regions, calibrated to Scandinavian temperatures	Need equipment to cool manure. Manure cannot stay in the stable	-33 - +6%	Combine manure cooling with heat exchange to heat stables makes it cost-effective				(Sommer et al., 2004)
Agricultural soils										

Agroforestry	-2.6 - -6.4	Stakeholder-discussion Review	Europe US, Canada	Low profitability. New technologies, machinery and knowledge needed Increases biodiversity	Results highly depend on the type of agroforestry, amount and variety of trees, herbs and bushes		The whole farming system needs to be changed and large investments are needed, so farmers are probably not willing to implement this strategy.	Governmental support. CAP appreciation. Training programs. Marketing strategies		(Feliciano et al., 2018; Hernández-Morcillo et al., 2018; Schoeneberger et al., 2012)
Woody-biochar application	-0.58 - -1.72	Experimental	United States	Yield reduction. Might have negative effects on human health.	Results vary depending on biochar feedstock, soil moisture content, and fertilization.				Mitigation needed 25 t/ha biochar. In literature, the effectiveness and applicability of biochar was limited	(Maienza et al., 2017; Ramlow and Cotrufo, 2018)
Shift to organic arable farming	-1.9	Modelling of 2 organic farms and 2 conventional farms	The Netherlands	Reduced yields. Maybe less farm profit if all farmers shift to organic. High risk on uncontrollable diseases when applied at large scale	-1.2 - -2.7 plus not investigated uncertainty in model inputs		Requires large shifts in farm management, although farmers do shift when the revenue is high.		The emissions per product were higher in organic farms compared with conventional farms.	(Bos et al., 2007)
Submerging drains to re-establish high water table in organic peat soils	-1.4	Experimental research	The Netherlands	Very expensive Prevents further decline of organic soils and the costs associated with it. Takes a lot of time to implement	Probably the reduction will be higher as first applications reveal	€1700-2000/ha	If financial costs can be shared, farmers might be willing as they see other negative effects of soil decline.	Subsidies	Drainage need to be replaced after 20 years	(Van Den Akker, 2016)
Cover cropping	-1.16 - -1.35	Modelling	Spain, Pennsylvania	Extra costs for seed and management Risk on pests and diseases Lower N-surplus Increased biodiversity	Depends on type of cover crop, especially legumes/non-legumes, and weather conditions	€28-73/ha depending on whether cover crop is sold for animal feed	Farmers are already partially applying cover crops, but full application might hamper their farming operations and makes farmers reluctant.		Not possible under low temperatures or when growing winter cereals. The higher potential of legumes is due to lower additional N-inputs	(Gabriel et al., 2013; Kaye and Quemada, 2017)
Precision agriculture	-0.66	Quantitative Research	Globally → regionally	Expensive technology Lower N-surplus Less pesticide use Increased biodiversity	-36 - -40% of N-application emissions. Different mechanisms and applications have	€775-1600/t CO_2-eq although money is saved due to reduced inputs and fuel use	It is expensive and technical problems are hampering implementation. However, farmers do like the idea of	More research in solving technical problems and adapting		(Balafoutis et al., 2017; van der Wekken, 2018; Winiwarter et al., 2018)

				Energy savings from less fertilizer and pesticide production	different results but all reduce GHG emissions.		precision agriculture. Solving the problems and subsidies would result in high implementation rates	machines for NL		
Nitrification inhibitor feeding to grazing cows (30g DCD/cow/day)	-0.1- -0.4	Experimental	Ireland, New-Zealand	When applied during lactating, DCD may be found in milk	Effectivity depends on soil texture and drainage as well weather conditions	€506/ t CO_2-eq	Farmers might do this when it is proven to be safe for animals and human and when it is not expensive.		It is cheaper and more efficient than applying NI to soils.	(Luo et al., 2016; Minet et al., 2018)
Increase wheat acreage from 25% to 50%	-0.38	Modelling	Netherlands, arable sandy soils	Wheat is a low-value crop and increasing acreage would reduce farm profits Saves labour	Results vary between sites and years and N-inputs. Model on SOC built-up is highly uncertain.	€340/ha/y	It involves many changes in way of farming, and crop rotation and is financially not achievable		Stubble should be incorporated in soil	(Bos et al., 2017)
Biologic Nitrification Inhibition	-0.3	Experimental, review	Brazil	GMO plant are not allowed in EU. Currently not available for temperate grasses. Yield increases	Effectivity also depends on C-loss by rhizodeposition		Farmers might be willing to apply this as it only involves sowing a modified version of their pasture grass.		Possibilities to also apply to crops/cereals. intercropping with high/low BNI	(Byrnes et al., 2017; Coskun et al., 2017; Subbarao et al., 2017)
Reduced tillage / no tillage		Experimental, Review	Globally	Increasing SOC. Higher resilience against weather conditions. Less fuel and labour. Soil compaction. Higher weed pressure.	Results are highly variable, from negative to positive. Results depend on many other factors, like climate, soil type, nitrogen availability		Management and way of farming needs to change a lot. Some farmers see the benefits and adopt this technology, others only see problems and are not willing to adopt. Farmers are willing to apply this depending on the crop species, soil and weather conditions but only if herbicides stay available.		Built-up of SOC only occurs in the upper layer, while ploughing brings SOC also to deeper layers.	(Abdalla et al., 2014; Autret et al., 2016; Ball et al., 2014; Bos et al., 2009; Dimassi et al., 2014; Ghimire et al., 2017; Huang et al., 2018; Krauss et al., 2017a, 2017b; Kuhn et al., 2016; Rutkowska et al., 2018; Sainju, 2016; Sainju et al., 2010; Sukkel, 2017)

