Mitigation options to reduce GHG emissions at dairy and beef farms

Results from a literature review and survey on mitigation options currently being used within the network of the Sustainable Agriculture Initiative Platform (SAI Platform)

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WAGENINGEN UNIVERSITY & RESEARCH

SAI PLATFORM

ERBS European Roundtable for Beef Sustainability

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Commissioned by the Dairy Working Group from the Sustainable Agriculture Initiative Platform (SAI Platform) and the European Roundtable for Beef Sustainability, an overview has been made based on literature research and a survey of 28 greenhouse gas mitigation options on dairy and beef farms and their degree of implementation. The mitigation options that have been implemented so far are mainly aiming at improving efficiency and productivity. A majority (63%) of respondents indicate that all or some of their supplying farmers know their individual carbon footprint. The big question is how to stimulate farmers to implement mitigation options.

Key words: Climate change, mitigation options, dairy, beef

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Preface

SAI Platform's Dairy Working Group (DWG) represents 30% of the global milk volume. It is a precompetitive platform in which dairy buyers and processors work together to develop sector transformational initiatives. A key topic is the reduction of greenhouse gas (GHG) emissions in the dairy industry. The European Roundtable for Beef Sustainability (ERBS) is a multi-stakeholder platform, hosted by SAI Platform, focused on European beef sustainability from farm to fork. ERBS unites and coordinates sustainability programmes around a common agenda to deliver positive impact within the beef value chain. One of the key outcome areas the ERBS is focused on is the reduction of GHG as part of improving the environmental footprint of farming systems. The Sustainable Agriculture Initiative Platform (SAI Platform) is a not-for-profit organisation transforming the global food and drink industry to source and produce more sustainably. With over 150 members, from companies and organisations in the food and drink value chain, SAI Platform is at the forefront in pioneering solutions to common challenges and promoting sustainable agriculture in a pre-competitive environment.

The Beef and Dairy industries recognise that GHG emissions produced at farm level are contributing to climate change. SAI Platform's Dairy Working Group and the European Roundtable for Beef Sustainability are committed to having a positive impact on driving down GHG emissions in the sector, and our members are actively working on this. To further enable change, the two groups created a joint project dedicated to identifying known and practical solutions to mitigate GHG emissions at farm level.

The aim of the first phase of this project was to present an overview of relevant practices currently being used by members in a consistent manner to create a toolbox that companies could apply within their own supply chains. On the next phase, the content of this report will be translated into a simpler toolbox format to be able to reach a wider audience. The toolbox aims to recognise such things as geographical locations, farm archetypes, potential for GHG reductions, implementation costs, potential barriers, and incentives, to name some aspects.

SAI Platform
Dairy Working Group
European Round Table for Beef Sustainability

Climate change is the major challenge for humanity in the 21st century and to overcome it, reduction of greenhouse gas (GHG) emissions is essential. Livestock production plays an important role in climate change by emitting GHG either directly (from enteric fermentation and manure management) or indirectly (from feed production and conversion of forest into pasture). The European Roundtable for Beef Sustainability (ERBS) and the SAI Platform’s Dairy Working Group (DWG) both concluded that a consistent overview of mitigation options that are currently already implemented or are promising for the near future was lacking. They joined forces to commission a project to make such an overview based on a combination of a survey amongst their network and a literature review.

We are very thankful for the guidance and support in this project by a joint work stream group with representatives from the ERBS, the SAI Platform’s Dairy Working Group and the International Dairy Federation (IDF) and for all the respondents from the networks that have filled out the survey.

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Summary

1. Goal and approach of the project
The project was commissioned jointly by the Dairy Working Group from the Sustainable Agriculture Initiative Platform (SAI Platform) and the European Roundtable for Beef Sustainability.

The goals of the project:
1. To make an overview of the actual implementation of various GHG mitigation options on farms within the supply chains of leading companies in dairy and beef globally. This includes mapping their associated properties such as GHG reduction, impact on farm profitability, the required skills, the relevance for different farming systems and stimuli relevant for their implementation.
2. To collect information on the use of tools to calculate farm level carbon footprint, on GHG monitoring programmes and other learnings from practical experiences.

This report is designed to give an overview of two mentioned goals that SAI Platform's Dairy Working group (DWG) and the ERBS will use to inform their own publications or tools to share best practices within their networks.

The project consisted of the following main steps:
1. Collecting information on available mitigation options by literature review.
2. Collecting information on the implementation of mitigation options by organising a survey and collecting information from the networks of the ERBS, SAI Platform's DWG and the International Dairy Federation (IDF).
3. Reporting the overall results by integrating the information from the literature review and the survey.

2. Key survey findings:
1. Sixty-seven respondents filled out the survey (50 dairy, 17 beef), mainly processors (26) and national programmes (19). Most respondents indicated that their supply base was in Europe (25 dairy, 11 beef).
2. A majority (63%) indicated that all or some of the supplying farmers know about their individual carbon footprint. Twenty-five per cent answered that this is not the case. Ten respondents indicated that more than 75% of the farmers in their supply base know their carbon footprint.
3. A large number of different tools are being used to calculate carbon footprint on farm level, especially in the dairy sector. Also within countries different tools are used.
4. A majority of the respondents (76% dairy, 66% beef) had some kind of a GHG emissions monitoring plan of the supply base in place. The monitoring can vary from an annual monitoring (52% in dairy, 20% in beef) to a pilot project.
5. The following are the implementation levels in total and separately for beef and dairy of the 28 mitigation options that were included in the survey:

Option		Total (n = 57)	Dairy (n = 41)	Beef (n = 16)
Genetics, breeding and enteric methane reduction				
1.	Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	81%	83%	75%
2.	Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	74%	76%	69%
3.	Breeding for reduction of enteric methane emission	21%	20%	25%
4.	Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	70%	73%	63%

Option	Total (n = 57)	Dairy (n = 41)	Beef (n = 16)
5. Use of feed additives to alter ruminal fermentation to reduce methane.	28%	32%	19%
Herd management			
6. Improving animal health (e.g. vaccination)	70%	68%	75%
7. Reduction of calf mortality rate	61%	59%	69%
8. Increasing longevity	56%	56%	56%
9. Reducing the share of non-productive animals (e.g. young stock, dry cows)	51%	54%	44%
Feed production, grassland management and land use			
10. Improving grazing management (e.g. subdividing farms to paddocks, sward analysis, measuring grass growth and planning grazing strategy for grazing season)	49%	49%	50%
11. Increasing carbon sequestration (e.g. increasing grassland areas)	39%	41%	31%
12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	60%	59%	63%
13. Improving forage quality (e.g. earlier harvest, improved varieties)	70%	71%	69%
14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)	40%	39%	44%
15. Planting trees, hedges, agroforestry	39%	41%	31%
16. Application of protected nitrogen fertiliser (e.g. urea treated with a urease inhibitor)	32%	32%	31%
Manure management			
17. Application of primary and/or secondary separation of manure	37%	41%	25%
18. Reduction of manure storage time in the barn	30%	29%	31%
19. Applying manure treatment (lowering manure pH e.g. application of sulfuric acid, manure aeration, manure cooling)	21%	22%	19%
20. Application of bedding materials (e.g. sand)	28%	34%	13%
21. Complete removal of liquid dairy manure from storage tank (inoculum removal)	14%	17%	6%
22. Oxidation of captured methane by flaring or filtration	11%	12%	6%
23. Anaerobic digestion	46%	49%	38%
24. Use different manure application methods on land (e.g. dilution and injection)	58%	59%	56%
25. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)	58%	59%	56%
26. Application of inhibitors for manure (e.g. Dicyandiamide and dimethypyrazole phosphate)	11%	7%	19%
Smarter energy management/use			
27. Reducing fossil fuel consumption	47%	49%	44%
28. Application and production of renewable energy	54%	56%	50%

6. Top 10 implemented mitigation options are listed in the table below, including results from the survey on relevance for farming system, profitability, required level of skills and main stimuli (chapter 4).

Mitigation option	% of respondents	Farming system[1]	Profitability[1]	Required level skills[1]	Main stimuli[2]
1. Improving animal productivity by breeding (e.g. higher milk yield, number of calves per cow per year)	81%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	74%	Universal	Profitable	Medium	Knowledge and training, technical assistance, subsidies
3. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	70%	Universal	Majority indicates profitable	Medium-high	Knowledge and training, subsidies
4. Improving animal health (e.g. vaccination)	70%	Universal	Profitable	Low-medium	Knowledge and training, subsidies, technical assistance
5. Improving forage quality (e.g. earlier harvest, improved varieties)	70%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
6. Reduction of calf mortality rate	61%	Universal	Profitable	Medium	Knowledge and training, subsidies, technical assistance
7. Reduction of manufactured fertiliser nitrogen application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	60%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
8. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)	58%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
9. Use different manure application methods on land (e.g. dilution and injection)	58%	Half indicate option is universal	Majority indicate net extra costs	Low-medium	Knowledge and training, subsidies
10. Increasing longevity	56%	Universal	Profitable	Medium	Knowledge and training, subsidies

1) Each category mentioned is based on at least two-thirds of the respondents, unless otherwise specified. Universal means: applicable on all farms.

2) Stimuli that have been mentioned 2 times or more.

3. Overall findings and discussion

GHG emissions on beef and dairy farms are complex, beware to simplify

GHG emissions on dairy and beef farms result from different sources and processes inside and outside the farm. The effect of one mitigation option can differ between different farming systems: 'It is an immense challenge for farmers to understand the complex interaction (...) and to implement reliably,' as one respondent mentioned in the survey. The large number of available mitigation options in combination with the great variety in farming systems makes it impossible to simplify the results of the survey in a top 5 of easy to apply mitigation options that will result in a major reduction of GHG emissions on all farms. As was clearly stated by one of the respondents of the survey: 'The solution for the dairy industry is widespread adoption of a portfolio of solutions according to the given system/situation. This is not about focusing on a handful of high leverage solutions.'

Currently implemented mitigation options focus mainly on efficiency and productivity. It makes sense that these mitigation options are currently already implemented because in general these mitigation options also have a positive impact on profitability: 'Farms are making improvements to impact bottom line economics rather than to reduce GHG emissions currently.' The GHG reduction potential of these mitigation options is the highest for low productive farming systems and is relatively low for high productive and input-intensive farming systems. Promising possibilities that are not yet broadly implemented are (1) breeding for reduction of methane emission (not yet available), (2) use of additives or vaccines to alter rumen fermentation (in development, expected to be available in the short term) and (3) some manure management options (in development, extra net costs expected).

How to stimulate farmers to implement mitigation options?
This is indicated as a challenge by several respondents. For many farmers the current drive to implement mitigation options will not be the reduction of GHG emission but improving the economic performance of the farm. In this phase it can be helpful to distinguish two main groups of farms: farms with a low productivity (including subsistence farmers) and farms with a high productivity. The priority for the first group is increasing productivity, which indirectly results in lower GHG emissions. In order to achieve substantial impact it is important to do this at scale and with pace. Application of specific mitigation options would be the next priority for this category of farms.

For the high productive farms, the situation is more complex. Improvement of efficiency will also be applicable for this group to reduce GHG emission. To assess the relevant and most effective mitigation options for an individual farm in this category the farming system and the current performance needs to be taken into account.

To achieve a large scale of implementation of mitigation two things have to be done:
1. Create clarity in what farmers can do specifically for their own situation and farming system: which options or best practices are available *and* fitting.
2. Create incentives and organise interventions to assure the implementation of these best practices.

A possible follow-up action that could help is to create a tool that can support a farmer or his advisor to make a choice for mitigation options that match with the specific situation of the farm. This can be quite basic as in a decision tree taking into account a limited number of farm characteristics up to very sophisticated models based on detailed farm data while also providing the estimated impact on GHG emissions and economics. It can also help to collect case studies and make them broadly available.

The second important point is how to motivate the farmers to make the first step. So what is the answer to the 'Why' question? For the farms with a relative low productivity the answer is quite simple: it is for their own benefit, it helps to achieve a better income. For high productive farms it is more complicated. Some will be intrinsically motivated because 'They want to do the right thing for the environment and for their children' as was mentioned in the survey. But this will not be the case for all the farmers as another quote from the survey shows: 'You need to instil confidence in the farming community that what they are doing, or being asked to do, is relevant and of economic value to them.' The respondents mainly mention two stimuli: provide knowledge (in different ways) and subsidy. More options are however available (e.g. by contract, economic incentives, social peer pressure) (Reijs et al., 2021).

It would be very useful to learn from experiences and use that to make an overview of incentives and interventions that help to adopt practices that reduce GHG emissions. Lessons about different types of incentives (regulation, education, social, financial etc) and different types of interventions (farmers learning from farmers in open days, providing tools and data, trainings etc) can be taken from members of networks of SAI Platform's DWG and the ERBS. Some examples were mentioned in the survey (making use of networks, nudging, etc.)

Tools, data and monitoring
The survey shows that a large number of different tools are used to calculate farm-level carbon footprints, especially for dairy. In itself this is very positive: it helps in creating awareness and can be a starting point for communication and for mitigation. It makes sense that national tools are being developed: they usually build on available data and are designed for the prevailing farming systems. This can work very well, especially if they are accepted and used by all relevant stakeholders. The

chances are however that the tools will differ e.g. in scope, in methodology (e.g. inclusion of sequestration and land use change), in granularity etc. The point of sequestration was specifically mentioned in the answer of the open question of survey. It can be very confusing, especially if different tools are used within a country.

However, also differences between countries in tools and definitions of GHG emissions will make exchange of data and knowledge complicated. It could be useful to explore the possibility to extract (basic) data from the national tools and use those to calculate a comparable carbon footprint for international exchange. Data availability is an important point, both related to tools and monitoring. A large amount and high quality of data is needed to accurately assess the current level and the impact of the implementation of mitigation options. If the carbon footprint calculation is basic and based on a limited number of farm characteristics, the effect of the implementation of some of the mitigation options from the list might not be visible in the tool and not in the overall monitoring of the supply base.

1 Introduction: goal and approach of the project

The project was commissioned jointly by the Dairy Working Group of the Sustainable Agriculture Initiative Platform (SAI Platform) and the European Roundtable for Beef Sustainability.

The Dairy Working Group of the Sustainable Agriculture Initiative Platform (SAI Platform's DWG) is a precompetitive platform in which dairy buyers and processors work together to develop sector transformational initiatives. A key topic is the reduction of greenhouse gas (GHG) emissions.

The European Roundtable for Beef Sustainability (the ERBS) is a multi-stakeholder platform, hosted by SAI Platform, focused on European beef sustainability from farm to fork. The ERBS unites and coordinates sustainability programmes around a common agenda to deliver positive impact within the beef value chain.

1.1 The need for an overview of options to reduce GHG emissions

Climate change is the major challenge for humanity in the 21st century and to overcome it, reduction of GHG emissions is essential. Based on the Paris Agreement, all signing nations committed themselves to tackle the climate change problems by reducing their GHG emissions (between 20% to 55% by 2030). Livestock production plays an important role in the climate change by emitting GHG either directly (from enteric fermentation and manure management) or indirectly (from feed production and conversion of forest into pasture).

Many attempts have been made to tackle the challenges of GHG emissions and improve the environmental impacts of animal farming. Several companies and (national) organisations in the dairy and beef sectors already have experience in the implementation of GHG mitigation options and thereby have gained important information they could share about these options.

What is lacking is a consistent overview of these practical experiences with the implementation of GHG mitigation options. Which options are already implemented in practice, which option fits with which farming systems, which skills are required, what is the economic impact and what are barriers for implementation?

1.2 The goal and approach of this project

The goals of the project are:

1. To make an overview of the level of implementation of GHG mitigation options on farm level including:
    a. Range of GHG reduction
    b. Profitability
    c. Required skills
    d. Relevance for different farming systems
    e. Stimuli for implementation
2. To collect additional information on the use of tools to calculate farm level carbon footprint, on GHG monitoring programmes and other learnings from practical experiences.

This project aims to result in a basic report with an overview of the collected information on the mentioned points. SAI Platform's DWG and the ERBS will use it as background information for their own publications or tools to share this information within their networks.

The project consisted of the following steps:
1. Making a general overview of key sources of GHG emission on dairy and beef farms, based on literature.
2. Collecting basic information on available mitigation options and their reduction potential by literature review.
3. Collecting practical information on the implementation of mitigation options by designing and sending out a survey within the networks of the ERBS and SAI Platform's DWG.
4. Analysing the survey results.
5. Reporting the overall results by integrating the information from the literature review and the survey.

This study was conducted by Wageningen Research in collaboration with a work stream group with representatives from SAI Platform's DWG and the ERBS. In bi-weekly progress meetings the different steps were discussed. The content of the survey was created in consultation with this group. The survey was distributed by SAI Platform's DWG and the ERBS.

1.3 Set-up of this report

First, we will give an overview of GHG emissions in dairy and beef production. Then, we will provide the results of the survey conducted among members of SAI Platform's DWG and the ERBS on mitigation practices currently used. These results also form the subsequent chapter, in which the mitigation options are described in more detail. In this description the results of the survey will be combined with input from the literature review and an interpretation from the Wageningen project team. Finally, the overall interpretation of the obtained results will be provided.

2 GHG emissions in dairy and beef

Livestock production plays an important role in climate change by emitting GHG either directly (from enteric fermentation and manure management) or indirectly (from feed production and conversion of forest into pasture). According to the Food and Agriculture Organization (FAO), the livestock sector is responsible for 14.5% of the global GHG emissions (Gerber et al. 2013b). The livestock sector contributes to about 7.1 Gt CO_2-eq per year of which about 4.6 Gt CO_2-eq comes from cattle sector. Beef and milk production are responsible for 41% and 20% of GHG emissions from the livestock sector (Gerber et al. 2013b). To define the mitigation strategies in livestock production, first it is important to identify the main sources of emissions:

1. Animal production
   Enteric fermentation is the main source of GHG emissions in this category. On-farm fossil fuel energy use (except energy for feed production) can be considered in this category.
2. Feed production on- and off-farm
   Different sources of GHG emissions such as fossil fuels, chemical fertilisers, biocides, manure application, agricultural operations, feed processing and other inputs are applied.
3. Land use and land-use change
   This is including the change of natural vegetation to pasture or arable lands. Note that this category can be added up to the feed production category.
4. Manure management
   This is mainly related to manure storage, and deposition activities.
5. Processing and transport
   These are both related to off-farm activities.

The share of different sources of GHG emissions on total emissions is highly variable among the production systems and regions. In low input smallholder systems, feed related emissions are a smaller fraction and methane from enteric fermentation is a larger fraction. Based on the FAO data, in dairy systems, the feed production process contributes around 45% of livestock emissions and after that enteric fermentation accounts for 39%, followed by manure storage (10%) and processing and transportation (6%) (Gerber et al. 2013a; Grossi et al. 2019). The share of main GHG gasses (CO_2, CH_4 and N_2O) in total emissions of dairy production systems highly depends on the intensity of production. The fraction of CO_2 emissions from fossil fuels is smaller in smallholder farms compared to specialised and high productive dairy systems (Gerber et al. 2011). As shown in Figure 2.1, the share of CO_2 in total GHG emissions of dairy farming increases while the shares of CH_4 and N_2O decrease with the productivity gains. The higher CO_2 emissions are due to the higher consumption of fossil fuel for production of feed. An intensive production system requires a variety of inputs which directly or indirectly use fossil fuels. These include the production of feeds (land preparation, harvesting, use of fertilisers and pesticides, drying, etc.), transport, storage, processing, etc.

Based on our literature review for GHG emissions of different beef production systems, diet composition plays an important role on the amount of GHG emissions. Concentrate-based systems had lower GHG emissions than the roughage-based ones.

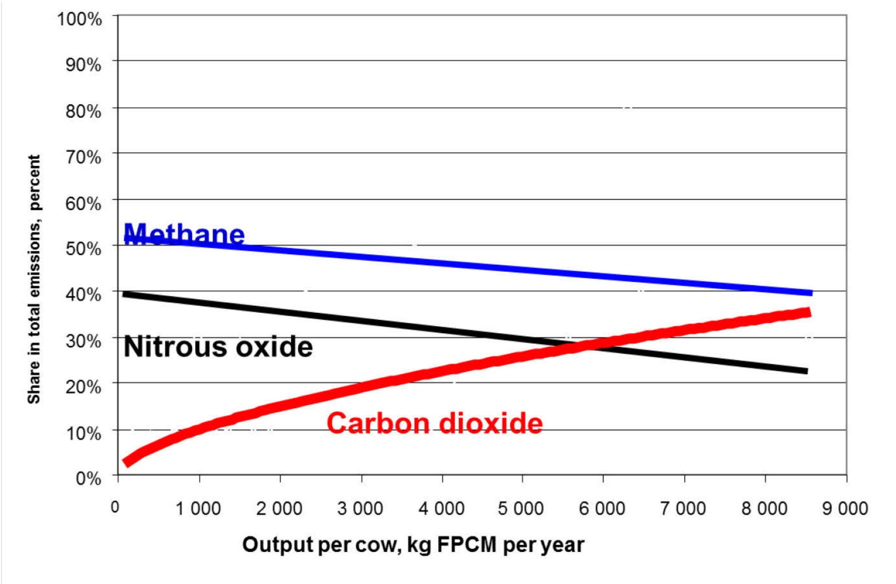


Figure 2.1 *Relationship between carbon dioxide, methane and nitrous oxide emissions and output per cow (productivity) in dairy farming systems*
Source: Gerber et al. (2011).

GHG emissions regarding the enteric fermentation and manure storage varies among the livestock species. Figure 2.2 which has been adapted from Global Livestock Environmental Assessment Model (GLEAM) developed by FAO (FAO 2017) shows the GHG emissions associated with the enteric fermentation and manure storage for different animal types. As shown, enteric fermentation is the main source of GHG emissions in ruminant animals. Also beef and dairy sectors have by far the greatest shares in GHG emissions from the livestock sector.