3.3.3.1. Enteric fermentation

Enteric fermentation results in current emissions of 8.5 Mton CO_2-equivalent per year, which is 4.9 tonnes CO_2-equivalent per hectare (RIVM, 2017). Those emissions rise from methanogens, rumen bacteria involved in feed fermentation (Wanapat et al., 2015). There are three ways to intervene in that process to decrease the methane emissions. First, changing the feed composition to manipulate microbial composition and feed conversion (Patra, 2016). This can be done by replacing roughage with concentrates or maize silage or feeding fresh grass instead of grass silage (Caro et al., 2016; Zifei and Yang, 2018). Dietary additives to reduce methane production are fat, by feeding linseed, tannins, by feeding clover or chicory, and bioactive compounds of plant extracts that have anti-methanogenic potential (Caro et al., 2016; Jayasundara et al., 2016; Moerkerken et al., 2014; Patra et al., 2017; Patra, 2016; Wagner-Riddle et al., 2017; Wanapat et al., 2015; Zifei and Yang, 2018). Changing feeding regimes might cause larger changes on farm-level. For example, more or less grazing influences the daily labour but also the amount of grasslands required and the subsequent grassland carbon stocks. Second, methane emissions can be reduced by catching in methane produced in stables (Pratt and Tate, 2018). That methane can be used to produce biogas, energy or even bioplastics and is thereby prevented from emission. This method is not yet applied in stables but does function in other places, like coalmines. This option has the highest mitigation potential, but as it is currently not yet applied for this purpose, implementation might be difficult to achieve (table 2). Third, changes in farming intensity by either increasing production per animal while reducing animal herd or having extensive organic farms can reduce emission (Bos et al., 2007; Genesis-Faraday Partnership, 2008; Gill et al., 2010; Jones et al., 2008; Zifei and Yang, 2018). Especially shifting to organic farming requires a large shift in the way of farming, as often new inputs need to be used, markets change and a new mind-set is necessary to focus on other goals than what is common in conventional farming. Mitigation options that are considered most feasible, are especially those options that do not require many changes in farm management and are not expensive, like having newly bred animals and adapting feeding regimes. The listed mitigation options can potentially reduce total agricultural GHG emissions by 0.24-4.45 tonnes CO_2-equivalent per hectare (table 2).

3.3.3.2. Manure management

Current emissions of manure management are 4.5 Mton CO_2-equivalent per year, or 2.6 tonnes CO_2-equivalent per hectare (RIVM, 2017). Methane and nitrous oxide present in the manure are released to the air under influence of nitrifying bacteria (Broucek, 2018; Skiba and Rees, 2015). Altering the bacteria environment decreases emissions, for example by decreasing the temperature of manure storage, adding nitrification inhibitors or acidification (Lam et al., 2017; Mohankumar Sajeev et al., 2018; O'Brien et al., 2014; Sommer et al., 2004; Winiwarter et al., 2018). Moreover, the manure and methane can be caught in and digested to produce biogas or bioenergy (De Vries, 2014; Mohankumar Sajeev et al., 2018; Pratt and Tate, 2018; Sommer et al., 2004; Zifei and Yang, 2018). These techniques have large reduction potentials (table 2). However, the financial costs are high and current manure digesters depend for two-third of their revenue on subsidies that are about to stop (van der Bas, 2018; Velghe and Wierinck, 2013). Those mitigation strategies for manure management do not require farmers to significantly change their management, but large investments are needed for implementation. Cheaper options, like adding nitrification inhibitors to the manure or grasslands seems to be more feasible than the highly expensive, but also highly effective measures (table 2) Implementation of strategies can potentially reduce emissions by 0.37-2.6 tonnes CO_2-equivalent per hectare.