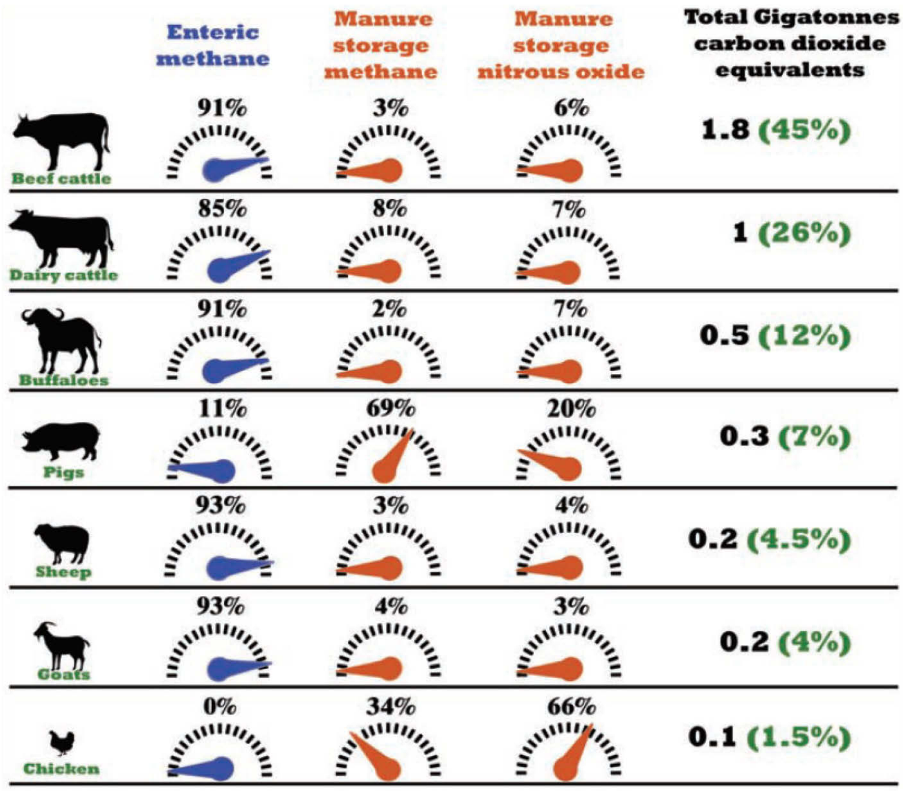


Figure 2.2 *GHG emissions associated with the enteric fermentation and manure storage for different animal type*
Source: Grossi et al. (2019).

To reduce emission intensity (emissions per unit livestock product) possible options are improving productivity (reducing the emission per product) and increasing the capacity of carbon storage (carbon sequestration). Grassland carbon sequestration could significantly offset emissions (with global estimation of about 0.6 gigatonnes CO_2-eq per year). However, there are some difficulties with the quantification of impacts and also better understanding regarding the economic impact of this option is required.

For sake of simplicity we defined five main categories of classification to group the mitigation options as follows:
1. Genetics, breeding and enteric methane reduction.
2. Herd management.
3. Feed production, grassland management and land use.
4. Manure management.
5. Smarter energy management/use.

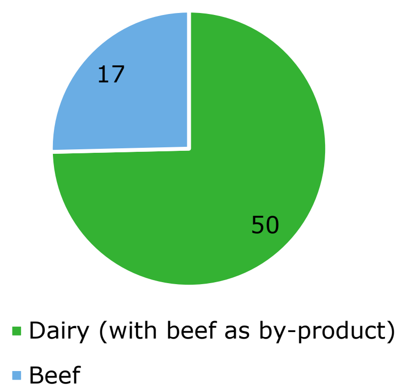
Over the last years, more attention has been paid to reduce the environmental impacts of dairy and beef production systems. Although many mitigation options and strategies have been introduced, the application of these depends on many factors including technical effectiveness (GHG reduction potential), cost-effectiveness, level of changes in farm, time and money investment, etc. In this report we aim to evaluate the status of various mitigation options for both dairy and beef productions.

3 Survey on practical experiences in working on farm-level mitigation options

3.1 Survey respondents

The content of the survey (Appendix 3) was created in consultation with a work stream group with representatives from SAI Platform's DWG and the ERBS. The survey was distributed by SAI Platform's DWG, the ERBS and IDF. Wageningen Research analysed the feedbacks and the results are presented in this chapter.

A total of 67 respondents filled out the survey between 26 May and 12 July. Of these, 50 respondents filled out the survey for farms that primarily produce dairy, and 17 respondents filled out the survey for farms that primarily produce beef. Of the total number of respondents, 26 indicated they filled out the survey as a processor, 19 as a national programme, 14 as farmer/supplier, 9 as buyer, 1 as retailer and 1 as food service. This total number of responses adds up to 70, as 3 respondents indicated multiple answers to this question.



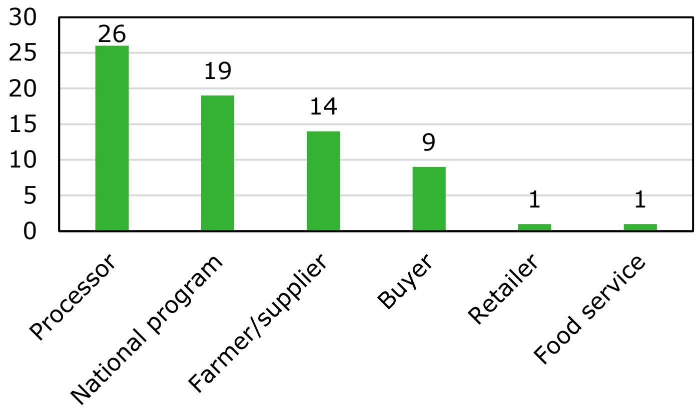


Figure 3.1 *'This survey is completed for farms that primarily produce...' and 'Please specify the type of company or organisation' (n = 67)*

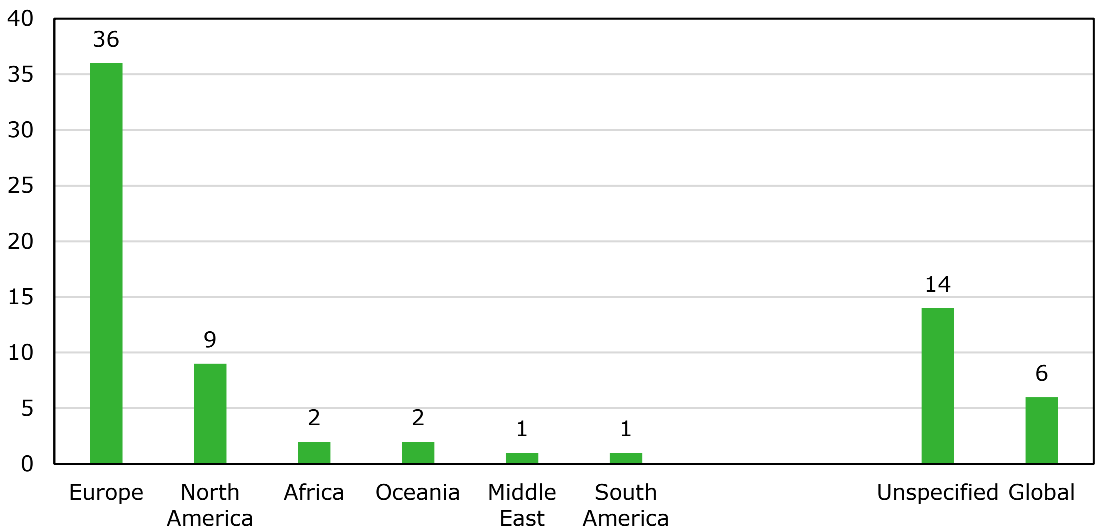


Figure 3.2 *Specification of the region of supplying farmers of the respondents (n = 71)*

Figure 3.2 shows that the majority of the respondents indicated that the region of their supplying farmers is in Europe, followed by North America, Africa, Oceania, the Middle East and South America. A number of respondents did not specify a region, and 6 respondents indicated their supplying farmers are based in multiple countries globally. The countries mentioned within these regions are specified in Table 3.1.

Table 3.1 *Regions of the respondents, total, dairy and beef*

Region	Total (n = 67)	Dairy (n = 50)	Beef (n = 17)
Europe	**36**	**25**	**11**
United Kingdom	7	2	5
Ireland	4	2	2
France	3	2	1
Italy	3	2	1
Germany	3	3	
Poland	3	2	1
Netherlands	3	2	1
Norway	1	1	
Denmark	1	1	
North America	**9**	**9**	-
United States	6	6	
Canada	3	3	
Africa	**2**	**2**	-
Nigeria	1	1	
South Africa	1	1	
Oceania	**2**	**2**	-
Australia	1	1	
New Zealand	1	1	
Middle East	**1**	**1**	-
Israel	1	1	
South America	**1**	**1**	-
Tropical countries	1	1	
Unspecified	14	9	5
Global	6	5	1

Table 3.1 shows the regions and individual countries mentioned for total, dairy and beef. Europe represents a high share of all respondents. It is important to be aware that almost all (11 out of 12) of the beef sector respondents that have indicated the region in the survey come from Europe. This was to be expected since this the working area of the ERBS. But also, if we look separately at the respondents on the dairy side, a high share of the respondents that have specified the region come from Europe (36 out of 53). None of the respondents specifically indicated their supplying farmers are based in Asia. Six respondents indicated to work globally.

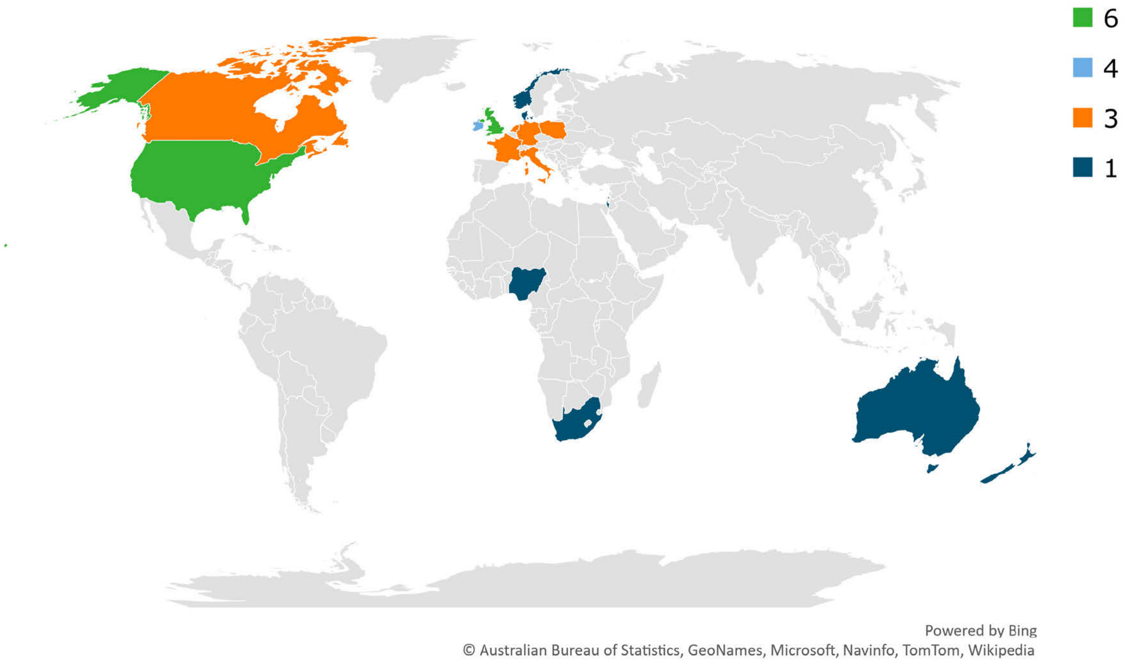


Figure 3.3 *'What is the region of your supplying farmers?', number of times specific countries were mentioned*

Figure 3.3 shows the number of times specific countries were mentioned by the respondents. The United States was mentioned 6 times, Canada 3 times and Nigeria, South Africa, Israel, Australia and New Zealand were all mentioned once. For South America, the respondent indicated 'tropical countries' as the region of their supplying farmers.

Figure 3.4 shows the number of times specific countries within Europe were mentioned. For North-West Europe, the United Kingdom was mentioned 6 times, Ireland 4 times, the Netherlands, Germany and France 3 times and Norway and Denmark both once. For the rest of Europe, Italy and Poland were both mentioned 3 times. The rest of the respondents either indicated North Europe, West Europe, or Europe as a response to this question.

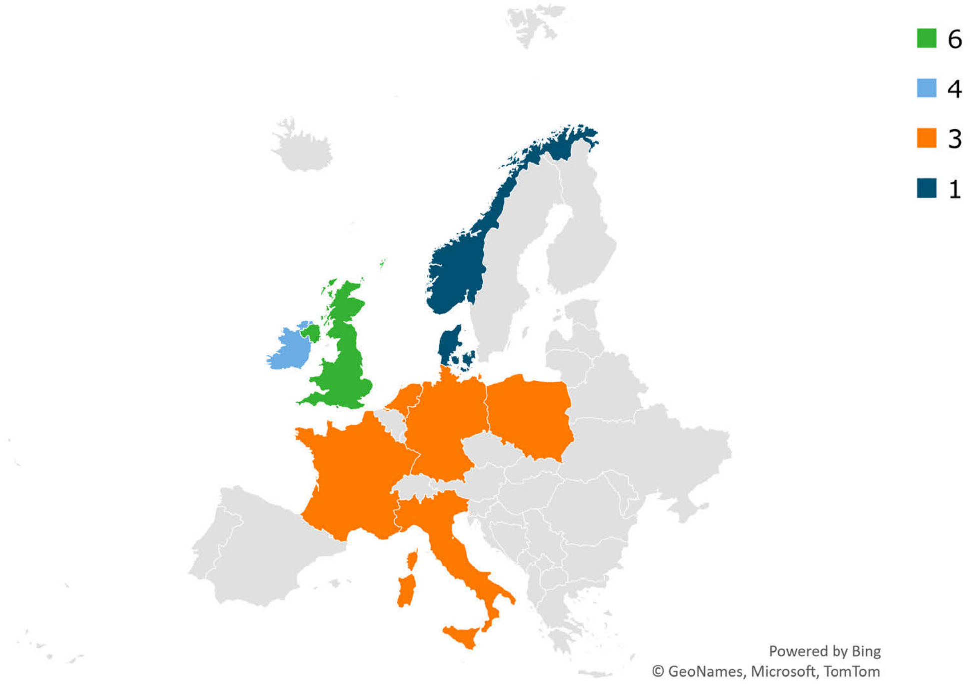


Figure 3.4 *'What is the region of your supplying farmers?', number of times countries were mentioned in Europe*

To conclude, by far the majority of the respondents indicate their supplying farmers are located in Europe for both dairy and beef. Asia is not mentioned specifically by any of the respondents, and the only respondent that indicated South America did not specify the countries. Six respondents indicated to work on a global level.

3.2 GHG emissions and tools

3.2.1 Carbon footprint

The majority of the 67 respondents for both dairy and beef indicate that supplying farmers know about their individual carbon footprint on farm level (42 respondents, 63%). The remaining respondents indicate either that their supplying farmers do not know about their individual carbon footprint (18 respondents, 27%) or that they do not know or do not want to answer this question (7 respondents, 10%). These results are shown in Figure 3.5. There is no significant difference in the results for dairy and beef.

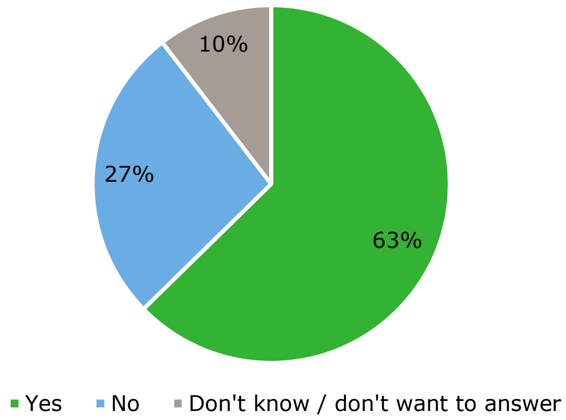


Figure 3.5 *'Do all or some of your supplying farmers know about their individual carbon footprint on farm level?' (n = 67)*

From the 42 respondents that chose 'Yes' for the previous question, equal numbers indicated that the individual carbon footprint is provided for the farmer through a national programme or chain partner, and that the individual farmer can calculate their carbon footprint themselves with an available tool (both 17 respondents).

The remaining respondents indicated 'Other'. Of these 7 respondents, 2 indicated that both answers were applicable, 2 respondents mentioned the carbon footprint was calculated by them (1 of which a national programme, and 1 a processor), 2 respondents mentioned the carbon footprint is provided by an independent service and 1 respondent indicated through a national programme or a farm-specific report. The results are shown in Figure 3.6. There is no significant difference in the results for dairy and beef.

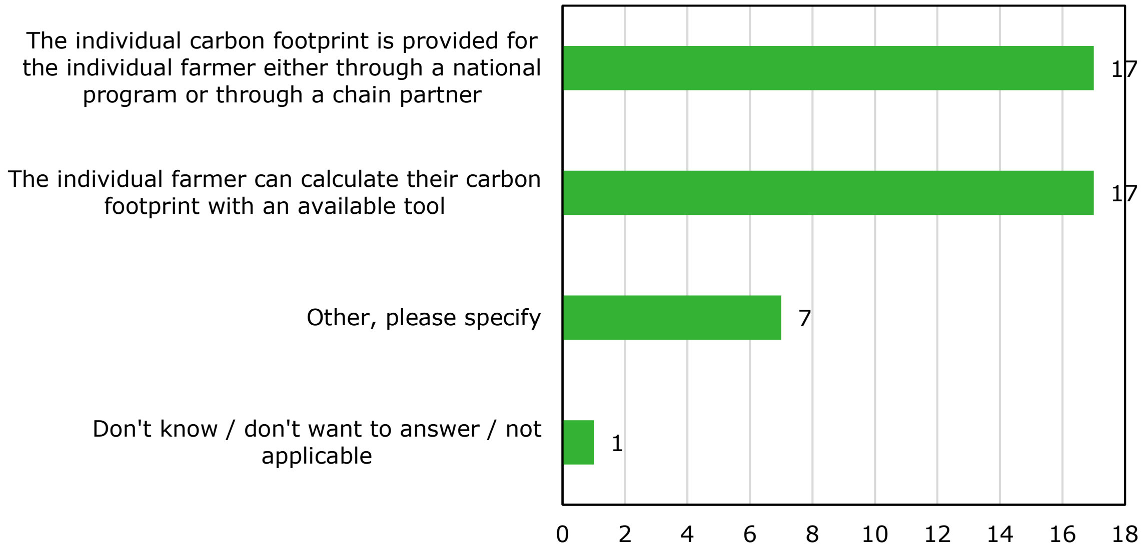


Figure 3.6 *'How do your farmers know about their individual carbon footprint?', total (n = 42)*

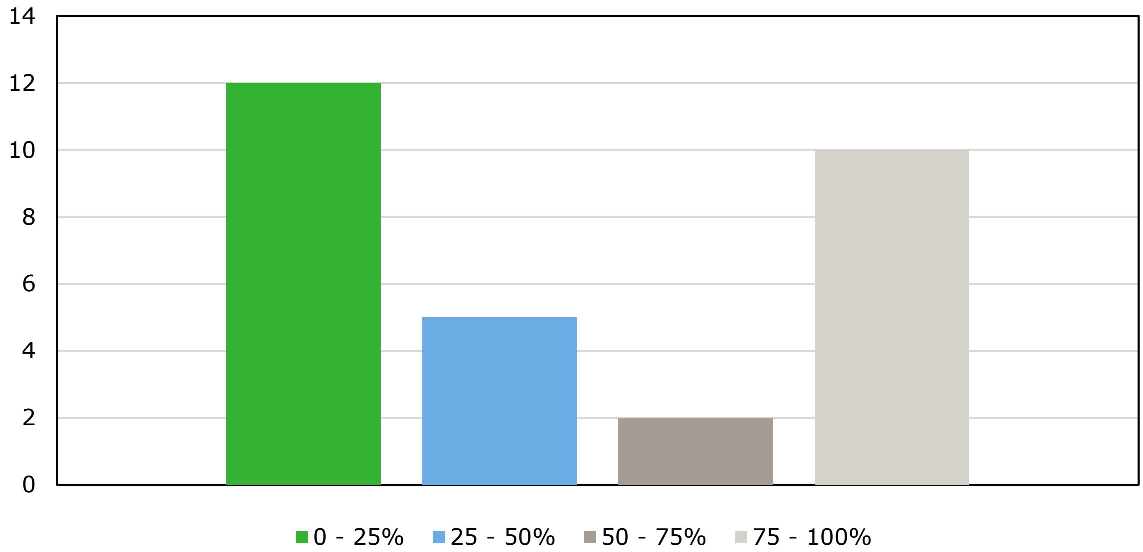


Figure 3.7 *'What is the percentage of farmers that know their individual carbon footprint?', (n = 29, dairy and beef combined)*

When asked for the percentage of farmers that know their individual carbon footprint, 12 respondents (10 dairy, 2 beef) indicated this is in the range of 0-25%, 5 respondents (4 dairy, 2 beef) indicated this is in the range of 25-50%, 2 respondents (one each) indicated between 50-75%, and 10 respondents (8 dairy, 2 beef) indicated between 75-100% (Figure 3.7). It is important to note that the number of respondents that have answered this question is low (12 out of 67) so this cannot be considered to be representative for the whole sample.

Table 3.2 shows the responses to the question which tool is used to calculate the carbon footprint. The number of times the tool was mentioned is specified for dairy and beef separately, as well as the regions of the supplying farmers as indicated by the respondents. The results show that there are a large number of different tools in use, especially in the dairy sector. Several countries seem to have their own national tool and sometimes different tools seem to be used within the same country.