3.3.3.3. Agricultural soils

Agricultural soils are responsible for the emission of 5.5 Mton CO_2-equivalent per year, which is 3.1 tonnes CO_2-equivalent per hectare (RIVM, 2017). Those emissions arise from both soil microbe activity and changes in soil carbon stocks as a consequence of applied management practices. Affecting practices mainly involve nitrogen management and soil carbon sequestration. Reduction of GHG emissions via nitrogen management involves strategies like organic farming, precision agriculture, and nitrification inhibition (Balafoutis et al., 2017; Bos et al., 2007; Byrnes et al., 2017; Coskun et al., 2017; Luo et al., 2016; Minet et al., 2018; Moerkerken et al., 2014; Subbarao et al., 2017; Winiwarter et al., 2018). Organic farming and precision agriculture either cause large shifts in the way of farming or need large investments (Balafoutis et al., 2017). However both strategies are not only positive for reducing GHG emissions, but also reduce pesticide use, nitrogen surplus and may increase biodiversity (Balafoutis et al., 2017; Bos et al., 2007). Increasing soil carbon sequestration requires a higher carbon input in soils, which involves strategies like cover cropping, more cereal production and agroforestry (Bos et al., 2017; Feliciano et al., 2018; Gabriel et al., 2013; Hernández-Morcillo et al., 2018; Kaye and Quemada, 2017; Schoeneberger et al., 2012). Of these options, cover cropping is the most feasible option as it is easy to apply and does not require large changes in farm management, although the mitigation potential is not that high (table 2). Agroforestry has the largest mitigation potential and can increase biodiversity and carbon inputs (table 2)(Feliciano et al., 2018; Sukkel, n.d.). However, it might also greatly reduce the farmers' income and requires large changes in farm management (Hernández-Morcillo et al., 2018; Schoeneberger et al., 2012). Currently known mitigation strategies for agricultural soils can potentially reduce total agricultural GHG emissions with 0.3-6.4 tonnes CO_2-equivalent per hectare.

A much debated GHG mitigation option is application of no- and reduced tilling (NT/RT). Studies find evidence for increases (Abdalla et al., 2014), decreases (Ghimire et al., 2017; Krauss et al., 2017b; Sainju, 2016) or no effect at all (Ball et al., 2014; Sainju et al., 2010) from NT/RT on emissions of CO_2, CH_4 and N_2O. Fact is that many other factors influence the mitigation potential of NT/RT, like soil type, rainfall, temperature, type and amount of fertilizer application, presence of cover crops, incorporation of stubble, crop type, C/N ratio of crops and cover crops, application of mono-cropping or rotation cropping (Autret et al., 2016; Ball et al., 2014; Dimassi et al., 2014; Ghimire et al., 2017; Kuhn et al., 2016; Rutkowska et al., 2018; Sainju, 2016; Smith et al., 2008). Moreover, duration of tilling management practices influences the mitigation potential over years (Dimassi et al., 2014). The built up of SOC occurs only in the upper layer and is often offset by an increase in N_2O emissions (Krauss et al., 2017a; Kuhn et al., 2016). In addition, GHG mitigation by carbon sequestration is only a temporary mitigation strategy, as soils have a maximum carbon bearing capacity and the carbon will also be released again (Kuhn et al., 2016; Smith et al., 2008). Taking this all into account, NT/RT was not quantified and considered as a plausible option to reduce agricultural GHG emissions in the Netherlands.

3.3.3.4. Implementation of mitigation strategies

Potentially, adding the effects of the mitigation strategies will result in the achievement of the stakeholders' emission goals by 2030 and 2050. However, the mitigation potentials are calculated based on full adoption by all farmers on all their fields. This will most likely not be achieved. Moreover, not all measures can be applied simultaneously at the same farm to achieve their added reduction. For example, when GHG emissions are reduced by catching the methane from the stable, a cattle dietary shift to decrease methane production will not cause additional reductions in GHG emission. As the easiest and large reductions have already been achieved in the past, by implementing manure legislation, quick but large reductions are not anymore available. Many of the strategies listed do require time, more research and a huge amount of money as well as incentives and support measures to be implemented (Fellmann et al., 2018). Innovative technologies are required but farms also might have to shift to a completely different farming system to reach the emission targets.

Implementation of the mitigation strategies will be difficult. Most of the measures require huge money investments while farmers often have small and even negative margins on their products (Schouten, 2018; Van Der Meulen et al., 2011; Vink and Boezeman, 2018). The question remains who will pay for the investments needed to reduce GHG emissions. If the whole agricultural budget of the government is used for the reduction of GHG emissions, a reduction of only 0.5 Mton CO_2-equivalent will be achieved in 2030 (Koelemeijer et al., 2017). Agricultural product prices might increase to compensate for farmers' investments, but then Dutch farmers might not be able to compete with farmers in other countries. Legislation can help to force traders and supermarkets to implement something like true pricing or promoting low emission labelled food (Agrimatie, 2017b; TruePrice, 2018). Whether farmers are willing to implement mitigation strategies does not only depend on financial aspects. They have to change their way of farming to implement the strategies, but they are not likely to do so unless that has benefits or they understand the urgency of changing (Moerkerken et al., 2014). At least, implementation of mitigation strategies requires money, time, research, and knowledge transfer, but legislation might be crucial to start changes.