Table 3.2 *'Which tool is used to calculate the carbon footprint on farm level?'*[1]

Tool	Times mentioned (dairy)	Times mentioned (beef)	Regions of respondents	Additional information
Cool Farm Tool	7	2	Europe, Global, United States	https://coolfarmtool.org/
Carbon Navigator	3	5	Europe	https://www.teagasc.ie/about/our-organisation/connected/online-tools/carbon-navigator/
Agrecalc	2	3	United Kingdom	https://www.agrecalc.com/
Farm Environmental Stewardship	6	-	United States, Global	https://nationaldairyfarm.com/dairy-farm-standards/environmental-stewardship/
CAP2ER	3	1	France	https://cap2er.fr/Cap2er/
Kringloopwijzer	3	-	The Netherlands	https://mijnkringloopwijzer.nl/
Alltech E-CO2	2	-	United Kingdom	https://www.alltech-e-co2.com/
Australian Dairy Carbon Calculator	2	-	Australia, New Zealand	https://www.dairyingfortomorrow.com.au/tools-and-guidelines/dairy-greenhouse-gas-abatement-calculator/
Arla Climate Check	2	-	Denmark, United Kingdom	https://www.arla.com/sustainability/sustainable-dairy-farming/how-arla-farmers-reduce-dairys-carbon-footprint/
Integrated Farming System Model	2	-	United States	https://data.nal.usda.gov/dataset/integrated-farm-system-model-ifsm
TEKLA	2	-	Germany	https://www.ktbl.de/themen/klimagasbilanzen/
Envirobench	1	-	United Kingdom	-
Farm Carbon Cutting Tool	1	-	United Kingdom	https://www.farmcarbontoolkit.org.uk/
Carbon Trust	1	-	United Kingdom	https://www.carbontrust.com/resources
Kingshay	1	-	United Kingdom	https://www.kingshay.com/
AIM	1	-	New Zealand	Agricultural Inventory Model https://www.mpi.govt.nz/dmsdocument/13906/direct
Overseer	1	-	New Zealand	https://www.overseer.org.nz/
Simapro	1	-	Italy	https://simapro.com/
Production Laitière Responsable	1	-	France	
Klimakalkulatoren	1	-	Norway	https://klimasmartlandbruk.no/klimakalkulatoren/
SelfCO2	1	-	-	
Sustainable Milk Production Diagnosis	1	-	-	
Farm Carbon Calculator	-	1	-	

3.2.2 GHG emissions

Of the total number of respondents asked how frequently the GHG emission of the supply base is monitored and reported, 25 indicated this is done yearly, 17 indicated 'other', 15 indicated it is not being monitored and 9 respondents indicated they did not know or were not willing to answer the question. When we distinguish the results for dairy and beef, we see the responses to this question differ (Figure 3.8).

For dairy, 22 respondents indicated the GHG emission of their supply base is monitored yearly, 10 indicated 'other', 10 indicated it is not being monitored, and 7 indicated they did not know or did not want to answer the question. Of the 10 respondents that indicated 'other', 2 indicated every

[1] Websites added by project team.

3 years, 2 indicated voluntarily, 1 indicated national inventory, 1 indicated every 18 months, 1 indicated each year for 3 years during the project, 1 indicated it varies between cases, and 2 indicated it is planned on a yearly basis.

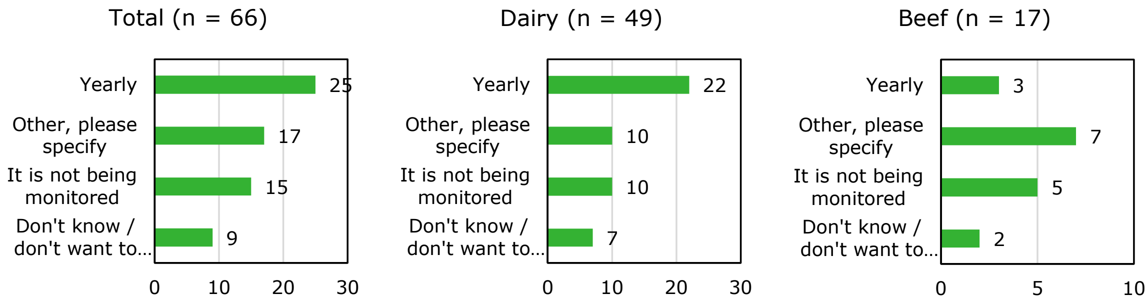


Figure 3.8 *'How frequently is the GHG emission of your supply base monitored and reported (internally or externally)?', results for total, dairy and beef*

For beef, 7 respondents indicated 'other', 5 respondents indicated the GHG emission is not being monitored, 3 indicated yearly and 2 respondents indicated they did not know or did not want to answer this question. Of the 7 respondents that indicated 'other', 3 indicated every 18 months, 1 indicated every 15 months, 1 indicated every 10 years, and 1 indicated annually as per SBTi Process, not by actual data from farms.

Of the 40 respondents that indicated the GHG emission of the supply based is monitored, 18 respondents mentioned they monitored themselves, 13 respondents indicated a national programme monitors, 8 respondents indicated 'other', and 3 respondents indicated the national government monitors. Of the 8 respondents that indicated 'other', 2 indicated GHG emission is monitored by the supplier, 1 indicated the LIFE DOP project, 1 indicated self-assessment, 1 indicated a national database, 1 indicated some processing companies monitor, 1 indicated an external consultant, and 1 indicated SBTi, CDP. The results are shown in Figure 3.9.

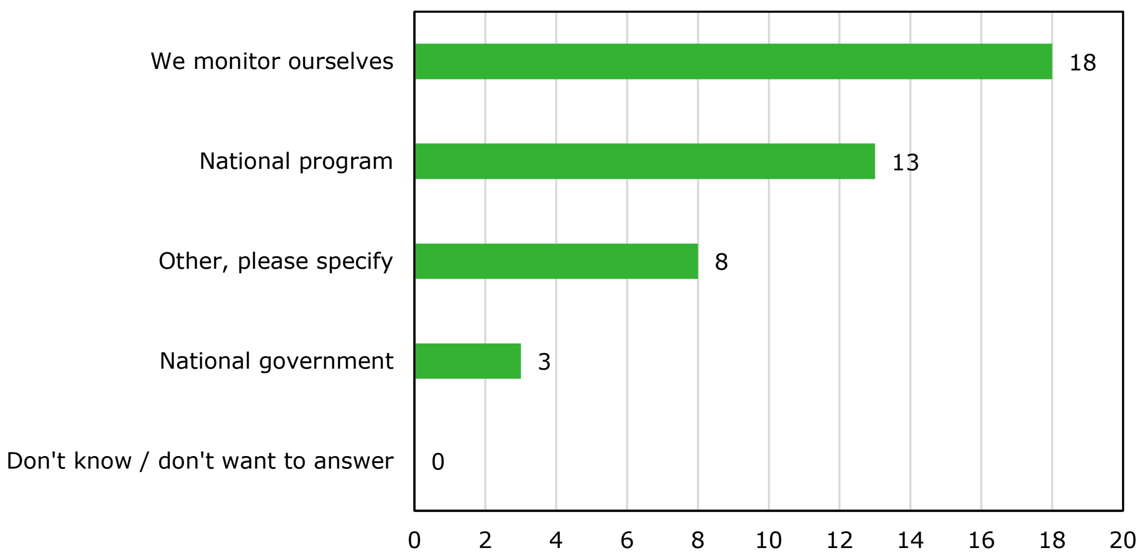


Figure 3.9 *'Who monitors the GHG emission of your supply base?' (n = 42)*

When we split the results for dairy and beef (Figure 3.10), we see that the majority of respondents for dairy indicated they monitor themselves, while a majority for beef indicated the carbon footprint is monitored by a national programme.

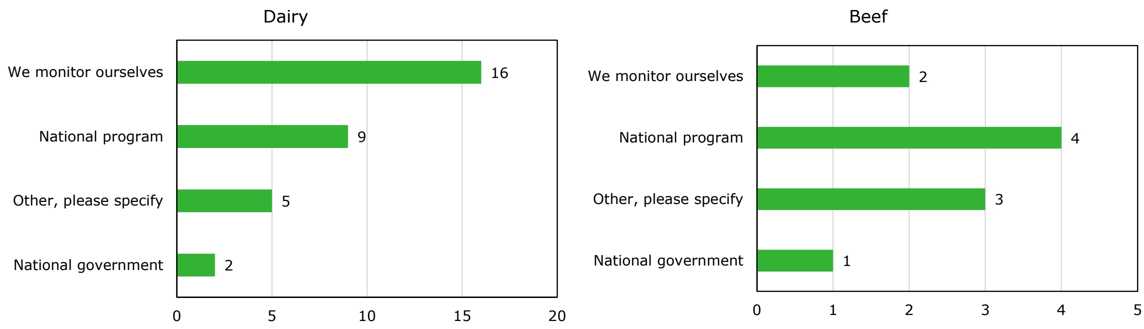


Figure 3.10 *'How do your farmers know about their individual carbon footprint?', dairy and beef*

In summary, we can conclude that for most of the respondents, some form of monitoring of GHG emission of the supply base is in place. This share is higher for dairy (76%)[2] than for beef (66%), and for dairy is more often done on a yearly basis (52% in dairy, 20% in beef).

3.3 Mitigation options currently used

3.3.1 Overview of mitigation options used

In the survey, the respondents were asked to select the farm level mitigation options that their supplying farmers apply to reduce GHG emissions. A list was provided of 28 options sorted in the 5 categories mentioned in Chapter 1: (1) genetics, breeding and enteric methane reduction; (2) herd management; (3) feed production; (4) manure management; and (5) smarter energy management/use. Table 3.3 shows an overview of all the options on the list and the percentage of respondents that indicated this option is applied. The results are presented as the percentage of the total number of respondents, and the percentages for the respondents for dairy and beef separately. For an overview of the total numbers of respondents that mentioned the options, see Appendix 2.

The overview shows that improving animal productivity by breeding is the most used option (81% of the respondents indicated this option is applied), followed by increasing animal efficiency (74%). Improving diet composition, animal health and forage quality were selected by an equal number of respondents (70%), followed by reduction of calf mortality rate (61%), reduction of manufactured nitrogen fertiliser application (60%), optimising manure application timing and using different manure application methods (both 58%), increasing longevity (56%) and application and production of renewable energy (54%). These options form the top 11 options that were mentioned 30 times or more (see Figure 3.11). For an overview of the options by the number of times they were mentioned in total, for dairy and beef, see Appendix 1.

[2] Without counting the answers 'don't know'.

Table 3.3 *Percentage of respondents that selected each mitigation option for the total number of respondents, dairy and beef*

Option	Total (n = 57)	Dairy (n = 41)	Beef (n = 16)
Genetics, breeding and enteric methane reduction			
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	81%	83%	75%
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	74%	76%	69%
3. Breeding for reduction of enteric methane emission	21%	20%	25%
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	70%	73%	63%
5. Use of feed additives to alter ruminal fermentation to reduce methane.	28%	32%	19%
Herd management			
6. Improving animal health (e.g. vaccination)	70%	68%	75%
7. Reduction of calf mortality rate	61%	59%	69%
8. Increasing longevity	56%	56%	56%
9. Reducing the share of non-productive animals (e.g. young stock, dry cows)	51%	54%	44%
Feed production, grassland management and land use			
10. Improving grazing management (e.g. subdividing farms to paddocks, sward analysis, measuring grass growth and planning grazing strategy for grazing season)	49%	49%	50%
11. Increasing carbon sequestration (e.g. increasing grassland areas)	39%	41%	31%
12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	60%	59%	63%
13. Improving forage quality (e.g. earlier harvest, improved varieties)	70%	71%	69%
14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)	40%	39%	44%
15. Planting trees, hedges, agroforestry	39%	41%	31%
16. Application of protected nitrogen fertiliser (e.g. urea treated with a urease inhibitor)	32%	32%	31%
Manure management			
17. Application of primary and/or secondary separation of manure	37%	41%	25%
18. Reduction of manure storage time in the barn	30%	29%	31%
19. Applying manure treatment (Lowering manure pH e.g. application of sulfuric acid, manure aeration, manure cooling)	21%	22%	19%
20. Application of bedding materials (e.g. sand)	28%	34%	13%
21. Complete removal of liquid dairy manure from storage tank (inoculum removal)	14%	17%	6%
22. Oxidation of captured methane by flaring or filtration	11%	12%	6%
23. Anaerobic digestion	46%	49%	38%
24. Use different manure application methods on land (e.g. dilution and injection)	58%	59%	56%
25. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)	58%	59%	56%
26. Application of inhibitors for manure (e.g. Dicyandiamide and dimethypyrazole phosphate)	11%	7%	19%
Smarter energy management/use			
27. Reducing fossil fuel consumption	47%	49%	44%
28. Application and production of renewable energy	54%	56%	50%

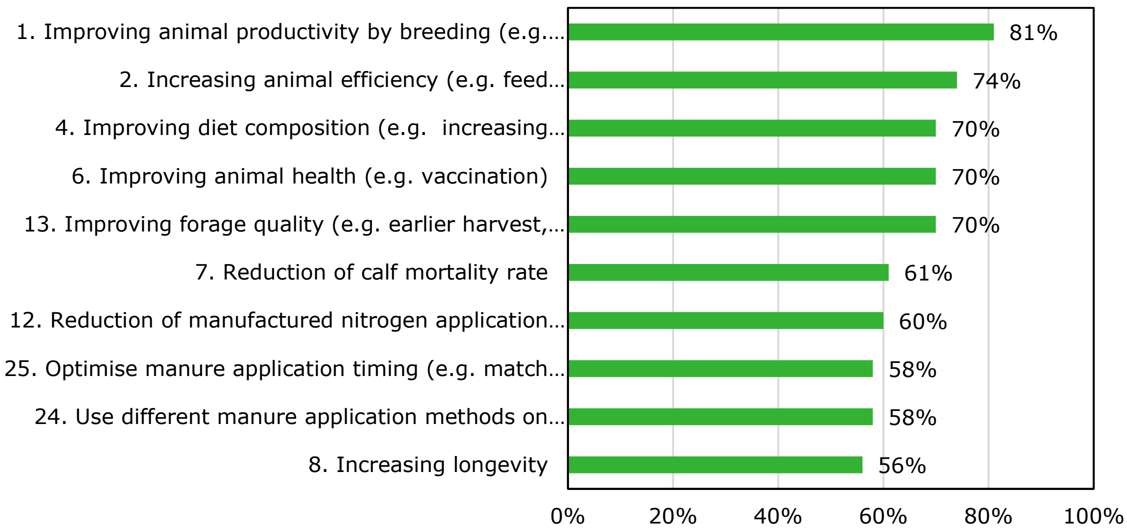


Figure 3.11 *'Which farm level mitigation options do your supplying farmers apply to reduce GHG emissions?', percentage of total respondents that selected the option, top 10 (n = 57)*

In summary, we find that the results for beef and dairy are quite similar. The only differences are found in the use of feed additives (option 5) and some options related to manure management (17 and 20). However, as the number of respondents for dairy is more than twice the number for beef, the results may not be representative enough for the sector.

Respondents were asked to provide additional information for the mitigation options they selected on farming system, profitability, skills required, and stimuli considered necessary. This information is integrated in Chapter 4. For an overview of the survey results, see Appendix 2.

3.3.2 Other mitigation options mentioned

Aside from the list with mitigation options provided for the respondents, an 'other' option was created to allow for additional mitigation options. Some of the mentioned options where however not directly related to greenhouse gas emission reduction but more to reducing N losses (reducing MUN in milk, reducing leaching via winter cover, applying nutrient boom) and some were similar to the options that were already in the list (enhancing concentrate utilisation per kg of meat and grassland management).

Two additional options remained:
1. Reduce tillage or no till (mentioned three times).
2. Introduction of legumes/make use of nitrogenase, to save use of synthetic nitrogen fertiliser (mentioned twice).

3.4 Additional comments shared

At the end of the survey, respondents were asked if they have any additional information or comments, they would like to share in relation to mitigation options to reduce GHG emissions on farm level. Additional comments were shared by 24 respondents. Most of these comments related to how to motivate farmers to change practices. Both economic and social aspects were mentioned in this regard. Other comments related to specific tools or data sharing and a number of best practices and experiences were shared. These comments have been a major input for Chapter 5.

For the full survey outline, see Appendix 3.

4 Top GHG mitigation options and assessment of impact

4.1 Top 10 mitigation options from survey

Table 4.1 shows the top 10 of most implemented mitigation options based on the survey results. For each mitigation options the percentage of respondents, the relevance for specific farming systems, the profitability, required skills and main motivators or stimuli are listed also based on the survey results. It should be noted that stimuli or incentives include all kinds of possibilities (e.g. knowledge and subsidy) to support the implementation of mitigation options.

Table 4.1 *Top 10 of highest scoring mitigation options from the survey with the share of respondents, farming system, profitability, required level of skills and main stimuli*

Mitigation option		% of respondents	Farming system[1]	Profitability[1]	Required skills[1]	Main stimuli[2]
1.	Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year) (1)[3]	81%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
2.	Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter) (2)	74%	Universal	Profitable	Medium	Knowledge and training, technical assistance, subsidies
3.	Improving diet composition (e.g. increasing digestibility, buying feed with low footprint) (4)	70%	Universal	Majority indicates profitable	Medium-high	Knowledge and training, subsidies
4.	Improving animal health (e.g. vaccination) (6)	70%	Universal	Profitable	Low-medium	Knowledge and training, subsidies, technical assistance
5.	Improving forage quality (e.g. earlier harvest, improved varieties) (13)	70%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
6.	Reduction of calf mortality rate (7)	61%	Universal	Profitable	Medium	Knowledge and training, subsidies, technical assistance
7.	Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning) (12)	60%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
8.	Optimise manure application timing (e.g. match crop nutrient demands, soil conditions) (25)	58%	Universal	Profitable	Medium-high	Knowledge and training, subsidies
9.	Use different manure application methods on land (e.g. dilution and injection) (24)	58%	Half indicate option is universal	Majority indicates net extra costs	Low-medium	Knowledge and training, subsidies
10.	Increasing longevity (8)	56%	Universal	Profitable	Medium	Knowledge and training, subsidies

1) Each category mentioned is based on at least two-thirds of the respondents, unless otherwise specified. Universal means: applicable on all farms.

2) Stimuli that have been mentioned twice or more. The stimuli question was an open question, answers have been categorised.

3) Number in survey list.

This chapter will describe all mitigation options from the survey. However, the results from the survey will only be used in the description for the mitigation options with the highest level of implementation within the group of respondents.

The description for each mitigation option is a combination of results from the survey (for the top 10), literature review and interpretation by the project team. For each mitigation option the following elements are described:

1. The category the mitigation option belongs to.
2. Short practical description of the mitigation option.
3. Scientific background (summary of literature review).
4. GHG emission reduction potential in low, medium, high. Given that the GHG reduction potentials of each mitigation option presented in different studies have different ranges, we classified mitigation options to three levels as low (with emissions intensity reduction potential up to 10%), medium (between 10% and 20%) and high (more than 20%). This is the reduction within the category, so not the overall reduction. It is important to be aware of this since the category itself may only comprise a small fraction of overall supply chain emissions as is the case with e.g. electricity.
5. Required skills: no extra skills/medium level/high level (result from survey) with additional reflection and interpretation.
6. Cost effectiveness: profitable, break even, net extra costs (result from survey) with additional reflection and interpretation.
7. Farming system which mitigation option fits with which farming system: universal or specified for size[3] or diet[4] (result from survey) with additional reflection and interpretation. Size is based on number of animals and diet is related to the share of roughage in the diet. When relevant a distinction will be made between systems based on confinement/housing and based on grazing.
8. Stimuli for implementation: result from the survey (only for the top 10).
9. Consequences of implementation: possible side effects and trade-offs. Only major points are addressed. Given the scope of the study a full assessment was not possible.

The mitigation options will be described per category in a separate section.

4.2 Genetics, breeding and enteric methane reduction

1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	
Category	Genetics, breeding and enteric methane reduction
Practical description	Improving animal productivity by breeding: - Genetic and genomic selection - Artificial insemination - Gender selected semen (i.e., sexed semen) - Embryo transfer - Oestrous or ovulation synchronisation
Overall estimate of GHG reduction potential (survey)	Medium - high
Scientific background	Increasing animal productivity by improving the genetic potential of livestock, their reproductive performance, health and liveweight gain is among the most effective GHG mitigation strategy in most of the countries (Gerber et al. 2013a; Herrero et al. 2016). As Flachowsky (2011) estimated, dairy cows with average milk production of 40 kg milk per day would have about 50% lower CO_2-eq per kg milk (or FPCM) compared to the dairy cows with a production of 10 kg milk per day. Modern molecular techniques revealed much greater diversity in the ruminal microbiota than previously known (Hristov et al. 2013b). Many attempts are under way for selecting more efficient animals or animals producing less CH_4. Genetic changes can improve the feed efficiency and subsequently reduce the GHG emissions. Also, increasing the productivity leads to reduction in number of animals needed to produce the same amount of milk and subsequently a lower environmental footprint. In different parts of the world this strategy was applied to reduce the number of animals to

3 Size categories from survey: <25 total herd, 25-200 total herd, 200-500 total herd, >500 total herd.

4 Diet categories from survey: grass/roughage based <20% DM from concentrates/grains, intermediate 20-50% DM from concentrates/grains based >50% DM from concentrates/grains.