3.3.3.5. Going beyond technical mitigation strategies

Most mitigation strategies presented above will keep the current agricultural production levels. However, reducing intensity and production levels can also result in decreased GHG emissions. NGOs like Greenpeace and Natuur & Milieu plead for a more extensive agriculture and especially a decreased livestock production (Greenpeace, 2018a, 2018c; Natuur & Milieu, 2017). Moreover, the government envisioned agriculture to become circular and close that circle as much as possible locally (Schouten, 2018). However, for farmers, only decreasing production per hectare is not possible due to the low margins on their products. Therefore, decreasing production needs to be combined with higher margins to ensure farmers' livelihoods. Less production might not only decrease GHG emissions but also decrease pesticide use, N-surplus, and increase biodiversity. However, the demand for food increases due to rising consumption levels and population growth (Conijn et al., 2018; FAO Food and Agriculture Organization of the United Nations, 2017). A decreased production in the Netherlands would then result in emission leakage (an increase of emissions in other countries) and no change or an increase in net GHG emission (Fellmann et al., 2018). Reducing GHG emissions will only be ensured when decreased production coincides with decreased consumption and food waste, which requires shifts in consumer behaviour (Bos et al., 2013).

Reducing GHG emissions in Dutch agriculture is possible via different pathways that will result in differences in agriculture in the future. Technology might play a large role in the solution and is in line with the evolution of Dutch agriculture over the past decades (Vink and Boezeman, 2018). However, technology does require money, research and education. Structural changes in farm management and production intensity, like organic agriculture and agroforestry, will also reduce national GHG emissions (Bos et al., 2007; Feliciano et al., 2018). However, this requires awareness and shifts in farming perception as well as money, research and education. Moreover, one should be careful not to cause emission leakage as a consequence of reduced farming intensity in the Netherlands. Consumers can also contribute by changing the diet to less meat consumption and more locally produced and seasonal food (Green et al., 2015; Natuur & Milieu, 2017; Springmann et al., 2018). Greenpeace aims at reducing meat consumption from 39 kg/person in 2016 to 23 kg/person in 2030 and 17 kg/person in 2050 (Greenpeace, 2018b, 2018a). That decrease in consumption would, when livestock production similarly decreases, result in emission reductions from 4 Mton CO_2-equivalent in 2016 to 2.1 in 2030 and 1.9 in 2050. That is an emission reduction of 0.9 tonnes CO_2-equivalent per hectare in 2030 and 1.2 in 2050 when compared with 2016. That reduction of about 2 Mton CO_2-equivalent does significantly contribute to the 2030 reduction goal of 2.5 Mton set by the Dutch government. Although technical options have the potential to result in even higher emission reductions, decreasing meat consumption has more potential than about half of the technical reduction options. Moreover, reducing meat consumption does not result in higher costs for consumers although it requires behavioural changes. Accepting food that does not comply with the currently high aesthetic standards and making an effort to reduce food waste will also reduce agricultural GHG emissions. Actually, achievement of the targets for 2050 requires the whole society to change their vision and value about food, food production and food consumption.

4. Discussion

4.1. Targets for emission reduction

Reaching a shared vision for the future of Dutch agriculture requires an overview of everyone's desires. Although there are many people and as many opinions and desires, it is clear stakeholders like governments, NGOs and consumers do demand from agriculture to reduce its pressure on the environment (European Union, 2018; GfK, 2018; Greenpeace, 2018c; Klimaatakkoord, 2018; Milieudefensie, 2018; Natuur & Milieu, 2017; Veldleeuwerik, 2018). The food processing industry and supermarkets respond to that demand by offering and advertising more sustainable food (Hakkenes, 2018; Lamb Weston / Meijer, 2018; Unilever, 2018). However, the environmental pressure of agriculture is still high (Planbureau voor de Leefomgeving, 2017). Stakeholders were divided in governmental stakeholders, NGOs, and stakeholders in the food-chain. Food production involves many stakeholders, but only a small selection was made. Only the largest stakeholder groups were considered and many stakeholder groups and aims were generalized to simplify target setting. This approach excluded many additional aims and desires on strategies how to reduce emissions. However, many of those aims are still reflected the highly diverse mitigation strategies listed and discussed in this thesis.

Targets regarding agricultural GHG emission reduction do not greatly differ between Dutch and European governments and NGOs. All of them wish to reach the Paris Climate Agreement. However, the Paris Climate Agreement only set a global target, which was translated to one national target. This leaves an enormous flexibility in how those targets are reached, for example, each sector could contribute in a different share to the national target. In this thesis, the EU and NGOs request from agriculture to have an equal share in emission reduction compared to other sectors, while the Dutch government assigned a reduced share to agriculture. Most companies in the food-chain do not have explicit targets for GHG emission reduction, but it was assumed their work and investments need to pay-off.

4.2. Reaching the desired futures

Most stakeholders desire a future with reduced agricultural GHG emissions, with reductions to 13.4 and 16.2 Mton CO_2-equivalent by 2030 and 1.3 Mton CO_2-equivalent by 2050 (Climate Action Network, 2016; European Union, 2018; Greenpeace, 2018c; Natuur & Milieu, 2017; Rijksoverheid, 2018b). Whether those goals are realistic depends on the possibilities to reduce emissions. Based on the quantified mitigation strategies, it is possible to reduce the emissions beyond the goals for 2030 and 2050. To achieve the mitigation potential, full implementation of the strategies by all farmers on all farming acreage is needed. This requires a highly radical transformation of agriculture that involves more than simply adopting the strategies.

After the Second World War, Dutch agriculture rapidly intensified and is now the second exporter of agricultural products globally while being a small country (Planbureau voor de Leefomgeving, 2018; Rijksoverheid, 2018c; van Dinther, 2018; Viviano and Locatelli, 2017). Using technology, both input use and production increased, as did the pressure on the environment (Bos et al., 2013). Currently, technology is available to increase production efficiency, reduce input use, convert harmful GHG into energy and reduce pressure on the environment and the climate (Planbureau voor de Leefomgeving, 2015). Technologies like precision agriculture and bio digesters have large potentials to decrease GHG emissions and also have additional beneficial effects (Balafoutis et al., 2017; Sommer et al., 2004; Winiwarter et al., 2018). Precision agriculture causes reduction of both pesticide use and nitrogen use while increasing nitrogen use efficiency and biodiversity (Balafoutis et al., 2017; Winiwarter et al., 2018). Bio digesters are a tool to reduce the manure surplus and deliver bio energy, enabling livestock farms to become climate neutral and increase the availability of renewable energy (Sommer et al., 2004; Terbijhe et al., 2010). Separation of solid and liquid manure fraction and eventual further processing enables manure transport and opens new markets to reduce the manure surplus (Wang et al., 2017). A drawback of those technologies is their requirement of scaling for implementation (Cavallo et al., 2014; Gebrezgabher et al., 2015). As those technologies are very expensive, only large farms can afford them (Long et al., 2016; Musch, 2017; van 't Westeinde, 2018). Obligation of these technologies to obtain certificates or licences to produce will reduce GHG emissions but is only achievable for large farms, further stimulating scaling (ING Economisch Bureau, 2016).

Besides achieving the emission goals with technology, this can also be done by decreasing production intensity (Planbureau voor de Leefomgeving, 2015). Decreasing production intensity is already occurring in the Netherlands, mainly via increasing acreage under organic agriculture (Centraal Bureau voor de Statistiek, 2018b). Other examples are nature inclusive agriculture and food forests (agroforestry). These farm types often have reduced production and increased labour and management complexity, but do deliver more ecosystem services like no or little pesticide use and stimulation of biodiversity (Feliciano et al., 2018; García de Jalón et al., 2018; Sukkel, 2018, n.d.; Torralba et al., 2016). If the focus of legislation and certificates was solely on technology to reach the GHG emission targets, such farm types would struggle to survive. However, forcing the whole agriculture to lower its production intensity won't be feasible either. Increasing production intensity using technology was stimulated by open markets and small product margins (Planbureau voor de Leefomgeving, 2018). Bulk production became increasingly urgent to be able to continue farming and earn a living (Oppewal, 2018). Farmers are now caught in that production path and changing is for many farmers impossible, even though they are willing to decrease production intensity (Vink and Boezeman, 2018). An easier way of reducing agricultural production is when governments or even NGOs buy up the phosphate rights of livestock farmers who stop farming and have no successors. Reducing the herd in this way will not cause farmers financial troubles but will significantly decrease GHG emissions. Livestock is the major emitter of GHG emissions and recent increases in emissions were caused by increases in livestock numbers (Compendium voor de Leefomgeving, 2018). In addition, reducing herd size also decreases manure surplus, fine dust and smell hindrance for neighbours. When decreasing food production while the global food demand is increasing, it is of major importance to prevent emission leakage (Conijn et al., 2018; FAO Food and Agriculture Organization of the United Nations, 2017). Emission leakage would not result in a net reduction of emissions but might even increase emissions (Fellmann et al., 2018). Instead, the focus should not solely be on decreasing production. Simultaneously it should occur with implementation of technology while keeping sufficient production levels to reach the emission goals.