1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	
	produce the target farm output. For example, during the milk quota system in the Netherlands increase in milk production per cow led to a reduction of the number of cows, which meant a concomitant decrease in CH_4 production from 17.6 to 15.4 g/kg FPCM (Hristov et al. 2013b). Based on the annual statistic report for the milk production in Netherlands, during the last 38 years (from 1980 to 2018) the average milk production per lactation of the milk recorded cows increased from 5500 to 9900 which shows the substantial impact of genetic improvement and other strategies for increasing the productivity (CRV, 2020). Body weight is an important factor because the dairy cows with higher body weight have higher energy requirement for maintenance. Smaller cows have a smaller carbon footprint due to smaller body weight. The impact of improvements in genetic potential also leads to a significant reduction of GHG emissions per unit beef product as shown for the Australian beef industry (Henry and Eckard 2009). Beef cattle with higher feed conversion factor can reduce the CH_4 production up to 28% (Hegarty et al. 2007; Nkrumah et al. 2004). Based on De Haas et al. (2011) findings, a reduction of 11 to 26% in CH4 production due to heritability is theoretically possible in 10 years after starting with breeding on animal productivity. Using reproductive technologies including genetic and genomic selection (Amann and DeJarnette 2012; Tiezzi et al. 2011), artificial insemination (López-Gatius 2012), gender selected semen (i.e., sexed semen) (DeJarnette et al. 2011; Rath and Johnson 2008), embryo transfer (Hansen and Block 2003; Lonergan 2007), and estrus or ovulation synchronisation (Gumen et al. 2011) improve the animal productivity and reduce the GHG emissions per product. As an example, artificial insemination reduces the number of male animals per farm and increases genetic merit for production and reproduction traits. Although applying genetic modified breeds is critically important, it should be considered that importing these animals into new regions may limit their production potential and in some cases their production may be worse than the native breeds or crossbreeds due to disease, management or climatic challenges (Hristov et al. 2013b). The important limitations for the mentioned technologies are their availability and cost-effectiveness which should be considered. Success in application of these strategies highly depends on the governmental supports specially in developing countries to facilitate the use of these options. As mentioned earlier, improving the genetic potential of livestock may affect the reproductive performance, health and liveweight gain of the animals. This makes it not possible to determine its impact on reduction of GHG emissions. However, based on the annual statistic report for the milk production it can be concluded that its GHG reduction potential is high.
Required skills (survey)	Medium – high
	Skills related to breeding and herd management. The breeding strategy has to be changed and if the farmer chooses to do this by himself, he has to collect the relevant information and implement a long-term breeding strategy. This can be done more gradually e.g. by using different semen with the current herd or more abrupt by fully switching to different breeds. To achieve the desired outcome, high level of animal care and nutrition management skills are required. New high productive breeds have higher energy and protein requirements. Moreover, new breeds may need special maintenance and may have new health issues.
Cost-effectiveness (survey)	Profitable
	If a farmer will completely switch to a new breed, this will require a high investment. If the farmer chooses a more gradual approach (selection within the existing herd), the investments will be limited. Generally, increase in efficiency will result in relative lower costs and will make this mitigation option overall profitable.
Farming system (survey)	Relevant for all systems
	Increase in productivity is relevant for all systems. The exact implementation will however differ much between different systems. In an extensive system with a low-quality feed, the focus should first be on improving the feed quality to improve efficiency and not so much on genetics and breeding. In case the cows already achieved high milk yields, further improvement requires a more controlled farming system which is better suited.
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	Increase of productivity in itself is in general positive for other sustainability aspects, because of general increase in resource efficiency.

2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	
Category	Genetics, breeding and enteric methane reduction
Practical description	Increasing animal efficiency by: - Improved feed systems (e.g. TMR) - Growth promoters - Shorter calving intervals
Overall estimate of GHG reduction potential (survey)	Medium - high
Scientific background	Increasing animal efficiency (fertility) reduces GHG emissions. Low fertility rate forces farmers to maintain more animals per unit of product and keep more replacement animals to maintain herd or flock size. Generally, nutritional status, timing of the initial insemination after parturition, and method and timing of pregnancy diagnosis of females are important parameters which play an important role in animal fertility (Mourits et al. 2000). In addition, feed conversion rate, calving interval and days to slaughter are important factors for reduction of GHG emissions per product. The most common reason limiting the animal efficiency is inadequate nutrition. However, some easy applicable at low cost approaches have been introduced to increase the animal fertility such as reducing inbreeding (Berman 2011; Zi 2003), sire mate selection from highly fertile animals, reducing stressors, and improving education on the factors influencing fertility (Banda et al. 2012). Garnsworthy (2004) found that improving the fertility leads to reduction of number of replacements which could reduce CH_4 and NH_3 by 24% an 17%, respectively. To reduce days to slaughter at the same slaughter weight, growth promotants such as ionophoric antibiotics, implants (hormones, melengestrol acetate, and trenbolone acetate), and β-agonists (ractopamine, the decrease in zilpaterol hydrochloride) are used in beef production systems. These compounds increase the growth rate (i.e., less days to slaughter) and feed efficiency (i.e., feed conversion rate) and therefore lead to reduction of GHG emissions per product (Al-Husseini et al. 2013; Parr et al. 2011). Although use of growth promotants is one of the GHG mitigation options, in many countries they are banned. Moreover, the use growth promotants highly depends on the final consumers (of meat or milk) acceptance and preference. Optimum productivity for suckler cow farmers is producing at least one calf every 365 days. One of the approaches to increase the animal productivity is shortening calving intervals, which is beneficial for the farmers to increase animal efficiency. Therefore, instead of 120- or 150-day windows for insemination, 60-day windows should be applied. To achieve the shorter calving intervals, it is essential to apply i) a good nutrient programme, ii) heat synchronisation protocols, and iii) making sure the bulls are reproductively sound. To keep the animal efficiency at high levels, it is essential to meet the animal nutritional demands. Some research has been conducted to study the impact of feeding systems (i.e., component or choice feeding of forage and concentrates vs. feeding of TMR) on milk production and CH_4 reduction. Generally, because in total mixed ration (TMR) more precise nutrient is allocated to different feeding groups and a more precise feeding of micronutrient supplements is done, the productivity of dairy cows increases by feeding complete rations (Nocek et al. 1986). Precision feeding, which refers to matching animal requirements with dietary nutrient supply, reduces feed waste, maximising production, and minimising GHG emissions per unit of animal product. Indirectly, precision feeding affects CH_4 emission through maintaining a healthy rumen and maximising microbial protein synthesis, which is important for maximising feed efficiency and decreasing CH_4 (Hristov et al. 2013a). Although there are some discussions that increasing feeding frequency may have a positive impact on animal efficiency, a literature review showed that it does not have impact on CH_4 emissions (Crompton et al. 2011).
Required skills (survey)	Medium
	Skills related to herd management and nutrition. Farmer needs to have a comprehensive view about the impacts of using different strategies to increase animal efficiency. To increase feed conversion rate, farmers need to know the animal potential for increasing the efficiency. For application of a TMR system, farmers should know the exact nutrient demands of different types of animals in the herd. In case the farmer decides to use growth promotants to reduce the days to slaughter, high-level nutrition management skills are required.
Cost-effectiveness (survey)	Profitable
	Improving feed systems increases the workload at farm level. Moreover, consultation with nutrient experts may have some additional costs. However, because application of this

2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	
	mitigation strategy leads to higher milk or meat production it will be profitable for the farmer.
Farming system (survey)	Relevant for all systems
	Increasing animal efficiency is in principle relevant for all systems. The possibilities to control and manage the diet are bigger for confined systems.
Stimuli to implement	Knowledge and training, technical assistance, subsidies
Consequences of implementation	In general increase in efficiency of converting feed into milk or meat has many positive side effects (reduced N losses, less land use). Some growth promotants may increase enteric fermentation, which needs to be considered for further assessments.

3. Breeding for reduction of enteric methane emission	
Category	Genetics, breeding and enteric methane reduction
Practical description	Implementing breeding programs focussing on low enteric emissions.
Overall estimate of GHG reduction potential	Medium - high
Scientific background	Improving the genetic potential of livestock, indirectly has a positive impact on reduction of GHG emissions per unit of livestock product. Based on the findings of the previous research (De Haas et al. 2011; Mollenhorst and de Haas 2019), there is great potential in adopting genetic and genomic selection strategies to tackle methane emissions from ruminants (Lesschen et al. 2020b). It is claimed that around 20% of methane emissions from enteric fermentation can be decreased up to 2100 by genetic modifications (Ahmed et al. 2020; Bell et al. 2010; Harmsen 2019). Newly modified genetic breeds in US have 5% less GHG emissions per animal and applying these breeds without any change in productivity would lead to reduction of the GHG emissions from 53 to 42 kg CH_4 per animal per year (Ahmed et al. 2020). Based on the Beukes et al. (2010) findings it is possible and feasible to decrease the methane emissions by at least 10-20% by increasing the genetic merit of herd.
Required skills	Skills related to breeding and herd management. Similar to improving animal productivity by breeding (mitigation option number 1).
Cost-effectiveness	Not yet available.
Farming system	In principle relevant for all systems.
Consequences of implementation	Specific breeding programmes for low emission cows are not yet available.

4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	
Category	Genetics, breeding and enteric methane reduction
Practical description	Improving diet composition by: - Replacing grass silage with maize silage - Buying feed with low footprint - Use of a balanced diet (based on the animal physiological needs) - Increasing concentrate feed availability - Reducing feeding losses - Inclusion of new feed components with lower enteric fermentation (e.g. seaweed)
Overall estimate of GHG reduction potential (survey)	Medium - high
Scientific background	Generally, there is a clear relationship between feed digestibility, concentrate or starch intake, and the amount of enteric fermentation (Hristov et al. 2013a). Previous researches confirmed a strong relationship between feed type (e.g. inclusion of concentrate and grain (or feeding forages with the higher content of starch such as whole-crop cereal silages)) and the enteric CH_4 production. One of the long-term strategies for mitigating the GHG emissions is replacing the grass silage with maize silage in the ration to reduce the enteric fermentation. This strategy not only affects the enteric fermentation but also has impact on other sources of GHG emissions at farm level and through the whole supply chain. According to the results obtained by Van Middelaar et al. (2013), it was revealed that this strategy can reduce the annual emissions by 12.8 kg CO_2-eq per tonne of FPCM. However, changing the grass land to maize land results in emitting 913 kg CO_2-eq per tonne of FPCM due to the land use change.

4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	
	Therefore, it takes 44 years that the annual emission reduction pays off the emissions due to land use change. Increasing the proportion of concentrate in the diet will reduce the CH_4 emissions if the production remains the same or is increased. However, the amount of reduction depends on the concentration of other feed components and makes it difficult to be calculated. Concentrates provide more digestible nutrients (per unit feed) compared to the roughage, which besides the GHG reduction can increase the animal productivity. However, it should be noted that increasing the concentrate proportion in the diet above certain levels, might have a negative effect on fibre digestibility which may lead to higher CH_4 emissions from stored manure. Concentrate-based diets are more efficient in terms of animal production and emit less GHGs per unit of product. However, when soil carbon storage in grasslands and land use changes are considered, the positive impact would be less or needs more evaluations. Cereal grain has impact on productivity of animals, however the growth of world population and the need for food for people raises the question whether more grain will be available for feeding ruminant animals in near future. Moreover, using grain for production of poultry or swine is more efficient than for ruminant production. Whether increasing the share of grain in rations of ruminants is an economically feasible strategy to increase milk and meat production and reducing the GHG emissions of products is questionable in the long term. Therefore, this strategy will be a challenging one in countries where the price of milk and meat products is low. Generally, as a mitigation strategy, improvement of animal diet composition through strategic use of a balanced diet (based on the animal physiological needs), increasing concentrate feed availability and reducing feed losses have a significant impact on increasing animal productivity and reducing GHG emissions per product. In addition to the common feed components some new feed components are recently introduced and applied in livestock production. One of the new feed components is seaweed which is claimed to substantially reduce the enteric fermentation. There are more than 10 thousand seaweed species around the world. Green, red and brown seaweeds are the main groups which have different nutritional value and impact on functionality of animal's ruminant. Compared to green and brown seaweeds, red seaweeds contain higher amount of protein. Brown seaweeds are the source of omega 3 and 6. Although seaweeds can be considered as a source of protein to the animal feed, the heavy metal concentration needs to be measured precisely. Levels of arsenic, mercury, lead, and cadmium are the main heavy metal elements. Recently the focus on using seaweed as a feed ingredient has grown because it can improve not only the livestock productivity (growth, lactation, gestation) but also the enteric fermentation. The red seaweed *Asparagopsis armata* has been introduced as the future solution for methane emissions reduction. Many researches have been conducted to determine the GHG reduction potential as a result of using seaweed in feed. In a study conducted by Roque et al. (2019) adding 0.5% and 1% of seaweed led to 27% and 67% reduction in methane intensity (per milk production). According to the results obtained by Kinley et al. (2020), using 0.10% and 0.20% seaweed (*Asparagopsis*) as a feed ingredient, it can decrease the methane production up to 40% and 98%, and also can improve the weight gain by 53% and 42%, respectively. Roque et al. (2021)determined the impact of *Asparagopsis taxiformis* on methane production in growing beef steers. The 0.25% (Low), and 0.5% (high) treatments reduced enteric methane yield 45 and 68%, respectively. Bromoform is the active ingredient of the seaweed, which is volatile and negatively affects the ozone layer. Effects of its application on animal health are yet unknown. It is recommended to be very careful with halogen containing materials. Although some researchers found promising results for this technique, there are many questions and debates about the negative impact of applying this technique on the livestock production system as a GHG mitigation option. For example, a recent study conducted by WUR showed that inclusion of seaweed does not reduce the enteric fermentation. However it increased the milk production resulting in lower GHG emissions per kg milk. The amount of GHG reduction was lower than in the previous studies. Some feed components (e.g. soybean) are produced far away and their transportation results in higher carbon footprint of feed component. Selecting the feed components with lower carbon footprint leads to lower GHG emission in livestock system.
Required skills (survey)	Medium - high
	Skills for feeding and herd management are required. Specific nutritional knowledge can also be obtained through external advisors.

4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	
Cost-effectiveness (survey)	Profitable
	Although concentrate-based diet increases feeding costs, higher revenues due to higher milk production and animal fertility can cover the additional costs and in total make this strategy profitable. The exact profitability depends on the farming system and input costs.
Farming system (survey)	Relevant for all systems
	Improving diet composition is relevant for all systems. The exact implementation will however differ much between the different systems and depends on the region. Confined systems where most or of the feed is bought have more options to manage the inputs compared with pasture based grazing systems.
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	The exact impact of this mitigation strategy needs to be evaluated precisely. If replacing grass silage with maize silage in the diet also results in reducing the grassland area, this will lead to extra carbon losses. Moreover, GHG potential reduction depends on the current situation. In case feed quality is low, improving diet composition results in lower GHG emissions.

5. Use of feed additives to alter ruminal fermentation to reduce methane	
Category	Genetics, breeding and enteric methane reduction
Practical description	Use of feed additives or vaccines to alter ruminal fermentation to reduce methane such as: - Fatty acids - Inhibitors addition - Electron receptors - Ionophoric antibiotics - Other feed additives - Use of vaccines to reduce methane production in the rumen.
Overall estimate of GHG reduction potential	Medium - high
Scientific background	There are various feed additives and supplements which affect GHG emissions of enteric fermentation. In the next sections some of the important additives and their impacts on GHG emissions will be discussed. **Fatty acids and inhibitors addition**: Addition of fatty acids and inhibitors to the ruminants' diets is widely applicable and recognised as effective in decreasing the enteric fermentation. Various fatty acid feed ingredients such as cottonseed, brewer's grains and cold-pressed canola meal can decrease the methane production. Inhibitors are various chemical compounds with a specific inhibitory effect on rumen archaea. Among the chemical compounds bromochloromethane (BCM), 2-bromoethane sulfonate, chloroform, and cyclodextrin are the most successful compounds. Experiments show a 50% reduction potential of enteric CH_4 in ruminants (Immig et al. 1996; Knight et al. 2011; Lila et al. 2004; Mitsumori et al. 2012). According to a study of Knapp et al. (2014) the highest GHG reduction was reported when 5-8% of diet (dry matter) was consisted of fatty acids. The enteric methane reduction potential was 15% per kg fat protein corrected milk. MacLeod et al. (2015) research indicated that every additional kg dry matter provided by fatty acids leads to 4% methane reduction. A good example of inhibitors is 3-nitrooxypropanol (3NOP). Based on the previous findings, a mitigation potential of 13-29% has been reported for inclusion of 3NOP (Rooke et al. 2016). In a study a low reduction in CH_4 production (8%) was seen for lactating cows (Hristov et al. 2013a). However, a sharp decrease in CH_4 was seen immediately after 3NOP use which may be because of that the compound was absorbed, metabolised, or washed out of the rumen (Hristov et al. 2013a). It should be considered that due to health issues, the fatty acid contents should not exceed 6% of feed dry matter (MacLeod et al. 2015). Also, too high fatty acid contents will lead to low quality pellets. Besides the high potential for reduction of enteric CH_4, the long-term effect of inhibitors is uncertain. Moreover, public acceptance (due to perception and/or existing or future regulations or because they are known carcinogens, e.g., chloroform) could be barriers to their adoption. **Other feed additives:** Feed additives such as electron receptors (e.g. fumarate, nitrates, sulphates and nitroethane)) and ionophoric antibiotics have shown a positive impact to reduce methane emissions (Beauchemin et al. 2009). For example, among additives promising results have been reported for nitrate which in some cases has reduced CH_4

5. Use of feed additives to alter ruminal fermentation to reduce methane	
	emissions by 30 to 60% (Jayasundara et al. 2016). Although the impacts of feed additives on reduction of enteric fermentation was observed, the health risks associated with using these additives should be considered (Herrero et al. 2016). Other additives which have recently received attention as GHG mitigation agents such as ionophores (e.g. monensin), plant bioactive compounds (e.g. tannins and saponins) and etc. (Beauchemin et al. 2007; Brown et al. 2011; Gutierrez-Bañuelos et al. 2007; Russell and Houlihan 2003). The results showed that electron receptors can decrease the GHG emissions by up to 50% (Gerber et al., 2013). The reduction potential between 7.5 to 15% was reported for ionophores (Grossi et al. 2019). Lipid supplements have also been indicated for 9 to 12% reduction however, this additive may have negative interaction when used in warmer climate in terms of higher CH_4 emissions (Hellwing et al. 2014). Among the ion ionophores, monensin is the most studied ionophore and it is routinely used in beef production and more recently in dairy cattle nutrition in North America. Although application of ionophores are common in livestock production, they are banned in the EU. The CH_4 mitigation potential of ionophores has been the subject of many researches (Grainger et al. 2010; Waghorn et al. 2008). Meta-analyses have shown that application of monensin leads to improve feed efficiency in feedlot cattle (by 7.5%; (Goodrich et al. 1984)), growing cattle on pasture (by 15%; (Potter et al. 1986)), and dairy cows (by 2.5%; (Duffield et al. 2008)) which may result in reduction of CH_4. Capelari (2018) showed that use of monensin reduces CH_4 production by 5% in growing steers. When it is combined with other additives the reduction potential will increase up to 16% without affecting ruminal fermentation. Long-term performance trials coupled with CH_4 measurements are needed to confirm that it does not limit the animal performance and is able to sustain reduction on CH_4 levels for longer periods. The use of high levels of antibiotics as feed additives can lead to anti-microbial resistance. Within the EU, this was the reason to come up with regulation to prohibit the use of four feed additives, namely monensin sodium, salinomycin sodium, avilamycin, and flavophospholipol, these are not allowed to be used anymore in livestock production in EU (EC 2002). **Use of vaccines** Works by stimulating the host animal to produce antibodies against methanogens. In vitro experiments have achieved emissions reductions of 30%
Required skills	Medium. For feed additives: in nutrition management. It is essential for the farmer to be aware of the acceptable usage level of feed additives and also long-term impacts on animal performance. Applying a vaccine would require virtually no change in farm practice nor any required extra skills.
Cost-effectiveness	Adding net costs. Given that this mitigation option aims to reduce enteric fermentation and will not increase the milk production.
Farming system	Use of feed additives are relevant for all systems, easiest to implement in confined systems Applying a vaccine would be applicable to all systems.
Consequences of implementation	In itself feed additives are easy to implement especially for confined systems. For grazing systems, it can be a bit more complicated. Vaccines are easy to implement in all systems. It is still in development, long-term impact on cows is uncertain. Moreover, it is not clear whether the reduced methane in rumen will shift to the manure and be released during manure storage or manure application. Therefore, further studies are essential. In western countries consumers might be concerned by the use of additives or vaccines from an animal welfare point of view.

4.3 Herd management

6. Improving animal health (e.g. vaccination)	
Category	Herd management
Practical description	Improving animal health by: - Vaccination - Applying health monitoring program - More comfortable barns
Overall estimate of GHG reduction potential (survey)	Low - medium
Scientific background	By improving animal health, animal mortality rate decreases and subsequently productivity increases. If the animal dies due to health issues before its productive value is harvested, all the GHG emissions produced during growing period are a net loss. As livestock industry changes, the practices of veterinary medicine also change their focus. During the last years the main focus of veterinary medicine was the eradication of clinical infectious diseases with the emphasis on individual animal treatment. However, when size of herd and animal productivity increases, focus shifts to preventive veterinary medicine and subclinical medicine. In this situation systematic health management programmes which target herd productivity have a greater emphasis (Hristov et al. 2013b). As an example, the major reported causes of dairy cow death in the US are lameness or injury (20.0%), mastitis (16.5%), and calving problems (15.2%) (USDA 2007). In addition to mortality, these health issues may have a negative impact on cow productivity and increase GHG emissions per unit of product. For the culling cows the major reported causes are reproductive problems (26.3%), mastitis (23.0%), poor production (16.1%), and lameness or injury (16.0%) (USDA 2007). Based on the study conducted by LeBlanc et al. (2006) the first month after calving is most sensitive period for calves where around 75% of the diseases occur. Based on the results of a study conducted in US, around 26% of dairy culls were reported for a period between the first 21 to 60 days after calving (Dechow and Goodling 2008). Among the health problems, metabolic disorders have negative impacts on milk production and may lead to culling (Berry et al. 2007; Duffield et al. 2009). New monitoring tools to improve herd management help to check the animal condition continuously and reduce risk of animal health problems. Mostert et al. (2018a) studied the impact of monitoring animal health on GHG emissions of milk production and found that preventing subclinical ketosis (SCK) reduces total emissions by 20.9 g CO_2-eq per kg FPCM (equal to 2% GHG reduction per kg FPCM). In similar studies it was found that it is possible to reduce 6.2% and 1.5% of total GHG emission per kg FCPM by preventing clinical mastitis and foot lesions in dairy cows, respectively (Mostert et al. 2019; Mostert et al. 2018b). Based on Hospido and Sonesson (2005), reduction of the clinical mastitis rate from 25 to 18% and the subclinical mastitis rate from 33 to 15% in Spain leads to 2.5% reduction in total GHG emissions. In North America 8% GHG reduction potential was reported by applying animal health management methods (Ahmed et al. 2020).
Required skills (survey)	Low - medium
	Implementing a vaccination programme does not require specific skills. The low-medium estimate from the survey is somewhat optimistic. Overall, the estimate is that actually improving the animal health situation on a farm does require medium to high level skills (herd management). Some kind of monitoring has to be in place in order to be able to assess if there is a problem and that an improvement plan has to be made and evaluated (PDCA-cycle). Health problems like mastitis are multi-factorial problems and not that easily solved.
Cost-effectiveness (survey)	Profitable
	Although health planning and monitoring the health issues will have some costs and require extra work it will overall be profitable because it will prevent loss of production and also decreases animal mortality rate.
Farming system (survey)	Relevant for all systems
	Improving animal health is relevant for all production systems.
Stimuli to implement (survey)	Knowledge and training, subsidies, technical assistance.
Consequences of implementation	Performance of other mitigation options highly depends on functioning of improving animal health strategy. In a herd with healthy animals GHG mitigation potential will be high and this is almost a prerequisite for a successful implementation of many other mitigation options.

7. Reduction of calf mortality rate	
Category	Herd management
Practical description	Reduction of calf mortality rate by: - Feeding pregnant cows according to their feed needs - Feeding minerals to dry cows during the last eight weeks of pregnancy - Vaccination against scours - Implement hygiene plan - Feeding colostrum as fast as possible after birth
Overall estimate of GHG reduction potential (survey)	Low - medium
Scientific background	Heifer calves are important in dairy systems because the old dairy cows will be replaced by the young heifers. The healthy young heifer guarantees the health of future milking cows. An important indicator to evaluate calf health is the calf mortality rate. Continued health monitoring helps the farmer to improve the quality of calf rearing and calf health. There are different strategies to reduce the calf mortality rate as follows: **Feeding pregnant cows according to their feed needs**, reduces incidents of calving difficulties. Over-feeding in the final stages of pregnancy leads to laying down fat around the birth canal which increases the risk of calving difficulties and calf mortality rate. This will happen especially for the thin cows. Therefore, it is essential that the farmer knows the ideal body condition score (BCS), which is 2.5, and try to group the thin cows separately to offer them additional feed (McCarthy 2021). **Feeding minerals to dry cows during the last eight weeks of pregnancy**, leads to strong calves. Lack of mineral results in weak calves at birth, joint ill, poor fertility, etc. the most important minerals which can be used are copper, iodine and selenium. Because the higher dose of minerals may have some health issues, it is essential that the farmer identifies the right dose of minerals (McCarthy 2021). **Vaccination against scours,** is a costly approach to prevent scour problem. However, it is advised to apply. Especially for the farm with the underlying problem, this option is recommended. **Implement hygiene plan.** A health issue which is the main killer of young calves, is cryptosporidium. Since this problem does not have any vaccine, it is essential to implement hygiene measures during calving and the post-calving period. When calving down, the cow should be moved to a clean pen with a clean dry straw as bed. The navel of a newborn calf should be dipped in an iodine solution to prevent any infection. Pens should be cleaned and disinfected after each calving. **Colostrum** is one of the most important items which should be considered in livestock farms. Because the rate of absorption of vital antibodies in the colostrum reduces with each hour after birth, it is essential to feed the new calves with colostrum as fast as possible. The amount of colostrum intake is about 10% of the calf's body weight (McCarthy 2021).
Required skills (survey)	Medium
	Herd management skills. Mortality rate of calves can be reduced by considering different actions. Most of the problems which lead to death of calves can be prevented. With a periodic monitoring plan the farmer is informed about the conditions of calves and can take appropriate actions at the right time. However, for the farms with higher mortality rates farmers needs to obtain the required skill and knowledge to overcome the problems that arise.
Cost-effectiveness (survey)	Profitable
	Reduction of mortality rate increases the farm's income. For the beef farms in particular this is more critical because the calf is the main product.
Farming system (survey)	Relevant for all systems
	Reduction of calf mortality is relevant for all systems.
Stimuli to implement (survey)	Knowledge and training, subsidies, technical assistance
Consequences of implementation	-

8. Increasing longevity	
Category	Herd management
Practical description	Increasing longevity by: - Reducing the replacement rate
Overall estimate of GHG reduction potential (survey)	Medium
Scientific background	Changing the productive life span per animal is a management parameter which affects the milk production per herd and indirectly has an impact on total GHG emissions per product. A high amount of GHG emissions is produced during the growing period (before first calving) of each dairy cow. This amount of GHG emissions is allocated to the produced milk. By increasing the life span of dairy cows (keeping dairy cows for a longer period in herd), fewer calves have to be grown and subsequently the GHG emissions will reduce. Changing the productive life span in a herd is done by changing the replacement rate. This can be management intensive and it requires a proper health management. The productive life span after first calving on most farms ranges from 2 to 6 years. Results of Vellinga and De Vries (2018) research showed that increasing life span (or decreasing the replacement rate in herd) from 2 to 6 years reduces the GHG emissions between 14-19% per kg FPCM. In this strategy, productive dairy cows are kept in the herd for a longer period where they can produce milk. In addition to positive impacts on reduction of GHG emissions, this mitigation option reduces the dairy farm costs related to raising young animals.
Required skills (survey)	Medium
	This strategy can be applied by changing the herd replacement ratio, and can only be achieved if in the current situation a limited number of animals are culled (so also limited forced culling by e.g. disease). Older dairy cows need more care and they are more sensitive to health issues. So, herd management skills are required.
Cost-effectiveness (survey)	Profitable
	Because keeping cows for a longer period reduces the number of required young calves, the costs of raising young stock reduce. Therefore, this option is in principle profitable for a farmer, but it also depends on the overall strategy of the farm. If the farm has a plan to expand the herd, it may be necessary to grow additional young stock during the expansion period.
Farming system (survey)	Relevant for all systems
	Increasing the productive life span is relevant for all systems, most relevant for dairy.
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	At the macro level increasing the productive life span leads to lower production of culled cows and subsequently lower production of meat. The shortage of meat should be compensated from suckler-based beef production system. Because beef production from a suckler-based system has higher GHG emissions than the dairy-based beef system, increasing life span leads to higher GHG emissions of meat products at macro level. Therefore, this negative impact on the environment should be considered for further evaluations.

9. Reducing the share of non-productive animals (e.g. young stock, dry cows)	
Category	Herd management
Practical description	Keeping less young stock, work with short dry-off period.
Overall estimate of GHG reduction potential	Low - medium
Scientific background	The proportion of non-productive animals (dry cows, calves, heifers, and bulls) versus the milking cows has an effect on total herd profitability. By reducing the non-productivity, the productivity of the herd will increase and GHG emissions per product will reduce. Herd composition is the result of a number of management decisions, such as replacement ratio, rate of reproductive success, mortality rate (health problems), and long-term goals regarding herd size. An appropriate herd management plan helps to keep the GHG emissions as low as possible.
Required skills	Medium. Herd management skills. Farmer should be aware of all the consequences regarding the herd management decisions and udder health (for short dry off period).
Cost-effectiveness	Profitable. But also risks for additional costs if it turns out that the number of young stocks was too low and udder health problems occur.
Farming system	Relevant for all dairy systems.
Consequences of implementation	-

4.4 Feed production, grassland management and land use

10. Improving grazing management (e.g. subdividing farms to paddocks, sward analysis, measuring grass growth and planning grazing strategy for grazing season)	
Category	Feed production, grassland management and land use
Practical description	Improving grazing management by: - subdividing farms to paddocks - sward analysis - measuring grass growth - planning grazing strategy for grazing season - preventing grazing in wet condition
Overall estimate of GHG reduction potential	Low - medium
Scientific background	Grazing management consists of various strategies which help a pasture to keep the highest productivity level and low GHG emissions. Intensive rotational grazing systems have been introduced and widely recommended to increase the forage production and to reduce nitrous oxide emissions (Grossi et al. 2019). DeRamus et al. (2003) demonstrated that intensive grazing management offers a more efficient use of grassland and leads to higher milk and meat production which results in a 22% reduction of CH_4 annual emissions from beef cattle. However, Pinares-Patiño et al. (2007) found that the stocking rate of heifers on pasture does not have impact on CH_4 emissions of beef production. Many researches have confirmed that rotational grazing systems provide higher levels of yield compared to the continuous grazing (Chen and Shi 2018). In these systems, farms or pastures are divided into smaller fields which are called paddocks. Subdividing farms into paddocks and rotating animals in the paddock helps the farmer to have more control on grazing duration, stocking density and nitrogen excreta distribution (Grossi et al. 2019). Besides impacting grazing management strategies on grass yield, it also affects manure management on pastures. Therefore, GHG emissions of manure deposition during grazing decreases. A more balanced distribution of animal urine in the pasture may reduce nitrogen fertiliser application rate. Also keeping animals off the paddocks during wet weather will reduce soil compaction (Grossi et al. 2019).
Required skills	High skills required. To achieve the highest productivity in a specialised farm requires a good plan to apply both grazing and harvesting grass (for production of grass silage). Dividing pastures into different paddocks also needs a good planning which is related to the level of farmers' skills. Knowing the nutrient demand of a pasture and utilising manure and fertiliser based on pasture need is important.
Cost-effectiveness	Applying grazing management results in higher grass intake by animals which is profitable for the farmer. Moreover, it helps to increase the grass yield.
Farming system	Improving grazing management is most relevant for grass-based systems.
Consequences of implementation	-

11. Increasing carbon sequestration (e.g. increasing grassland areas)	
Category	Feed production, grassland management and land use
Practical description	Increasing carbon sequestration by: - Increasing share of permanent grassland - Grazing managements (e.g. avoiding overgrazing, sowing improved grass varieties) - Restoration of organic soils/peatlands - Reduction of land use change (e.g. deforestation, change of grasslands to croplands) - Reforestation - Grassland renewal without ploughing
Overall estimate of GHG reduction potential	Low - medium
Scientific background	Carbon sequestration can be considered as an important mitigating option in the grassland soil. Carbon sequestration is the process in which the carbon from atmosphere is converted via photosynthesis to stable biomass, stored in the soil or (long term) above ground biomass. Therefore, it can be considered as a GHG mitigation option for the livestock sector. Based on the study conducted by Salvador et al. (2017), grasslands can have a high impact on reduction of GHG emissions by carbon sequestration and the average reduction of 28% GHG emissions per kg FPCM was estimated for dairy farms. This high impact can only be realised with young pastures on previous arable land and should be considered as a theoretical maximum level. In

11. Increasing carbon sequestration (e.g. increasing grassland areas)	
	temperate climates the maximum sequestration rate is calculated at about 3.5 to 4.5 tonnes of CO_2 per hectare per year. This very high figure cannot be realised in permanent grassland areas. Older pastures have reached an organic matter equilibrium and sequestration levels off. The main goal of grassland management is to prevent loss of the high equilibrium levels. Results of Lesschen et al. (2020b) study showed that carbon sequestration reduced the carbon footprint of milk by 2% in the case of permanent pastures with a milk production of about 15,000 kg per hectare. This is a sequestration rate of about 300 kg CO_2-eq per hectare per year. To increase the carbon sequestration or to maintain current high levels of carbon stocks, land use changes (e.g. deforestation, change of grasslands to croplands) and ploughing up long-term grasslands should be avoided. In addition, it should be considered that carbon sequestration requires additional nitrogen, due to the C to N ratio of 10-15 to 1, which means that for every 1,000 kg CO_2 sequestered, 18 to 27 kg N surplus is required. Although carbon sequestration has a certain potential, especially in degraded soils, expectations have to be managed to moderate levels. Afforestation and deforestation are among the main strategies to increase the capacity of carbon removal out of the air. Although this strategy can be considered as an option for a dairy production system, it is recommended to be applied on waste lands not on pastures. Peatlands are one of the biggest sources of world's soil carbon. They are wetlands with a thick layer of organic soil. In many countries (e.g. Netherlands) peatlands are drained and used for agriculture. In this situation they become a net source of GHG emissions. Therefore, it is important to prevent degradation of peat soils. The primary method of restoration is re-wetting peat soils. This will result in less loss of soil carbon from peat soils or – in case of very high water level - storing extra carbon in the soil.
Required skills	Medium.
Cost-effectiveness	Depends on the exact implementation of the option.
Farming system	Increasing carbon sequestration is relevant for all systems however, since pasture is the main source of carbon sequestration it is more relevant for the grass-based system.
Consequences of implementation	Increasing carbon sequestration is directly connected with grassland management. Replacing grass by maize in animal rations will lead to lower enteric fermentation; however if this ration adjustment is the result of replacing grassland by maize land, this ploughing of grassland will release carbon from the soil that will be partly emitted as CO_2. Therefore, precise evaluation on farm level is essential to consider the negative impact of any change in an animal ration which may lead to a reduction of carbon sequestration.

12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	
Category	Feed production, grassland management and land use
Practical description	Reduction of synthetic nitrogen fertiliser application by: - Planting clover - Application of manure - Application of composting
Overall estimate of GHG reduction potential (survey)	Medium
Scientific background	In most of developing countries and also in China and India, a high level of chemical fertiliser application in crop production is seen which leads to a great amount of nitrous oxide entering the atmosphere by evaporation. To stop this situation, it is essential that all countries correct the overapplication of nitrogen fertilisers to the standard levels. It is asserted that this strategy will lead to approximately 24% reduction in global GHG emissions (Ahmed et al. 2020). An optimal use of animal manure (right time, right amount, right method of application) can be very effective and save the use of chemical fertilisers. The use of catch crops in annual crops can save nitrogen to be leached, which can be utilised in the year after and then save chemical fertiliser. Moreover, catch crops add organic matter. Another effective strategy is the introduction of clover in pastures. Fuchs et al. (2018) studied the impact of this strategy and found a 33% reduction on kg N_2O-N per kg grass dry matter by increasing the clover proportion in grassland and reducing fertilisation. Organic manures such as slurry, solid manure and litter, and compost are natural sources of nitrogen to maintain the soil fertility and support plant growth.
Required skills (survey)	Medium - high

12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	
	A more efficient application of manure, in or close to the growing season and with application methods with low N-losses, requires a nutrient management plan approach (including plan–do–check–act cycle). Introduction of legumes as a source for nitrogen also requires a nutrient management plan approach in order to take the N from clover into account and to be able to save on synthetic N fertiliser. Clover-grass mixtures are more complicated to manage: it is difficult to keep the clover share at the right level.
Cost-effectiveness (survey)	Profitable
	This mitigation option is considered to be profitable for the farm according to the survey results. But a lot depends on the starting situation. If it is about doing better within the current system, then it will profitable. To be able to apply manure at the right place and time, there has to be enough manure storage capacity available on the farm and the right equipment for application. If this requires additional investments this will not be profitable. In many countries an x month storage capacity is mandatory. Using clover should lead to saving fertiliser costs, but mixed grass-clover systems tend to have a somewhat lower dry matter production resulting usually in extra net costs. This depends on the current level of nitrogen application. So overall the score for profitability will be in the range of break-even – extra net costs.
Farming system (survey)	Relevant for all systems
	Most relevant for land-based farms that grow a relevant share of their own need for feed. It is relevant for farming systems that apply their own manure on their own land. Replacing fertiliser by legumes (clover) is most relevant for grass-based systems.
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	It helps to close the nutrient cycle which is a step toward circular agriculture.

13. Improving forage quality (e.g. earlier harvest, improved varieties)	
Category	Feed production, grassland management and land use
Practical description	Improving forage quality by: - Early harvesting (higher digestibility) - Forages with higher nutrients - Improved variety of forage with higher nutrient
Overall estimate of GHG reduction potential (survey)	Medium - high
Scientific background	A good forage quality has a positive impact on the reduction of CH_4 emission per kg of product (meat or milk). When combined with a higher amount of dry matter intake, the reduction of CH_4 per kg of product due to a higher forage quality is even more significant. Low quality feeds (with low digestibility) affect the nutrient uptake and lead to low animal productivity. The feeds with lower digestibility result in higher enteric fermentation. The quality of feeds can be evaluated based on content and also digestibility of organic matter and crude protein. As an example, grass silage because of lower starch concentration and higher fibre digestion in the rumen significantly has higher enteric fermentation compared with maize silage (Hellwing et al. 2014). Comparing the effects of forage source (red clover and corn silage) on CH_4 emissions of manure from dairy cows showed that adding red clover results in 54% reduction in CH_4 compared to corn silage (Hassanat and Benchaar 2019). Generally, there are different techniques for improving forage quality. The first option is selecting forages with higher quality. Forages such as maize silage, coarse straws from millet and sorghum have better feeding quality than straws from rice, wheat and barley. It should be noted that selection of forage based on their quality can be considered for specialised farm where the forage crop is cultivated as primary fodder and farm use residue is out of scope. The forage species in grasslands also have an impact on quality of produced forage. The forage variety has impact on nutrient content of the forage. For example, growing highly digestible brown midrib (BMR) maize compared to the standard maize has higher digestibility (lower lignin and higher carbohydrates). The maturity of a forage or crop has also impact on the amount of carbohydrates (sugars) of the crop. Harvesting grass and maize silage at earlier stages increases the level of digestibility. A research showed that by early harvesting, methane emission may be reduced up to 5% per kg fat protein corrected milk (FPCM) (Knapp et al. 2014). In another study it was shown that feeding grass silage at an early growth stage can reduce the total enteric methane production

13. Improving forage quality (e.g. earlier harvest, improved varieties)	
	of lactating dairy cows around 11% where this reduction is equal to 22% per kg FPCM (Warner et al., 2017). Although early harvest results in lower enteric fermentation, the lower yield should also be considered. Unpublished research, shows that the lower enteric fermentation can be counteracted by the higher emission intensity of feed production. Some other activities to increase the quality of silages forages are fast wilting and ensiling, with good quality plastics as a cover. Impact of forage quality on reduction of enteric fermentation was the subject of some studies. In a study conducted by Keady et al. (2012) the effects of silage quality on animal performance in various production systems was studied. The results showed that 10 g/kg increase in digestible organic matter concentration of grass silage increases daily milk yield of lactating dairy cows by 0.37 kg and daily carcass gain of beef cattle by 28 g/head. Therefore, feeding animals with the high-quality silages increases the production efficiency and indirectly it leads to lower CH_4 per product. Generally, the lower CH_4 production has been reported by replacing grass by maize silages. The result of previous studies showed a 6% reduction in CH_4 per unit of milk when a ration with 25:75 grass silage:maize silage is replaced by 75:25 maize silage:grass silage (Hristov et al. 2013a). Moreover, the high maize silage diet increases the milk production around 4% (Hristov et al. 2013a). In a grass silage-based beef production system, adding maize silage to the ration increases the performance of finishing beef cattle (Hristov et al. 2013a). Besides the CH_4 reduction potential of increasing the share of maize silage in the ration, the potential increase in total carbon footprint due to land use and higher fertiliser consumption associated with the production of maize silage compared to permanent pasture should also be considered (Van Middelaar et al. 2013; Vellinga and Hoving, 2011).
Required skills (survey)	Medium - high
	First of all, farmer has to be aware of his current situation and the options for improvement. Selecting and cultivating forage varieties with the higher quality and paying attention to harvest time and local weather patterns will ask for extra attention.
Cost-effectiveness (survey)	Profitable
	Improving the forage quality affects the nutrient uptake and increases animal productivity. Therefore, it is profitable for farmer.
Farming system (survey)	Relevant for all systems
	Improving forage quality is relevant for all systems. However, it is most relevant for a roughage-based system.
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	Improving the forage quality increases feed efficiency and production therefore it is connected with the animal efficiency and productivity.

14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)	
Category	Feed production, grassland management and land use
Practical description	Improving forage digestibility by: - Chopping - Grinding of straw - Steam treatment
Overall estimate of GHG reduction potential	Low
Scientific background	According to the previous studies, forage mechanical processing operations including chopping, grinding the straw, and steam treatment can improve the digestibility of feed which leads to less enteric fermentation (Gerber et al. 2013a). It was found that grinding of straw increases consumption resulting in 30% higher digestible energy intakes (Fluharty 2020). Similarly, chopping hay allows the cows to get more energy (around 25-30%). Steam flaking is the widely applied method in the US, although the high operation costs limit the mitigation potential in small-scale farms (Ahmed et al. 2020). The GHG mitigation potential has been reported to be less than 2% per kg FPCM (Knapp et al. 2014). Results of another study showed that applying feed processing decreases the methane production by around 15% per animal (Ahmed et al. 2020).
Required skills	The required skill is mostly related to the use of required machineries for forage processing. Moreover, in some cases such as steam treatment, farmers require very good skills regarding forage processing practices and the right conditions in which the highest forage quality is obtained.