Reducing production is a good strategy to decrease emissions only when consumption decreases simultaneously. As animal production has significantly higher emissions than plant production, substituting animal proteins in the diet with plant proteins would allow reduced animal production and subsequently reduce emissions (Aleksandrowicz et al., 2016; Green et al., 2015; Hallström et al., 2015; Planbureau voor de leefomgeving, 2016; van de Kamp et al., 2018). Consumption levels are too high, resulting in increasing occurrence of overweight and obesity (Volksgezondheidenzorg, 2018). Sticking to the food advice, which gives indications for a balanced and varied, healthy diet, would in the Netherlands reduce consumption, leaving space to reduce production as well (Planbureau voor de leefomgeving, 2016; Temme et al., 2015; van de Kamp et al., 2018; Voedingscentrum, 2018). However, changing consumer behaviour is very difficult although consumer awareness for sustainability issues is rising (Green et al., 2015; GfK, 2018). Consumer behaviour can be influenced by forcing supermarkets to only provide low emission food, or decrease the meat portions, either by legislation or agreements in the chain. This however raises the question "who is responsible for the emissions, producer or consumer?".

4.3. Paying the bill of mitigation strategies

It is clear that, no matter how the emission goals will be reached, it will cost large amounts of money and someone needs to pay for that. According to 'the polluter pays' principle, farmers should pay for all measures to reduce emissions. However, many farmers do not have the money for such investments as their income is low (Agrimatie, 2018). Moreover, these investments often do not pay off, impeding implementation from a financial perspective (Long et al., 2016). This could change when product prices increase, as implementation of strategies might become affordable and/or bank loans might be procured. The consequence, however, is that consumers need to pay more for their food. In general, consumers buy the cheapest food and only part of the consumers is willing to pay more for more sustainable food (Morren et al., 2018). This might result that supermarkets buy cheaper food from outside the Netherlands, leaving Dutch farmers unable to compete. A recent, often heard solution is applying the principle of fair pricing, or true cost accounting. This includes visualizing environmental and societal costs in the product price (Agrimatie, 2017b; Baltussen et al., 2017). However, it is difficult to shape fair pricing, what aspects are included in the price, how those values should be converted into money and how to internationally apply fair pricing (Baltussen et al., 2017; Morren et al., 2018). In addition, it remains unclear who would receive the extra money for environmental and societal costs, how the money should be spent and the expenses monitored (Morren et al., 2018). Moreover, if food prices increase, food might become unaffordable for an increasing part of Dutch citizens (Morren et al., 2018).

Governments could also provide money for investments to reduce emissions. Money of the EU and several Dutch governments combined in 'Plattelandsontwikkelings Programma' (POP) that is meant for farmers could be used to support mitigation options (Rijksdienst voor Ondernemend Nederland, 2018e; van Os and Martens, 2018). Currently, farmers can apply for subsidies via POP also for sustainable innovations (Rijksdienst voor Ondernemend Nederland, 2018e). However, this money is not available for most of the farmers. Mainly nature organizations and large farms receive those subsidies as accessibility to the subsidy is difficult, requires a lot of paper work and many rules need to be met (Ampt, 2018; Rijksdienst voor Ondernemend Nederland, 2018f). Many farmers have neither the time nor the knowledge to access the subsidy. Moreover, the farmers and nature organizations whose requests are granted receive large amounts of money (Lenderink, 2012). That results in a few people being able to get much money, while many others receive nothing (Lenderink, 2012). Rearranging and simplifying requirements and access to those subsidies can help implementation of mitigation strategies on a larger scale. As Dutch agriculture is highly diverse and many issues occur regionally, regional governments might have an important role in steering agriculture (van Egmond et al., 2018). Currently regional governments already started projects related to sustainability of agriculture. In Drenthe, dairy farmers get for example subsidies for using "kringloopwijzer" to reduce their emissions and increase biodiversity (Gedeputeerde Staten van Drenthe, 2018). As regional governments decide on subsidies like the POP money as well as local regulations, their meddling might be useful, unless they do have the needed expertise.

4.4. Implementation of mitigation strategies

The mitigation potential was calculated based on the full potential, meaning the reduction in GHG emissions if every farmer adopts the mitigation strategy. However, unless legally forced, it is not likely all farmers will adopt the strategies. Farms and farmers are very diverse in their products, goals and farming intensity (Mandryk et al., 2014; Reidsma et al., 2015). Some measures fit in the management of a group of farmers but will mostly not be interesting for all farmers. Moreover, some farmers are more technology oriented and are willing to apply technological measures (Gebrezgabher et al., 2015). However, all farmers should check for their own farm where the emissions arise and what management changes or technical options can be used to reduce those emissions. Most arable farmers are not aware they are emitting GHG, often they think they have positive impact and store carbon in soils (Nederlandse Akkerbouw Vakbond, 2018). Therefore, farmers should be educated and awareness should be created (Frank et al., 2018). Farmers are already experiencing the consequences of climate change, like the extreme drought of this year, but they do not know they can help in climate mitigation. Actually, education is one of the major factors explaining implementation successes. Younger and more educated farmers tend to show a higher rate of implementation of sustainable technologies than older or less educated farmers (Long et al., 2016). The farmer population in the Netherlands is aging, which might hamper implementation (Centraal Bureau voor de Statistiek, 2015). On the other hand, farmer education level is rising, mainly because younger farmers are more often more educated, which is promising for the implementation of mitigation strategies in the future (de Rooij, 2011).