14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)	
Cost-effectiveness	Break-even. This depends on which investment level (in machinery) is necessary. Forage processing results in higher consumption of forages by cow. Therefore, the additional costs due to forage processing will be covered with less purchase of feed supplements.
Farming system	Relevant for all systems
Consequences of implementation	-

15. Planting trees, hedges, agroforestry	
Category	Feed production, grassland management and land use
Practical description	- Planting trees, hedges - Agroforestry systems on pastures
Overall estimate of GHG reduction potential	Low – high. Depending on the area that will be planted, it might have high GHG reduction potential.
Scientific background	Agroforestry and related practices are currently recognised as a GHG mitigation option by sustainable land use measures, avoiding GHG losses and improving carbon sink. This is achieved by planting trees and woody perennials which can both have deep roots placed in deeper soil layers than crops and herbaceous vegetation. Thus, new forests are able to prevent nitrogen losses which will lead to a better nitrogen recycling and management. Improving nitrogen use efficiency by agricultural systems would lead to increased biomass production per unit land. The biomass can be a source of animal feed. On the other hand, the combination of horticultural farming with livestock farming (mixed cop-livestock systems) will bring conditions for circular agriculture by reducing fertiliser needs while reducing fodder needs as useless tree parts can be used as feed. Planting hedges and shrubs can also help as a mitigation tool for livestock systems by avoiding less dependency on external feed transport. In the surroundings of livestock farms, planting trees and the presence of forests can help to moderate temperature changes leading to lower ammonia and nitrous oxide volatilisation (Mosquera-Losada et al. 2016). Benefits from improving agroforestry have been emphasised in the Koronivia Joint Work on Agriculture (KJWA) of the UNFCCC that highlights enhancing soil carbon storages, soil health and biodiversity by supporting a sustainable livestock system (Rosenstock et al. 2019). Forests can also consume more methane than other crops and plants. Since CH_4 emissions are a major source of GHG emissions from livestock systems, agroforestry systems on pastures can help to alleviate this negative impact by oxidation of CH_4 and its uptake in forested areas and hence offsetting the emissions from dairy farms on pasture (related to enteric methane production) (Baah-Acheamfour et al. 2017). Based on studies in the prairies, agroforestry systems types such as hedgerow, shelterbelt, and silvopastures had greater CH_4 uptake rates than adjacent cropped fields (Amadi et al. 2016; Baah-Acheamfour et al. 2016).
Required skills	Planting trees itself does not require extra skills. Agroforestry is a different approach and will require a new set of skills.
Cost-effectiveness	It is not clear whether this mitigation option is costly or profitable for farmers.
Farming system	It is relevant for all systems, but mostly for systems that grow their own feed, especially grass-based systems
Consequences of implementation	Using more manure, reduced nitrogen fertiliser and improved water sources are examples of positive effects of agroforestry. An example of agroforestry system types in Canada is 'Silvopasture' i.e. growing trees irregularly on pastures in a systematic pattern. This creates wildlife habitat, provides shelter for livestock grazing on pasture and provides biodiversity.

16. Application of protected nitrogen fertiliser (e.g. urea treated with a urease inhibitor)	
Category	Feed production, grassland management and land use
Practical description	Application of protected nitrogen fertiliser by: - Urea treated with a urease inhibitor
Overall estimate of GHG reduction potential	Low
Scientific background	These compounds block the urease activity and hence prevent ammonium formation and protect applied fertilisers against ammonia volatilisation. This occurs through buffering soil against pH increase and hence avoiding rapid hydrolysis of urea to ammonia. Such inhibitors provide potential to improve sustainability in grass-fed cattle systems. Use of these products, if managed well, would lead to reductions in N_2O and NH_3 emissions from agriculture and therefore lead to environmentally viable dairy and beef practices. As a result, more N sources will remain in the soil and less need for synthetic fertilisers is created. Previous research suggests that the risk of milk contamination with inhibitor materials is low, however more research is required to ensure no negative impact on human health. Nitrification inhibitors can enter the food chain through grazing cattle (Byrne et al. 2020). In a study conducted by Krol et al. (2020), it was shown that urease inhibitors reduced N_2O significantly and to a level of unfertilised control. Addition of this material reduced NH_3 by nearly 70%.
Required skills	This mitigation option does not require a high level of skills. What is important regarding application of protected nitrogen fertiliser is the permissible amount of nitrogen fertilisers treated with inhibitors which can be applied on arable and grasslands which does not have negative impacts on animals and humans.
Cost-effectiveness	Break even. Costs of protected nitrogen fertiliser are higher, but N efficiency is also higher.
Farming system	Application of protected nitrogen fertiliser is relevant for mixed farming system where the fertiliser is used on arable and grasslands.
Consequences of implementation	Based on literature review this mitigation option leads to lower nitrogen fertiliser use however, the risk of milk contamination with inhibitor materials is still not clear. Therefore, extensive use of protected nitrogen fertiliser needs further evaluations.

4.5 Manure management

17. Application of primary and/or secondary separation of manure	
Category	Manure management
Practical description	Application of primary and/or secondary separation of manure by: - Sedimentation - Mechanical separation (centrifuge systems, belt press, etc.) - Application of filters - Evaporation - Coagulation flocculation
Overall estimate of GHG reduction potential	Low - medium
Scientific background	Manure is a source of both CH_4 and N_2O. Under anaerobic conditions bacteria decompose the organic matter and produce methane and nitrous oxide. Separation of urine and faeces and limiting the air exchange with separate storage for both components is the basis of the low-emission floor types. The theme of 'separation at the source' has received attention in the research world for years. Primary manure separation (keeping faeces and urine separated as much as possible) in the barns has potential advantages: the ammonia emission is greatly limited and the individual manure products can be better processed or used more specifically, more biogas can be extracted from fresh manure, there is less methane emission from the barn (no more deep pit manure storage). In principal, the physical separation of faeces and urine in the housing system reduces the hydrolysis of urea (cow urine contains nitrogen in the form of urea), resulting in reduced emissions from both housing and further manure spreading (Moller et al. 2007). The potential of the separation of dung and urine collection and storage have been discussed by Lesschen et al. (2020a), leading to significant emission reductions of 75% for methane and ammonia. For secondary separation, different techniques such sedimentation, mechanical separation (centrifuge systems, belt press, etc.), evaporation, coagulation flocculation and filters are used. Except coagulation flocculation, all the separation methods are well known. Coagulation flocculation is a new technique for solid-liquid separation. In this approach chemicals are being used to aggregate suspended solids (coagulation) to form settleable particles and to convert particles into large, rapidly settling flocs (flocculation).

17. Application of primary and/or secondary separation of manure	
	Based on the previous research, more than 30% of emissions decreases by applying solid-liquid separation compared to the untreated manure (Montes et al. 2013). The liquid part can easily be spread with band spreading techniques. A reduction of ammonia emissions by slurry separation of up to 63% is possible for the liquid. On the other hand, the liquid part of the separated slurry has a narrow C/N-ratio resulting in lowering the potential for N immobilisation in the soil; thus, N is more available for plant uptake. In the Netherlands, a toilet especially for cows is being developed to separate dung and urine. Such a toilet would prevent urine coming on the floor and tackle the problem of ammonia emissions in dairy farming. Research at Wageningen Livestock Research (WUR) has shown that if 80% of the urine discharges per day could be collected and therefore do not end up on the barn floor, the expected emission reduction in a conventional free stall barn with slatted floor is approximately 56% (Verdoes and Bokma, 2017).
Required skills	Medium. Overall, primary and secondary manure separation might require additional skills regarding the use of manure separation facilities or machinery and constructions.
Cost-effectiveness	Extra net costs. Application of primary and/or secondary separation of manure is costly for the farmers. This mitigation option requires investments in barns, manure storage or machinery. In a case where the solid part of manure is used for further processing there could be some added value for manure which can have some profit for farm.
Farming system	Confined systems. Primary and/or secondary separation of manure is relevant for the systems for which manure is collected and stored. Therefore, for the grass-based system this mitigation option is not usable.
Consequences of implementation	Systems are in development and being tested for impact on methane emissions. The type of manure application methods on land is under influence of manure treatments in barn. After primary and/or secondary separation of manure it is essential to apply machineries for application of liquid and solid manure on lands.

18. Reduction of manure storage time in the barn	
Category	Manure management
Practical description	Reduction of manure storage time in the barn by: - Adapting barn system to remove manure quickly and to close manure storage to prevent methane emission.
Overall estimate of GHG reduction potential	Low
Scientific background	There is always a trade-off between the optimal moment of slurry application on pasture and cropland and storage duration. Farmers are increasingly recommended to store the manure for extended periods to recycle manure nutrients to crops in spring. Unfortunately, this increases the potential for CH_4 emissions during storage. Therefore, in-barn and outside storages facilities should both be traced separately and with high spatial and temporal resolution while measures can alleviate the unavoidable emissions. Methane emissions from slurry pits can be significant due to continuous inputs of fresh excreta and often higher temperatures than in outside storages, but these emissions are difficult to be quantified because of conjunction with enteric emissions from the housed animals, which may vary with time of the day and stage of a production cycle. Therefore, reducing the storage time by frequent removal of manure helps to reduce the GHG emissions by around 50% (Mohankumar Sajeev et al. 2018) and in some cases reported as 66% (Hilhorst et al. 2002). Designing stables with underfloor channel (combined with scraper) helps to remove the manure easier. In addition, measurements showed a reduction of more than 50% of methane emissions for well covered outdoor storages (Hilhorst et al. 2002). If manure is stored outside the barn (due to the rapid removal), the methane emissions will decrease by about 25%. The costs for this method of manure removal will of course increase, but savings are also possible at the floors and manure cellars. Although application of manure on crop farms reduces storage time, it has to be matched with the growth potential of crops. In temperate regions where crop growth in winter periods is very low, manure application in winter will lead to high losses of N and contamination of ground and surface waters.
Required skills	Reduction of manure storage time in barn does not require additional skills.
Cost-effectiveness	Extra net costs: investment is required to adapt barn system to be able to remove manure quickly and/or to make the manure storage facility gastight so methane cannot emit.
Farming system	Reduction of manure storage time in barn is more relevant for confined systems.
Consequences of implementation	This mitigation option is in development and tested for impact on methane emission. Capturing methane is one step, but there is some discussion about whether this captured methane might be released during the application of manure.

19. Applying manure treatment (lowering manure pH, manure aeration, manure cooling)	
Category	Manure management
Practical description	Applying manure treatment by: - Lowering manure pH by acidification - Manure aeration - Reduction of storage temperature
Overall estimate of GHG reduction potential	Low
Scientific background	There are different manure treatment approaches which can be applied to reduce the CH_4 emissions as follows: **Lowering manure pH by acidification:** Little is known about the impact of acidification of manure in manure pits or storages. Acidification is done to bind nitrogen and hence prevent ammonia emission. Slurry, however, is a strong buffer and relatively large amounts of acids are required. Moreover, when acidifying, CO_2 gas in manure flows out. Acidifying the slurry during storage, reduces both ammonia and methane formation. Environmental issues to be considered with this technology are changes in the odour profile, and field application of sulfur in excess of crop needs, because 5 to 6 kg per tonne of H_2SO_4 is needed for acidification of cattle slurry (Groenestein et al. 2011). **Manure aeration:** In dairy farms equipped with a slatted floor above a deep manure pit, the remained manure (after removal of manure) forms a basis for methane formation. In this situation, methane and ammonia are released. Frequent mixing of manure can influence the formation of these gases. Low rate slurry aeration causes a reduction in chemical reaction and prevent crust formation in the slurry pit. This method is now tested in the Netherlands and a study carried out by van Dooren et al. (2019a) showed that daily mixing of slurry either with air pumped into the slurry or with an electrical mixer did not result in reduction of ammonia emission. However, Calvet et al. (2017) explained a reduction in the emission of CH_4 by 40%. **Reduction of storage temperature:** Methane production increases by a higher storage temperature. In lower temperature, methanogenic activity stops. Currently several researches are ongoing to observe the effect of cooling manure in the barn or in outdoor storages during summer. A reduction of 30-50% of emissions was reported by a reduction of storage temperature (Borhan et al. 2012). However, the energy consumption should be considered when this strategy is being applied.
Required skills	Applying manure treatment needs a medium level of skills. Manure aeration and reduction of manure storage temperature require additional facilities. Working with the new facilities might need extra skills. Moreover, farmers need to know the right amount of applying acid for acidification purposes. This also requires additional skills.
Cost-effectiveness	Extra net costs. All the manure treatment approaches will have additional costs for the farm. For manure acidification, the manure aeration and reduction of storage temperature additional facilities and constructions are required which will be costly.
Farming system	This mitigation option is not relevant for the grass-based system where manure is not stored in the barn.
Consequences of implementation	-

20. Application of bedding materials (e.g. sand)	
Category	Manure management
Practical description	Application of bedding materials such as: - sand - straw - dried manure solids - wood chips - saw dust
Overall estimate of GHG reduction potential	Low
Scientific background	There are several types of materials used as bedding i.e. straw, dried manure solids, wood shavings, sawdust, sand, mattress and etc. Each bedding material has its own pros and cons. Sand is used as bedding material and there are some advantages for use of it. Clear benefit of sand bedding compared to the stalls without bedding material is the reduction in the number of animals with swollen hocks, hair off hocks, and knee injuries. Also, it has shown its effectiveness in reduction of prevalence of lameness in cows. Sand prevents pathogen growth.

20. Application of bedding materials (e.g. sand)	
	Lower incidence of clinical mastitis which is caused by environmental organisms such as E. coli. and environmental streptococci can be another positive consequence of using sand as bedding. Organic material in bedding increases the opportunity for bacterial growth and because no organic material is used for sand bedding, less incidence of clinical mastitis would be logical. In terms of environmental impact, the ammonia emission (per square metre) of sand bedding has been shown to be lower than that of the slatted floor in a cubicle barn. Besides the advantages, it is difficult to apply sand with the slatted floors. Regular maintenance of sand stalls is needed because after cows lying in the sand the bedding may have become concave which leads to reduction of lying time. Disposal and separation of sand and manure can be a challenge. Separation needs additional facilities and equipment which are costly. In beef cattle farming straw can be utilised as bedding. In this method, the ammonia emissions can be reduced by using organic substances because the pH is lower, bacteria uptake is higher and higher amount of ammonia can be absorbed. The risk of forming nitrous oxide in litter-based systems should be considered. With bedded pack barns nitrous oxide emissions were measured to be 3 to 26 times higher than the reference system (a concrete slatted floor with slurry storage in a pit underneath the floor) (van Dooren et al. 2016). The research by WUR showed that wood chips for composting is better than composted manure in terms of animal welfare and emissions from the barn. However, emission of N_2O from bedded pack barns was higher compared to free stall barns (Van Dooren et al. 2019b). Ammonia emission was reduced by 31% but methane emission increased by 34% and emissions of nitrous oxide were 14 times higher than a reference slurry-based housing system (van Dooren et al. 2019a; Van Dooren et al. 2019b).
Required skills	No extra skills. Farmer needs to know how frequently the bedding materials need to be replaced. For some bedding materials such as sand additional machinery (for separating manure and sand) would be needed which might need additional skills.
Cost-effectiveness	Break-even. The extra costs should be compensated by the positive impact an animal health and productivity.
Farming system	Application of bedding material is relevant for confined systems
Consequences of implementation	Application of different bedding material can have effects on ammonia production. For some of the bedding material as it has been discussed that ammonia emissions is reduced but the amount of N_2O emissions increased.

21. Complete removal of liquid dairy manure from storage tank (inoculum removal)	
Category	Manure management
Practical description	Complete removal of liquid dairy manure in the barn (e.g. by flushing)
Overall estimate of GHG reduction potential	Low
Scientific background	Inoculum removal significantly reduces CH_4 emissions. In a study overwintered liquid dairy manure storage tanks were examined for the impact of inoculum removal in the spring and summer. Overall, there may be greater benefit from removing inoculum in the spring, but emissions were still reduced with fall inoculum removal. The timing of inoculum removal may affect the efficiency of this CH_4 mitigation strategy. However, this method may be impractical for larger manure storage tanks.
Required skills	No extra skills.
Cost-effectiveness	Adding extra costs.
Farming system	It is more relevant for housed systems.
Consequences of implementation	Is in research, impact on methane emission has not yet been confirmed. Frequent removal with water will increase water use on the farm.

22. Oxidation of captured methane by flaring	
Category	Manure management
Practical description	Oxidation of captured methane by: - Flaring or filtration
Overall estimate of GHG reduction potential	Low
Scientific background	While manure is stored, gas is formed which approximately for 60% consists of methane. Although the livestock sector is responsible for reducing the methane formation, methane production cannot be stopped. Therefore, methane flaring can convert methane to CO_2. While a certain amount of CO_2 is released into the atmosphere with flaring, based on the current estimate of the GWP CO_2 is 34 times less harmful than methane itself. In this approach the methane produced in a sealed storage tank is captured and burnt. Another method is to lead the gas from the storage through a filter bed where methane is oxidated.
Required skills	No additional skill is required.
Cost-effectiveness	Extra net costs.
Farming system	For confined systems where it is possible to capture produced methane.
Consequences of implementation	It can only work if manure is stored in a gastight facility. The consequence of this mitigation option would be increasing the CO_2 emissions which - compared to the methane - have lower global warming potential.

23. Anaerobic digestion	
Category	Manure management
Practical description	Capturing methane and using as energy source by: - Anaerobic digestion
Overall estimate of GHG reduction potential	Medium - high
Scientific background	Anaerobic digestion of animal manure is promoted as an emission mitigation measure since it captures most of the methane and produces renewable energy. While the biogas digestate can still be used as a an organic fertiliser for nutrient cycling, it should be considered that application of digestate in a similar way as manure may not work and should be treated (infiltrate) and be applied with low emission techniques near the soil surface, e.g. band application or injection. The awareness of the trade-offs and limitations in terms of the biogas feedstocks and the consequences on the nutrient cycling (especially nitrogen recycling capacity) should be taken into account when making decisions related to anaerobic digestion (Hoang et al. 2020). To address this, a recent study in the Netherlands showed that net present value (a feasibility indicator) of biogas plants treating cow manure and sugar beet pulp was negative to an extent that the subsidy was not sufficient to make it feasible while switching to anaerobic digestion with cattle manure combined with straw increased the cost effectiveness (Achinas et al. 2019). Overall, high investment and operating costs limit feasibility of anaerobic digestion and therefore subsidy plays a great role in the profitability of this technique (Gebrezgabher et al. 2012). Depending on the size of the farm and also the level of technology, large- and small-scale digesters can be used. According to research the reduction potential of 50% to 85% has been reported (Frank et al. 2018).
Required skills	Managing a digester requires high level skills.
Cost-effectiveness	Anaerobic digestion requires high investments. Profitability depends on the price of electricity and subsidies.
Farming system	Large-scale confined farming systems. In some countries like Denmark farmers jointly invest in a digester.
Consequences of implementation	This mitigation option has positive consequences such as producing processed manure, extracting the available methane and using it as renewable energy.

24. Use different manure application methods on land (e.g. dilution and injection)	
Category	Manure management
Practical description	Use different manure application methods on land by: - Manure dilution - Manure injection
Overall estimate of GHG reduction potential (survey)	Low - medium
Scientific background	Regarding mitigation strategies relating to the manure application on land, factors such as manure composition, application method and soil conditions define the potential for GHG emissions (Petersen, 2018). Manure is a source of valuable mineral elements which can be lost as emissions during and after land application. Typically, solid manure is applied to the soil surface. Liquid manure or slurry can be applied to the soil with different methods including; i) surface spreading, ii) surface spreading + tillage, where the applied manure is tilled into upper layer of soil, ii) shallow injection, and iv) deep injection to depth more than 10 cm. Although these approaches can be applied before planting (or after harvest season) and during growing period (just between rows), tillage is not an option in perennial crops due to root damage. Surface spreading is a common practice of manure application but results in the loss of N and P components (e.g. loss of ammonia due to volatilisation and phosphorus runoff) and can cause odour issues. Placing manure below soil surface reduces these environmental issues. Preventing CH_4 and N_2O emissions from manure applied on the land is of paramount importance and most practices focus on preventing anaerobic conditions or reducing the degradable C flux to the soil at the placement site (Gerber et al. 2013a). Moreover, proper manure application on soil results in NH_3 reduction (indirectly effect GHG emissions). The amount of CH_4 emissions after manure application is low because the high fraction of CH_4 is released from enteric fermentation and manure storage. Research reports show a wide range of results on CH_4 and N_2O emissions. Many parameters including application technique, soil type and management, soil moisture and climate can impact emissions. Besides, the conditions in pre-application manure treatments such manure separation, anaerobic digestion and the storage conditions (temperature and duration) can influence the organic matter content and nutrients and hence also the emissions after field application. For instance, separation of manure solids and anaerobic degradation can mitigate CH_4 and N_2O emissions on soil after manure injection, which may otherwise be greater than that from surface-applied manure. Injection of manure slurries into the soil can create the anaerobic conditions and together with the high degradable C pool may increase the CH_4 and N_2O emissions compared to the surfaces applied methods (Amon et al. 2006; Clemens et al. 2006; Flessa and Beese 2000; Külling et al. 2003). Reducing the degradable C flux through dilution, manure separation and anaerobic degradation pre-treatments are options to reduce the risk of anaerobic condition in soil after manure injection (Gerber et al. 2013a). Manure injection reduces NH_3 volatilisation and if it is applied during the growing period of plant it will be consumed by plant. Most of the produced N_2O from manure is caused by the manure that has been applied to the soil. Controlling the amount of nitrogen available for nitrification and denitrification in soil as well as the availability of degradable carbon and soil oxidation reduction-potential are options to reduce N_2O emissions that can be achieved through the manure application method. In the first few weeks after application, manure injection often increases N_2O emission compared with surface applied manure. Dilution, solid separation and anaerobic digestion pre-treatments of manure before injection reduce the availability of degradable carbon and as a result, tend to decrease N_2O emission. Dilution can also affect the GHG emissions indirectly. The amount of ammonia emissions increases by increasing dry matter content of liquid manure (Sommer and Olesen 1991). A field experiment showed diluting a swine slurry from 4.4 to 2.2% of DM reduced the NH_3 loss by 41% (Mkhabela et al. 2009). Since N_2O production is affected by N availability, soil temperature, pH and soil aeration, timing of manure application (e.g. to match crop nutrient demands, avoiding application before rain) and maintaining soil pH above 6.5 (Mkhabela et al. 2006) can affect the N_2O emissions of soil. Generally, application of manure during cold season is discouraged because of water pollution (during the snowmelt). It is recommended to store the manure during winter to apply it during the spring. Injection of manure can greatly reduce odour issues compared to spreading of manure on land. Liquid manure injection in a proper time (prior to seeding or during the growing season) reduces N volatilisation losses and provides the plant the required N. Therefore, indirectly it reduces the consumption of N fertiliser on arable lands. Injection also reduces the risk of P runoff and loss of particulate P due to less tillage operation. Therefore, indirectly prevents GHG

24. Use different manure application methods on land (e.g. dilution and injection)	
	emissions associated with the production of synthetic fertilisers. Since for manure injection no tillage operation is needed, it allows farmers to apply manure to the growing crops such as grass, alfalfa, etc. Injection preserves more soil organic matter compare to the tillage-based manure application methods.
Required skills (survey)	Low - medium
	Using different manure application methods on land requires the skill of knowing the dilution and injection methods and how to apply it with the machineries required for these techniques. Overall, it is more about availability of the optimal technology than about required skills.
Cost-effectiveness (survey)	Extra net costs
	Investment in machinery, possibly also in storage of water (for dilution). Dilution requires extra capacity for application of the manure on the land and will also lead to extra costs.
Farming system (survey)	Relevant for all systems
	The option is most relevant for farming systems that store most of their manure and also apply it on their own land and is less relevant for systems that don't store a relevant share of the produced manure (e.g. grazing systems).
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	Dilution or injection is also of great relevance for the reduction of ammonia-emission.

25. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)	
Category	Manure management
Practical description	Optimise manure application timing by: - Matching the amount of manure applied to the crop nutrient demands - Avoiding application during cold seasons (autumn and winter) - Avoiding application on wet soils
Overall estimate of GHG reduction potential (survey)	Low
Scientific background	Manure is a source of nutrients and application of manure instead of synthetic fertilisers can reduce the GHG emissions. Application of manure on arable lands has impact on the total GHG emissions. It is important to match the amount of applied manure to the crop nutrient demands to prevent the amount of leakage. Manure application timing is also important to reduce the emissions. Emissions can be reduced by avoiding manure application during autumn or winter seasons and shifting the application to spring season. Generally, it is recommended to avoid applying manure on wet soils.
Required skills (survey)	Medium - high
	Optimising manure application time requires a nutrient management plan approach (including PDCA).
Cost-effectiveness (survey)	Profitable
	Optimising in itself is profitable if it can be done within the current farming system. If additional investments are required in machinery or storage, it will result in net costs.
Farming system (survey)	Relevant for all systems
	The option is most relevant for farming systems that store most of their manure and also apply it on their own land and is less relevant for systems that don't store a relevant share of the produced manure (e.g. grazing systems).
Stimuli to implement (survey)	Knowledge and training, subsidies
Consequences of implementation	Optimising manure management will also lead to a reduction of N-losses.

26. Application of inhibitors for manure (e.g. Dicyandiamide and dimethypyrazole phosphate)	
Category	Manure management
Practical description	Application of inhibitors for manure such as: - Dicyandiamide (DCD) - Dimethylpyrazole phosphate (DMP)
Overall estimate of GHG reduction potential	Medium- high
Scientific background	Like feed inhibitors which suppress specific enzymes that trigger methane production in a cow's rumen and consistently reduces enteric methane emission, inhibitors can reduce methane emissions from manure. The most well-known inhibitors of manure are: DCD and DMPP which can reduce N_2O emissions by 30% to 50% with highest effect in grasslands. Roche et al. (2016) showed that adding a nitrification inhibitor reduces N_2O emission from urea but a urease inhibitor did not reduce N_2O emissions relative to Calcium Ammonium Nitrate (CAN). More information on nitrification inhibitors can be found in Velthof and Rietra (2018). A one-year study at the Department of Agroecology at Aarhus University found that the nitrification inhibitor DMPP significantly reduced nitrous oxide emissions from manure applied to maize on a sandy soil. It was concluded that DMPP and probably also other nitrification inhibitors can be used as a strategy to lower the nitrous oxide emissions from farming. By contrast, DMPP had only a minor effect as a means of reducing nitrate leaching (Nair et al. 2020). Despite of this recent study, in 2016, using nitrification inhibitors to mitigate agricultural N_2O emission was introduced as a double-edged sword (Lam et al. 2017). This study claimed that while inhibitors decrease emissions of nitrous oxide, they can increase emissions of ammonia which is later converted to nitrous oxide. They recommend these effects are considered when evaluating inhibitors as a mitigation technology. To alleviate this problem, the researchers suggest ammonia mitigation measures, such as urease inhibitors, could be used alongside nitrification inhibitors. Urease inhibitors limit the breakdown of urea, a process that results in ammonia. Adding a urease inhibitor to urea has shown to decrease ammonia emissions.
Required skills	Low skills. The only skill farmer requires is the knowledge of determining the appropriate dosage of using manure inhibitors.
Cost-effectiveness	Break-even.
Farming system	Application of manure inhibitors is mostly relevant for confined systems where manure is stored.
Consequences of implementation	This mitigation option reduces GHG and ammonia emissions from manure. It may have some positive impact on the soil nitrogen content.

4.6 Smarter energy management/use

27. Reducing fossil fuel consumption	
Category	Smarter energy management/use
Practical description	Reducing fossil fuel consumption by: - Adopting energy efficiency measures and using new technologies that will directly reduce the energy use (e.g. LED for lighting, high efficiency electric motors of livestock equipment, high efficiency equipment for milking parlours and cooling milk) - Smart control of energy processes and optimal energy management for maximising the use of energy. - Thermal and/or electricity storage where appropriate
Overall estimate of GHG reduction potential	Low - medium
Scientific background	The most energy consuming subsector of livestock production is milk production followed by pig and broiler production. Therefore, it is very substantial to adapt, design and demonstrate solutions (including smart farming technologies/systems), capable to establish optimal conditions in the indoor environment of the energy intensive agricultural buildings and to reduce direct energy use in livestock farm and crop (feed) production systems. This is not the case for open dairy barns, but it is common for pig and poultry barns. To identify areas for improvement and implement changes to reduce fossil fuel consumption in dairy farms conducting on-farm energy audits is essential. By utilising incentive and rebate programmes to invest in the latest, most-efficient technologies, dairy farms change the way they light barns

27. Reducing fossil fuel consumption	
	and milking parlours, pump water, refrigerate milk, and keep cows comfortable. These efforts reduce GHG emissions by reducing the use of fossil fuels. To reduce the energy consumption in livestock sector different activities can be conducted as follows: a. Integrating innovative ground heat pumps, for the precise environment control of livestock buildings, since it is most appropriate to cover effectively thermal needs (for heating, cooling and dehumidification), from both technical as well as economic point of view. b. Adopting energy efficiency measures that will directly reduce the energy use (e.g. LED for lighting, high efficiency electric motors of livestock equipment). c. Smart control of energy processes and optimal energy management are of key importance towards maximising energy savings. d. Thermal and/or electricity storage where appropriate.
Required skills	Medium skills.
Cost-effectiveness	Break-even. Some new facilities may have some additional costs for farmer however, because saving energy reduces the cost energy break-even is possible.
Farming system	All systems.
Consequences of implementation	-

28. Application and production of renewable energy	
Category	Smarter energy management/use
Practical description	Application and production of renewable energy by: - PVs to cover electricity consumptions (lighting, equipment, heat pump) - Producing biofuels (e.g. biogas) - Using electricity and other energy sources produced from renewable sources
Overall estimate of GHG reduction potential	Low - medium
Scientific background	The most energy consuming subsector of livestock production is milk production followed by pig and broiler production. Therefore, it is very substantial to adapt, design and demonstrate easily replicable renewable energy efficient solutions (including smart farming technologies/systems), capable to: i) Establish optimal conditions in the indoor environment of the energy intensive agricultural buildings and to reduce direct energy use in crop (feed) production systems. This is not the case for open dairy barns, but it is common for pig and poultry barns, ii) Produce the required feed for the annual needs of the inhabited animals using (a) biofuels for self-propelled machinery (tractors, sprayers, fertiliser spreaders either granular or liquid, mowers and harvesters), (b) pulled machinery electrification and (c) smart farming techniques and technologies, iii) Make use of renewable and energy efficiency technologies, measures and practices in livestock buildings, in order to change the energy consumption mix and reduce the farm's dependency on fossil fuel and electricity providers. To increase energy production in livestock sector different activities can be conducted as follows: a. PVs to cover electricity consumptions (lighting, equipment, heat pump). b. Biofuels (especially biogas derived from combined digestion of animal waste and crop residues optimising C/N ratio). The use of biodiesel and bioethanol is often controversial and up for debate, as it requires extra land.
Required skills	Low-Medium. PV systems are not complicated to operate. Thermal and/or electricity storage where appropriate needs requires extra skills.
Cost-effectiveness	Break-even – net costs. Depends on development in cost of non-renewable sources, available subsidies.
Farming system	Relevant for all systems.
Consequences of implementation	-

5 Overall findings and reflection

1. GHG emission on dairy and beef farms are complex, beware to simplify
It is quite complicated to assess GHG emission on dairy and beef farms accurately. This is partly because multiple processes on the farm have varying effects on the three relevant GHGs. An important part of GHGs is directly related to the cow as is the case with enteric methane emission, other parts are related to manure storage (CH_4) and manure application (N_2O) but also to inputs that come from outside the farm (energy, purchased feed, synthetic fertiliser) (CO_2) contribute to the overall emissions. All these sources together add up to the total farm level emissions. This also implies that there are many mitigation options available. In the survey, we have used a list of 27 mitigation options. Further in-depth evaluations of the proposed mitigation options would show that each option corresponds to several measures/actions that a farmer can or should take.

Another complicating factor is the great variety in farming systems. With large differences in size and management level: from smallholders keeping a small number of animals, fed with feed that is collected from the roadside to large scale farms with thousands of animals and extensive own facilities to make balanced rations. But also, with major differences in diet, e.g. from 100% grass with almost no concentrates up to diets that are mainly based on maize and concentrates. This also implies that a mitigation option that is relevant for one system can be irrelevant for another system. It also means that the effect of one mitigation option can differ quite between different farming systems. And even within farming systems the effect of a mitigation option can differ a lot depending on the starting point. If a farmer is already buying feed with a low footprint, not much progress can be made by buying different feed. The differences in performance within a farming system are for many indicators bigger than differences between farming systems. This complexity is also the main reason why the GHG reduction potential is not quantified in this report. Literature shows major differences in reduction potential for specific mitigation options even within one farming system. In theory one could extract an average reduction potential from literature, but this cannot be a well substantiated number. For the same reason the costs or profitability is also not quantified in this report.

It is important to be aware of these points when looking at the results from the survey and the list of mitigation options in the report. It cannot be used to single out a top 5 of mitigation options that will result in a major reduction of GHG emissions on all dairy and beef farms. In order to assess the relevant and most effective mitigation options for an individual farm the farming system and the current performance need to be taken into account. This statement was also mentioned in comments from the respondents in the answers for the final open question of the survey: 'We need to be careful with the results of this survey. The solution for the dairy industry is widespread adoption of a portfolio of solutions according to the given system/situation. This is not about focusing on a handful of high leverage solutions.'

2. Currently implemented mitigation options are mainly focussing on improving efficiency and productivity.
The mitigation options that are currently most frequently implemented according to the survey are focussing on improving efficiency and productivity. The only exception in the top results is the reduction of synthetic nitrogen fertiliser. It makes sense that these mitigation options are currently already implemented because in general these mitigation options also have a positive impact on profitability. If the survey would have asked for options to improve the (economic) performance of the farm this might have resulted in quite a similar list.

It is however also important to be aware of the effect that the impact on GHG emission of implementation of these mitigation options will depend also on the current level of efficiency of a farm. If the current level is already high, the impact of further improvement will be limited. In general, there will be limited impact on GHG emission of these mitigation options for well managed productive farms. For farms that are less well managed and have a low performance, the impact can be very high.

Figure 5.1 shows the relationship between total GHG emissions and output per cow for various farming systems in dairy. As it is shown here three different farming systems can be defined based on the level of production and GHG emissions: specialised, smallholder and subsistence farming systems. For the specialised dairy production systems which are seen in industrialised countries optimising animal performance plays an important role. In the case of dairy production systems in less industrialised countries in Africa, Asia and partially Latin America, these are mainly smallholder farming systems with low input levels and low animal productivity. Mitigation for the smallholder systems can focus on the application of existing technology, the development of markets and a supporting infrastructure.

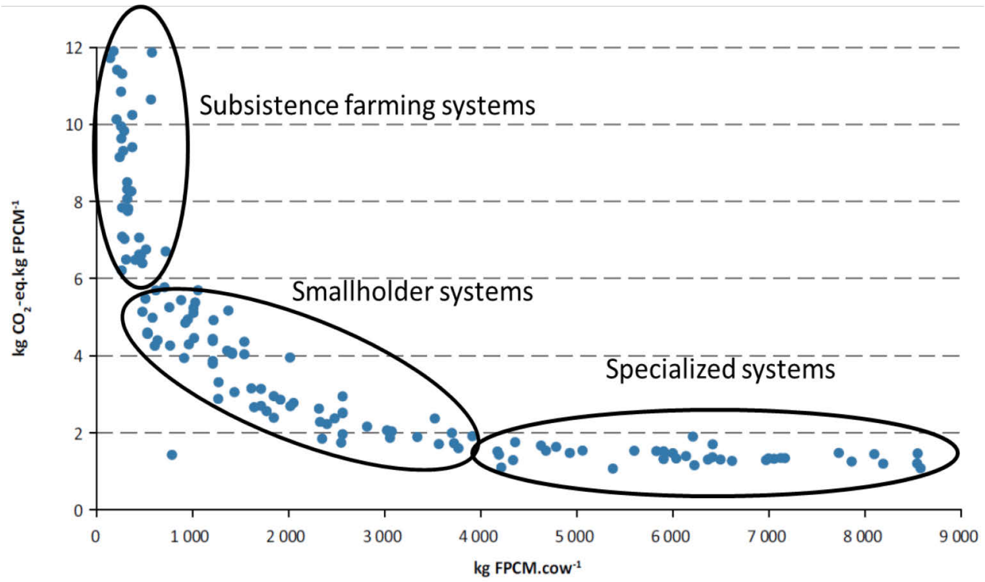


Figure 5.1 *Relationship between total GHG emissions and output per cow for various farming systems. Each dot represents a country*
Source: Gerber et al. (2011).

Some of the mitigation options that are not in the list of highest scoring options can still be very practical and relevant. Improving grazing management is one of the best examples. This option is very relevant for all farming systems that apply grazing and it is also cost effective. Anaerobic digestion is another example. This can be effective to reduce GHG emission. But is not relevant for farming systems that are based on grazing and it is not cost effective for smaller farms. The profitability of anaerobic digestion in many cases depends on the availability of local subsidies, also for larger farms.

We can also identify a number of mitigation options that is not yet broadly implemented but can be seen as promising options.

- Breeding for reduction of methane emission
  The presence of a big variation in emissions among individual animals raises opportunities for breeding and selection programmes to select for lower emitting animals. Selective breeding of animals with low methane emissions per unit of feed consumed could be possible with the use of genomic markers. This option is not yet available. It can be seen as a relevant long-term option.

- Use of additives or vaccines to alter rumen fermentation
  A lot of work has been done in this field in the last couple of years. And several options are (almost) ready for implementation. Feed additives are easiest to implement in confined systems. Vaccines can be used for all farming systems.

3. How to stimulate farmers to implement mitigation options?
The survey shows two main incentives to support the implementation of mitigation options: knowledge and subsidy. The input in the open question in the survey also showed that respondents are struggling with the economics of the mitigation options and with the required knowledge to be able to assess

what the best option in an individual situation is. ‘Farms are making improvements to impact bottom line economics rather than to reduce GHG emissions currently.’ ‘It is an immense challenge for farmers to understand the complex interaction (...) and to implement reliably.’

Building on the point that was made earlier on the difference between the specialised farms and the smallholders and subsistence farms two main types of farms can be distinguished:
1. Farms with low productivity (including subsistence farms).
2. Farms with high productivity.

For the first group the focus can be full on increasing productivity. For these farmers the drive to implement mitigation options will not be the reduction of GHG emission but will be improving the economic performance of the farm. For them there is actually no direct need for information or communication on GHG emissions. For this group the focus can be on the fundamentals of dairy and beef farming. This was also mentioned in one of the comments in the survey: ‘In general, in this region, there is no focus at all on the topic. However, the work done to improve the farms’ productivity actually helps in the same direction - to reduce the GHG emission along improved factors at those farms.’

For the high productive farms, the situation is more complex. It will still be useful to look at further improvement of efficiency, but this can only result in a limited reduction of GHG emissions. If further reduction is desired or required, other options have to be explored. For this situation it will not be easy to find a single mitigation option that will have major impact. It will be necessary to look at the full portfolio of mitigation options and assess which options are relevant for each specific situation taking into account the farming system and, if available, the current performance. It would be very helpful to have a system in place that can help the farmer or his advisor to make the right choice for a package of mitigation options to implement for his specific situation. This can start with a relatively simple system which results in relevant mitigation options based on input of a limited number of farm characteristics. This can go as far as a system that works from detailed farm data (farm structure, on-farm processes, farm inputs, etc.) to assess where improvement is possible and suggests mitigation options with an estimated effect including the economic impact. Given the differences in farming systems it would be best to develop such kind of systems on a regional or farming system level.

There is lot of information available on the possibilities to reduce GHG emission on dairy and beef farms. Obviously in the (near) future new knowledge will become available, but in principle there is enough to start now already with mitigation as several initiatives already show in practice.

A main question to be answered is how to motivate farmers to make the first step and start considering working on reduction of GHG emissions. So what is the answer to the ‘Why?’ question. For the low productive farms the answer is quite simple as has been mentioned earlier: it is for their own benefit, it helps to achieve a better income. For high productive farms it can be more complicated. Some will be intrinsically motivated because ‘They want to do the right thing for the environment and for their children’ as was mentioned in the survey. But this will not be the case for all the farmers as another quote from the survey shows: ‘You need to instil confidence in the farming community that what they are doing, or being asked to do, is relevant and of economic value to them. Discussing GHG emissions will in many cases hit a brick wall as the industry is fed up of being blamed for everything.’

One of the respondents emphasises the profitability itself is not enough: ‘What we experienced, even though several mitigation levers are closely linked to farm efficiency and farmers profitability, but in the majority of the cases the implementation in short term needs close assistance to farmers with training, advisory, technical support and financing mechanisms to support the transition period.’ In this specific case the focus is on a ‘multi-stakeholders approach including different actors in the value chain (input suppliers, farmers, ..., advisory etc).’

Looking more in detail at ways to stimulate adoption of mitigation options it is notable that the respondents mainly mention two stimuli: provide knowledge (in different ways) and subsidy. Quite a number of ways to improve knowledge are mentioned: trainings, excursions, technical guidance. These are indeed important ways to stimulate farmers, but there are more options available. A respondent mentioned that organisations like SAI Platform and the ERBS 'Should work on the social change elements of adopting practices that reduce GHG emissions'. A relative simple method called reset is based on 5 options or 'buttons to push' to change behaviour. It consists of 5 options to change behaviour Rules (obligation to implement), Education (trainings, farmer to farmer, etc), Social -peer-pressure (communication), Economic (premiums, penalties, economic benefit) and Tools (making implementation easy). This method and other similar methods can be used to design a program to stimulate farmers to implement mitigation options (Reijs et al., 2021). Interesting is also a comment from one of the respondents that they have started a project researching effectiveness of different approaches to 'nudging' adoption of sustainability practices among farmers.

Summarising: to achieve large-scale implementation of mitigation two things have to be organised:
1. Create clarity in what farmers can do specifically for his own situation and farming system: which options or best practices are available and fitting.
2. Create incentives and organise interventions to assure the implementation of these best practices.

4. Tools, data and monitoring
The survey resulted in a large number of tools that are being used to monitor GHG emissions on farm level. In itself this is very positive, it helps in creating awareness and can be a starting point for communication and for mitigation.

Many countries have their own national tool and in some countries several tools seem to be in use. It is understandable that countries have their own tools. Each country has its own specific situation, related to specific farming systems but also to availability of data. It can be very confusing however if different tools are used within a country, it will make it complicated to compare results within a country e.g. within a regional discussion group of farmers. In some countries stakeholders have worked on alignment and have chosen for one tool. It is clear that this is very helpful in creating possibilities to exchange knowledge between farmers and to create alignment on the side of the farm advisors and it will also make monitoring easier.

The different tools that were mentioned in the survey have not been analysed or compared in this study. But given the number of tools and some practical experiences it seems reasonable to assume that there will be differences between these tools. The chances are that they will differ e.g. in scope, in methodology (e.g. inclusion of sequestration and land use change), in granularity etc. The point of sequestration was also mentioned in the comments in the survey: 'We need good science and recognition of the sequestration part.' All these national tools will make it complicated to exchange and compare data on an international level. This is also a worry from some of the respondents: 'We as an industry, need to take a global approach to this topic, as currently we are all using different calculations, so how do we benchmark anyone regarding the success of their GHG mitigation?'

Data-availability is an important point, both related to tools and monitoring. One of the respondents mentioned this specifically: 'However, there is a high amount of data that farmers need to share and this can be a bottleneck. Also, the quality of the data must be high in order to achieve accurate results.' The last point is very relevant: we've seen that some of the mitigation options are about optimising the farming system on quite a detailed level. If the carbon footprint tool is basic and based on a limited number of farm characteristics the effect of the implementation of some of the mitigation options from the list might not be visible in the carbon footprint tool and not in the overall monitoring of the supply base.