Adoption of measures to reduce GHG emissions is currently not likely to occur on a large scale without legislation or incentives. Legislation would be helpful to start transforming agriculture. However, there is already a huge burden of legislation for farmers (de Snoo, 2017; ING Economisch Bureau, 2016; RTV Oost, 2018; van 't Westeinde, 2018; van Gruisen, 2017; van Paasse, 2018; Welink, 2018). They not only have to meet governmental legislation, but also varying requirements of certificates and purchasers (Globalgap, 2018; PlanetProof, 2018). An overly large burden of legislation hampers farm management and interferes with innovative and creative ideas. More legislation would not be suitable to stimulate the variation in farm management and farm types. Therefore, changing existing legislation might be more effective. Instead of making new legislation on what to do and what not to do, targets should be set, enabling farmers to meet those targets in ways suitable to their management (van Egmond et al., 2018). For GHG mitigation, the government could oblige farmers to use the CoolFarmTool, set a threshold for GHG emissions per farm and leave it to the farmer the decision of how to keep within that threshold (CoolFarmTool, 2018). Legislation might also help in defining product availability in supermarkets by requiring products with lower emissions (Chkanikova and Mont, 2015). Besides legislation, the government can stimulate implementation of technology through subsidies.

The food processing industry and supermarkets determine the requirements products should meet. Therefore, they can demand more climate neutral products, not only from Dutch farmers but also from international suppliers. For the ease of adoption of product requirements, all supermarkets as well as the food industry could collaborate to set up the same requirements. Otherwise, farmers have to meet all different requirements from all different supermarkets and industry to be able to sell their products. A start has already been made with the Planet Proof certificate (PlanetProof, 2018). However, prices of those low emission products should increase, as measures to reduce emissions cost money. A different approach of reducing GHG emissions could be to use as much as possible products produced at close distances, to reduce transportation emissions. Moreover, supermarkets can reduce the environmental impact of their products via curtailment, for example by decreasing meat portion sizes (Verain et al., 2015).

In reduction of agricultural GHG emissions, consumers have a central role (Bos et al., 2013). Their choices determine what is produced. When they choose for more sustainably produced food, more food will be produced sustainably as a result (Chkanikova and Mont, 2015). Consumers can buy seasonal vegetables and fruits, to reduce transport and storage emissions for providing vegetables and fruits out of the season. Moreover, a reduction of meat consumption would significantly reduce diet emissions (Aleksandrowicz et al., 2016; Green et al., 2015; Hallström et al., 2015). In addition to changing and reducing consumption, making an effort to reduce food waste and accept less 'perfect' food would enable decreasing production levels (van Egmond et al., 2018). Education and awareness are requirements to help consumers change their food choice and consumption (Verain et al., 2015).

NGOs have a large history in influencing public opinions and causing societal transformation (Junk, 2016; Tallberg et al., 2018). They were able to eliminate smoking in public, increase animal welfare and introduce additional requirements based on environmental issues for supermarket products (de Graaff, 2018; Knuivers, 2018; Tuenter, 2017). Therefore they are potentially able to do so for reducing agricultural GHG emissions. Firstly, they can create consumer awareness on the food footprint and possibilities to reduce that footprint. Secondly, they can stimulate supermarkets and the food industry to change product requirements. Thirdly, they can make information and technology more accessible for farmers, both educationally and financially.

4.5. Impact of agricultural production on more emissions

Besides emissions from enteric fermentation, manure management and agricultural soils, agriculture can influence many other emissions. Starting with input use, reducing the application of externally produced inputs will also reduce their associated emissions. Making an effort to closing the cycle as much as possible, by local production of feed, local processing of manure and local selling of products, will cause large reductions in transportation distance and associated emissions (Thijssen, 2018). Additionally, agriculture can play a major role in reducing emissions from energy (Moerkerken et al., 2014). This can be done by reducing energy use, especially in greenhouses, stables and storage systems (Moerkerken and Smit, 2016). But more importantly, agriculture has a great potential to create renewable energy (Moerkerken et al., 2014). Large stable and barn roofs are available for solar panels and land for windmills. Moreover, agriculture is the only sector creating biomass, among which manure and crops or crop residues that can be used in bio digesters for energy and gas production. There are even possibilities to apply intercropping of a crop together with solar panels (Dupraz et al., 2011). Agriculture is tightly linked to emissions from land use and land use change, especially concerning peat soils. Organic peat soils have large GHG emissions due to carbon release (Tiemeyer et al., 2016). Carbon is released when the water table of those soils is lowered to be able to cultivate crops on those soils (Tiemeyer et al., 2016). Increasing the water table would reduce emissions and increase biodiversity, but also requires changes in crop cultivation and management choices (Bos et al., 2013; Wilson et al., 2016). Similar effects would be achieved when the herd size decreases and less peat soils are used for grazing. Currently, peat soils emit almost 7 Mton CO_2-equivalent per year (CBS, 2017b). Restoration of those peat soils has therefore a large potential to significantly contribute to GHG emission reduction. Full restoration has even a two third larger potential than the agricultural mitigation strategy with the largest potential (table 2). As agriculture has not only capability to reduce its own emissions but also in other sectors, a broader view on emission reduction will be useful.