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Appendix 1 Mitigation options currently used per category

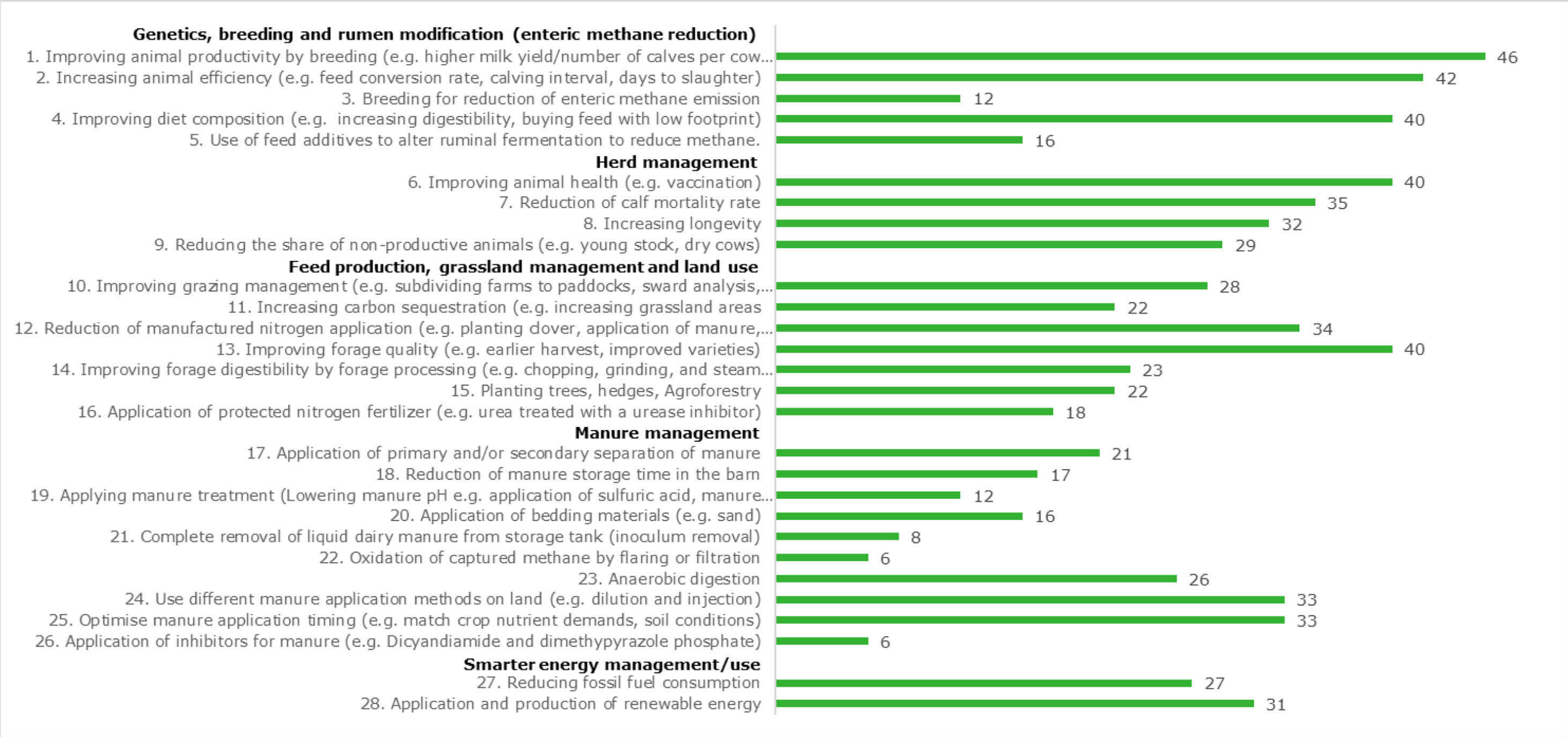

Figure A1.1 *Number of times mitigation options were selected, total (n = 57)*

Figure A1.2 *Number of times mitigation options were selected, dairy (n = 41)*

Figure A1.3 *Number of times mitigation options were selected, beef (n = 16)*

Appendix 2 Additional information per mitigation option

Table A2.1 *Additional information for the mitigation options as mentioned by the respondents. For 'Farming system', 'Profitability' and 'Required skills', the classifications were given when 75% or more respondents indicated the same response. Where this was not the case, an explanation of the responses is given*

Option	Respondents	Farming system	Profitability	Required skills
Genetics, breeding and enteric methane reduction				
Option	**Respondents**	**Farming system**	**Profitability**	**Required skills**
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	46	Universal	Profitable	Medium – high
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	42	Universal	Profitable	Medium
3. Breeding for reduction of enteric methane emission	12	Universal	Unclear from survey	Medium – high
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	40	Universal	Majority indicates profitable	Medium – high
5. Use of feed additives to alter ruminal fermentation to reduce methane.	16	Universal	Half respondents indicate profitable, half indicate results in net extra costs	Unclear from survey
Herd management				
Option	**Respondents**	**Farming system**	**Profitability**	**Required skills**
6. Improving animal health (e.g. vaccination)	40	Universal	Profitable	Low - Medium
7. Reduction of calf mortality rate	35	Universal	Profitable	Medium
8. Increasing longevity	32	Universal	Profitable	Medium
9. Reducing the share of non-productive animals (e.g. young stock, dry cows)	29	Universal	Profitable	Low – medium
Feed production, grassland management and land use				
Option	**Respondents**	**Farming system**	**Profitability**	**Required skills**
10. Improving grazing management (e.g. subdividing farms to paddocks, sward analysis, measuring grass growth and planning grazing strategy for grazing season)	28	Universal	Profitable	Medium - high
11. Increasing carbon sequestration (e.g. increasing grassland areas	22	Universal	Majority indicate 'don't know'	Medium – high
12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	34	Universal	Profitable	Medium – high
13. Improving forage quality (e.g. earlier harvest, improved varieties)	40	Universal	Profitable	Medium – high

14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)	23	Universal	Majority indicate profitable	Medium – high
15. Planting trees, hedges, Agroforestry	22	Universal	Results in net extra costs	Low – medium
16. Application of protected nitrogen fertiliser (e.g. urea treated with a urease inhibitor)	18	Universal	Unclear from survey	Low – medium
Manure management				
Option	**Respondents**	**Farming system**	**Profitability**	**Required skills**
17. Application of primary and/or secondary separation of manure	21	Half of respondents indicate the option is not universal, diet and size unclear	Unclear from survey	Low – medium
18. Reduction of manure storage time in the barn	17	Majority indicates the option is universal, diet and size unclear	Majority indicate 'don't know'	Medium
19. Applying manure treatment (Lowering manure pH e.g. application of sulfuric acid, manure aeration, manure cooling)	12	Majority indicates the option is not universal, diet and size unclear	Unclear from survey	Unclear from survey
20. Application of bedding materials (e.g. sand)	16	Majority indicates the option is universal, diet and size unclear	Unclear from survey	Low – medium
21. Complete removal of liquid dairy manure from storage tank (inoculum removal)	8	Majority indicates the option is not universal, diet and size unclear	Majority indicate 'don't know'	Medium
22. Oxidation of captured methane by flaring or filtration	6	Size: >500 total herd	Unclear from survey	Medium – high
23. Anaerobic digestion	26	Size: >500 total herd	Unclear from survey	High
24. Use different manure application methods on land (e.g. dilution and injection)	33	Half of respondents indicate option is universal, Size: unclear from survey Diet: not relevant	Majority indicate results in net extra costs	Low - medium
25. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)	33	Universal	Profitable	Medium – high
26. Application of inhibitors for manure (e.g. Dicyandiamide and dimethypyrazole phosphate)	6	Unclear from survey	Unclear from survey	Low – medium
Smarter energy management/use				
Option	**Respondents**	**Farming system**	**Profitability**	**Required skills**
27. Reducing fossil fuel consumption	27	Universal	Profitable	Medium
28. Application and production of renewable energy	31	More than half of respondents indicate option is universal, diet and size unclear	Majority indicate profitable	Medium - high

Table A2.2 *Overview of stimuli mentioned per mitigation option. The number in brackets indicates how many times an option was mentioned. No brackets mean the stimulus was mentioned only once*

Option	No. of respondents	Stimuli
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	46	Knowledge and training (25), subsidies (4), technical assistance (2), data, labor needs, breeding program
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	42	Knowledge and training (26), subsidies (2), technical assistance (3), data, breeding program, demonstration, research, farm visits
3. Breeding for reduction of enteric methane emission	12	Knowledge and training (6), subsidies (2), technical assistance
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	40	Knowledge and training (27), subsidies (5), technical assistance, excursions to successful farmers, nutritionist support
5. Use of feed additives to alter ruminal fermentation to reduce methane.	16	Knowledge and training (5), subsidies (3), technical assistance, nutritionist support, proving that the correct nutrition does not reduce the milk production
6. Improving animal health (e.g. vaccination)	40	Knowledge and training (27), subsidies (3), technical assistance (2), labour needs, veterinary support
7. Reduction of calf mortality rate	35	Knowledge and training (21), subsidies (2), technical assistance (2), labour needs, farm visits
8. Increasing longevity	32	Knowledge and training (19), subsidies (2), technical assistance, committed staff, breeding program
9. Reducing the share of non-productive animals (e.g. young stock, dry cows)	29	Knowledge and training (23), technical assistance (3), labour needs
10. Improving grazing management (e.g. subdividing farms to paddocks, sward analysis, measuring grass growth and planning grazing strategy for grazing season)	28	Knowledge and training (19), subsidies (2), technical assistance, data, excursions to successful farmers, research, farm visits
11. Increasing carbon sequestration (e.g. increasing grassland areas	22	Knowledge and training (10), subsidies (4), technical assistance, research
12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)	34	Knowledge and training (25), subsidies (3), data, technical assistance, plant breeding program, risk reduction, labour needs, skilled team, tools, legislation
13. Improving forage quality (e.g. earlier harvest, improved varieties)	40	Knowledge and training (26), subsidies (3), good weather, agronomist guidance, excursions to successful farmers
14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)	23	Knowledge and training (13), machinery investment, skilled operators and vendor support, subsidy
15. Planting trees, hedges, Agroforestry	22	Knowledge and training (9), subsidies (7), suitable land (2), labour needs
16. Application of protected nitrogen fertiliser (e.g. urea treated with a urease inhibitor)	18	Knowledge and training (6), subsidies (3), agronomist coordination with fertiliser vendors, availability of product, technical assistance
17. Application of primary and/or secondary separation of manure	21	Knowledge and training (13), investment arrangement (2), equipment, technical assistance
18. Reduction of manure storage time in the barn	17	Knowledge and training (8), subsidy and investment (4), technical assistance, change in legislation, uses more electricity to reduce ammonia and mastitis risk

Option	No. of respondents	Stimuli
19. Applying manure treatment (Lowering manure pH e.g. application of sulfuric acid, manure aeration, manure cooling)	12	Knowledge and training (5), investment, technical assistance
20. Application of bedding materials (e.g. sand)	16	Knowledge and training (7), technical assistance, research, risk reduction, skilled teams, better comfort
21. Complete removal of liquid dairy manure from storage tank (inoculum removal)	8	Knowledge and training (2), investment, technical assistance
22. Oxidation of captured methane by flaring or filtration	6	Knowledge and training (2), investment, technical assistance
23. Anaerobic digestion	26	Subsidies and investment (11), knowledge and training (9), resources, jumpstart program to facilitate, risk reduction, skilled team, technical assistance
24. Use different manure application methods on land (e.g. dilution and injection)	33	Knowledge and training (12), subsidies and investment (11), technical assistance, legislation, research, risk reduction, skilled team, farm visits
25. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)	33	Knowledge and training (22), subsidies (3), technical assistance, data, risk reduction, skilled teams
26. Application of inhibitors for manure (e.g. Dicyandiamide and dimethypyrazole phosphate)	6	Innovation and technology, knowledge
27. Reducing fossil fuel consumption	27	Knowledge and training (16), subsidies (3), equipment investment, improve environment, risk reduction, skilled teams
28. Application and production of renewable energy	31	Subsidies and investment (14), knowledge and training (10), excursions to successful farmers, risk reduction, skilled teams, administrative assistance, technical assistance, suitable site and infrastructure, technology, labor needs

Appendix 3 Survey outline

SAI Platform's DWG member survey

Start of Block: Survey start

The goal of this survey is to collect experiences on relevant farm level GHG mitigation options that supplying farmers are currently using to reduce GHG emissions. The collected information will be combined with data from literature in order to make a structured overview of mitigation options, their applicability for different farming systems, profitability, the range of GHG reduction and required skills. **Individual survey results will be treated as confidential and will be anonymised.** Data will be collected and stored by Wageningen University & Research. Only aggregated results will be published.

End of Block: Survey start

Start of Block: Introduction

Q1 **Please specify the type of company or organisation**

[1] Buyer: e.g. companies like Nestlé, Unilever, etc.
[2] National program: e.g. national organisations like Dairy Australia, Innovation Center for U.S. Dairy, etc.

- ☐ Processor
- ☐ Buyer[1]
- ☐ Retailer
- ☐ Food service
- ☐ National Program[2]
- ☐ Farmer/supplier

Q2 **This survey is completed for farms that primarily produce**

- ☐ Dairy (with beef as by-product)
- ☐ Beef

Q3 **What is the region of your supplying farmers?**

The level of region we are looking for is national or higher (e.g. North West Europe)

- ☐ National, please specify: ____
- ☐ Higher, please specify: ____

End of Block: Introduction

Start of Block: GHG mitigation practices

Q4 **Do all or some of your supplying farmers³ know about their <u>individual</u> carbon footprint on farm level?**

³ in case of a national program, supplying farmers can be read as the farmers in your country

- ☐ Yes
- ☐ No
- ☐ Don't know / don't want to answer

Display This Question:

If Do all or some of your supplying farmers³ know about their individual carbon footprint on farm le... = Yes

Q5 **How do your farmers know about their <u>individual</u> carbon footprint?**

- ☐ The individual farmer can calculate their carbon footprint with an available tool
- ☐ The individual carbon footprint is provided for the individual farmer either through a national program or through a chain partner
- ☐ Other, please specify ____
- ☐ Don't know / don't want to answer / not applicable

Display This Question:

If Do all or some of your supplying farmers³ know about their individual carbon footprint on farm le... = Yes

Q6 **What is the percentage of supplying farmers that know their <u>individual</u> carbon footprint?**

- ☐ Actual: ____
- ☐ Guestimate: ____
- ☐ Don't know / don't want to answer

Display This Question:

If Do all or some of your supplying farmers³ know about their individual carbon footprint on farm le... = Yes

Q7 **Which tool is used to calculate the carbon footprint on farm level?**

Multiple tools are possible

____

Q8 **How frequently is the GHG emission of your supply base[3] monitored and reported (internally or externally)?**

Please note this question pertains to GHG emission levels on *supply base* level

[3] in case of a national program, supplying farmers can be read as the farmers in your country

- ☐ It is not being monitored
- ☐ Yearly
- ☐ Don't know / don't want to answer
- ☐ Other, please specify ____

Display This Question:

If How frequently is the GHG emission of your supply base[3] monitored and reported (internally or ext... = Yearly

Or How frequently is the GHG emission of your supply base[3] monitored and reported (internally or ext... = Other, please specify

Q9 **Who monitors the GHG emission of your supply base?**

Please note this question pertains to GHG emission levels on *supply base* level

- ☐ We monitor ourselves
- ☐ National program
- ☐ National government
- ☐ Don't know / don't want to answer
- ☐ Other, please specify ____

End of Block: GHG mitigation practices

Start of Block: GHG mitigation options

Q10 **Which farm level GHG mitigation options do your supplying farmers apply to reduce GHG emissions?**

From this list of 28 farm level mitigation options, please select the mitigation options that are **currently being implemented** by farmers. Additional information on the applicability for different farming systems, profitability, required skills and relevant stimuli will be collected for the selected mitigation options.

☐ 1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)

☐ 2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)

☐ 3. Breeding for reduction of enteric methane emission

☐ 4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)

☐ 5. Use of feed additives to alter ruminal fermentation to reduce methane.

☐ 6. Improving animal health (e.g. vaccination)

☐ 7. Reduction of calf mortality rate

☐ 8. Increasing longevity

☐ 9. Reducing the share of non-productive animals (e.g. young stock, dry cows)

☐ 10. Improving grazing management (e.g. subdividing farms to paddocks, sward analysis, measuring grass growth and planning grazing strategy for grazing season)

☐ 11. Increasing carbon sequestration (e.g. increasing grassland areas

☐ 12. Reduction of manufactured nitrogen fertiliser application (e.g. planting clover, application of manure, composting, soil testing and nutrient planning)

☐ 13. Improving forage quality (e.g. earlier harvest, improved varieties)

☐ 14. Improving forage digestibility by forage processing (e.g. chopping, grinding, and steam treatment)

☐ 15. Planting trees, hedges, Agroforestry

☐ 16. Application of protected nitrogen fertiliser (e.g. urea treated with a urease inhibitor)

☐ 17. Application of primary and/or secondary separation of manure

☐ 18. Reduction of manure storage time in the barn

☐ 19. Applying manure treatment (Lowering manure pH e.g. application of sulfuric acid, manure aeration, manure cooling)

☐ 20. Application of bedding materials (e.g. sand)

☐ 21. Complete removal of liquid dairy manure from storage tank (inoculum removal)

☐ 22. Oxidation of captured methane by flaring or filtration

☐ 23. Anaerobic digestion

☐ 24. Use different manure application methods on land (e.g. dilution and injection)

☐ 25. Optimise manure application timing (e.g. match crop nutrient demands, soil conditions)

☐ 26. Application of inhibitors for manure (e.g. Dicyandiamide and dimethypyrazole phosphate)

☐ 27. Reducing fossil fuel consumption

☐ 28. Application and production of renewable energy

☐ Other: ____

☐ Other: ____

☐ Other: ____

Q11 **Is the mitigation option relevant for all farming systems, independent from farm size and main feed source/average diet?**

	(Yes; No; Don't know / don't want to answer)
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	▼ Yes ... Don't know / don't want to answer
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	▼ Yes ... Don't know / don't want to answer
3. Breeding for reduction of enteric methane emission	▼ Yes ... Don't know / don't want to answer
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	▼ Yes ... Don't know / don't want to answer
5. Use of feed additives to alter ruminal fermentation to reduce methane.	▼ Yes ... Don't know / don't want to answer

Etc.

Display This Question:

If Is the mitigation option relevant for all farming systems, independent from farm size and main feed... = No

Q12 **Which farming system does this option apply to?** (1)
Please select farm **size**.

	a. Not relevant b. < 25 total herd c. Between 25 and 200 total herd d. Between 200 and 500 total herd e. > 500 total herd f. Don't know / don't want to answer
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	▼ Size: a. Not relevant ... Don't know / don't want to answer
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	▼ Size: a. Not relevant ... Don't know / don't want to answer
3. Breeding for reduction of enteric methane emission	▼ Size: a. Not relevant ... Don't know / don't want to answer
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	▼ Size: a. Not relevant ... Don't know / don't want to answer
5. Use of feed additives to alter ruminal fermentation to reduce methane.	▼ Size: a. Not relevant ... Don't know / don't want to answer

Etc.

Display This Question:

If Is the mitigation option relevant for all farming systems, independent from farm size and main feed... = No

Q13 **Which farming system does this option apply to?** (2)
Please select farm **diet**.

	g. Not relevant h. Grass/roughage based (< 20% DM concentrates, grains[5]) i. Intermediate (between 20- 50% DM concentrates, grains[5]) j. Concentrates/grains[5] based (> 50% DM) k. Don't know / don't want to answer
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	▼ Diet: a. Not relevant ... Don't know / don't want to answer
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	▼ Diet: a. Not relevant ... Don't know / don't want to answer
3. Breeding for reduction of enteric methane emission	▼ Diet: a. Not relevant ... Don't know / don't want to answer
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	▼ Diet: a. Not relevant ... Don't know / don't want to answer
5. Use of feed additives to alter ruminal fermentation to reduce methane.	▼ Diet: a. Not relevant ... Don't know / don't want to answer

Etc.

End of Block: GHG mitigation options

[5] And equivalents as by products from food industry

Start of Block: Economic viability and skills & knowledge

Q14 **In general, what is the economic viability of the mitigation option for the average farmer (without subsidies)?**
We are aware that the impact on profitability of a mitigation option depends on the individual farm situation. Have the mitigation options that you have implemented had a positive or negative impact on the profitability for an average farm?

	(Is profitable for the farmer; Breakeven; Results in net extra costs for the farmer; Don't know / don't want to answer)
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	▼ Is profitable for the farmer ... Don't know / don't want to answer
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	▼ Is profitable for the farmer ... Don't know / don't want to answer
3. Breeding for reduction of enteric methane emission	▼ Is profitable for the farmer ... Don't know / don't want to answer
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	▼ Is profitable for the farmer ... Don't know / don't want to answer
5. Use of feed additives to alter ruminal fermentation to reduce methane.	▼ Is profitable for the farmer ... Don't know / don't want to answer

Etc.

Q15 **In general, does the mitigation option require extra skills and knowledge from the average farmer?**
We are aware that the required extra skills also depend on the current available skills. Will this mitigation option require additional skills training for the average farmer?

	(No extra skills from farmer required; Medium level skills required; High level skills required; Don't know / don't want to answer)
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	▼ No extra skills from farmer required ... Don't know / don't want to answer
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	▼ No extra skills from farmer required ... Don't know / don't want to answer
3. Breeding for reduction of enteric methane emission	▼ No extra skills from farmer required ... Don't know / don't want to answer
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	▼ No extra skills from farmer required ... Don't know / don't want to answer
5. Use of feed additives to alter ruminal fermentation to reduce methane.	▼ No extra skills from farmer required ... Don't know / don't want to answer

Etc.

End of Block: Economic viability and skills & knowledge

Start of Block: Stimuli

Q16 **In general, which stimuli do you consider critical for successful implementation of this mitigation option by farmers?** Multiple aspects can be listed: e.g. providing knowledge to the farmer, subsidy, coaching/advice, etc.

	Stimuli
1. Improving animal productivity by breeding (e.g. higher milk yield/number of calves per cow per year)	
2. Increasing animal efficiency (e.g. feed conversion rate, calving interval, days to slaughter)	
3. Breeding for reduction of enteric methane emission	
4. Improving diet composition (e.g. increasing digestibility, buying feed with low footprint)	
5. Use of feed additives to alter ruminal fermentation to reduce methane.	

Etc.

End of Block: Stimuli

Start of Block: Final questions

Q17 **Do you have anything else that you can share to help us learn from your experience in mitigating GHG emissions on farms?**

____

Q18 **If needed, would you be willing to participate in a follow-up interview?**

Please note the responses to this survey will remain confidential.

- ☐ Yes
- ☐ No

Display This Question:

If needed, would you be willing to participate in a follow-up interview? Please note the respo... = Yes

Q19 **Please leave your contact details. Thank you!**

____

End of Block: Final questions

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The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,800 employees (6,000 fte) and 12,900 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.

To explore the potential of nature to improve the quality of life

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