Dutch agriculture is a high emitter of GHG compared to the agriculture of other European countries when looking at the emissions per hectare (Dace and Blumberga, 2016). This is mainly due to the highly intensive agriculture that is characterized by high input use (Dace and Blumberga, 2016). However, when comparing the emissions per product, the Netherlands have relatively low emissions (Gil et al., 2018). Low emissions per hectare indicate low total agricultural emissions for a country as a whole. However, that also may implies a low production (Dace and Blumberga, 2016). Shifting production in the Netherlands from highly intensive towards extensive production would result in lower emissions per hectare, towards a more European average emission level. This might either cause a decrease in production or increase in agricultural acreage. A production decrease could possibly result in production increase elsewhere, which is emission leakage and causes globally no net reduction of GHG emissions. Increasing agricultural acreage to remain absolute production will be difficult in the Netherlands, as land is scarce and very expensive (Farjon et al., 2014; Luijt and Voskuilen, 2013).

Moreover, acreage expansion will increase total emissions as there is more land used for production. It might also decrease the availability of land for nature or increased use of peat soils for agriculture, which would increase emissions. Judging what is better is difficult, but it shows the importance of analysing both emissions per hectare and per product instead of focussing on one.

4.6. Strengths, weaknesses and uncertainty

First setting targets and afterwards exploring measures to reach those targets, as proposed in the backcasting approach, was applied to agricultural GHG emission reduction. The advantage of this approach was that it resulted in a broad range of solutions, from production and demand side, technological options as well as extensification, directly applicable strategies as well as strategies that need further development. While projecting current trends towards the future would not have resulted in such a broad range of options. The mitigation strategies explored would result in large emission reductions. However, as the applied approach resulted in many strategies that require large changes, many of the strategies will not directly be implemented and might even never be implemented. Although it does show the possibilities and chances of agricultural GHG mitigation reduction and might help guiding decision making and setting priorities to work towards reducing emissions.

Full implementation of the quantified mitigation strategies would result in the achievement of the stakeholders' goals for 2030 as well as 2050. However, the uncertainty is considerable. Firstly, it is not likely full implementation of the strategies would be achieved and thereby the actual mitigation will be lower. Secondly, the strategies are already partly adopted, which was not taken into account, resulting in an overestimation of the mitigation potential (Carolan, 2017; Centraal Bureau voor de Statistiek, 2018b; Velghe and Wierinck, 2013). Thirdly, it is not clear whether the mitigation potentials as quantified would hold for the Netherlands, as many research was done not explicitly for Dutch agriculture. The high uncertainty illustrates the difficulty to quantitatively assess GHG emission potential and the inability to draw firm conclusions based on such quantitative data. Therefore, the study should merely be used as an indication of possibilities and their likely effectiveness.

5. Conclusion

Achievement of targets for climate mitigation in Dutch agriculture is a challenge. But as the world's second exporter of agricultural goods, having a highly intensive but also innovative and diverse agriculture and hosting the best agricultural university worldwide, the Netherlands has a large responsibility to reduce emissions. The technical potential is high, mitigation options like changing cattle diet, catching methane, cooling manure and precision agriculture have potential reductions ranging from 0.24-6.4 t CO_2 equivalent per hectare per mitigation option. Combining more options might even be sufficient to reach reduction targets of 2.9-4.3 and 10.3 Mton CO_2 equivalents per hectare in 2030 and 2050 respectively. However, implementation requires attention and many issues need to be solved, of which financing the mitigation strategies is most critical. Reducing agricultural emissions is not only an issue concerning farmers. Governments, NGO's, food industry, supermarkets and consumers have responsibilities and the power to reduce emissions. They can influence by changing legislation, providing money, education and knowledge, demanding more sustainable food while also paying more for that, but also reducing consumption and food waste or increasing consumption of locally produced food. To reach the goals, actually the whole society needs to change their way of making decisions and thinking about food, food production and food consumption. Thereby it remains of inevitable importance to make sure reducing emissions here does not cause emission leakage nor pollution swapping. But it is also important to realize that food production cannot take place without emissions. Those emissions are part of the biologic processes required to produce food and mankind will never be able to do so without any emission. Although some emission is unavoidable, Dutch agriculture has the potential and the responsibility to decrease GHG emissions and contribute to meeting the SDG's and the Paris Climate Agreement.

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