Cutting emissions from farming

Climate mitigation potential, costs, trade-offs and co-benefits of measures and the barriers to implementation

CE Delft

Committed to the Environment

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CE Delft
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

1 Introduction

1.1 Backgound

Agriculture accounts for a significant impact on climate change, both directly and indirectly through supply chains. At the same time the reduction of emission is often complex, because the different greenhouse gases originate from biological processes, that are connected to other environmental policy objectives as well. Moreover, the number of stakeholders involved is significantly larger compared to other sectors, as millions of individual famers would need adjust their farming practices.

While agriculture can potentially help reach climate change targets, and benefit from measures reducing GHG emissions, it is also crucial to understand potential barriers to implementation as well as to seek co-benefits and avoid trade-offs with other policy objectives. Therefore, the European Environmental Bureau and Birdlife, in collaboration with local partners in Ireland, Germany, France, Hungary and Spain commissioned this study to identify the potential barriers to implementation of climate mitigation measures, and find out how the Common Agricultural Policy (CAP) post 2020 can help to overcome such barriers.

1.2 Objective

The goal of this study is to identify barriers to implementation of climate mitigation measures in the agricultural sector. Additionally, potential trade-offs and synergies with other policy objectives are also being assessed. To get the most hands-on practical input, discussions (workshops) about measures and barriers to implementation of these measures were held in five different countries. The information gathered in these workshops will give input for optimizing the new CAP.

1.3 Scope

The main focus of this study are climate change mitigation measures that could be implemented by farmers (i.e. on a farm level) and be accounted under a future CAP. Measures that are still in early research phase are not considered. Measures were chosen because they have a GHG emissions reduction potential; measures that only target other aspects of environmental sustainability were also excluded.

The list of measures is not meant to be comprehensive, but rather to be diverse so that a very broad set of barriers could be explored. The goal was to cover a wide range of different approaches, farming practices and sub-sectors of agriculture (e.g. crop and livestock farming). The resulting broad set of measures also allows identification of a variety of barriers as well as different potential co-benefits and trade-offs.

We have identified barriers to implementation based on ten mitigation measures.
The measures included in this study are:
1. Manure storage management.
2. Anaerobic digestion of manure.
3. Animal management.
4. Soil carbon conservation and sequestration.
5. Synthetic fertilizer management.
6. Organic fertilizer management.
7. Switch in agricultural product.
8. Land-based livestock farming.

9. Agroforestry.
10. Conversion to other use.

More elaborate information on the different measures can be found in Annex A.

Limitations

The scope chosen for this study — mitigation measures on a farm level — also brings some limitations. Taking a pure farm-level perspective narrows the policy options mostly to supply side measures. As there is a dependence between supply and demand, a more holistic approach is necessary in policy development. For instance, emissions may simply move from one farm to another (carbon leakage). This can only be taken into account to a limited extent within the scope of this study but should be kept in mind.

Another limitation of this study is that the results presented here are based on stakeholder input. A different set of stakeholders could have led to a more elaborate set of barriers.

1.4 Approach

In order to meet the objective following steps were carried out:

1. Identification of measures: Ten measures were identified based on a literature study. The findings of the literature study were summarized in factsheets. To illustrate the potential importance of the measures, the potential reduction of greenhouse gas (GHG) emissions and costs was quantified (if possible), the main co-benefits and trade-offs were described qualitatively. In addition, the main categories of barriers were identified, which were used as input for a more detailed discussion in the workshops: Financial, Knowledge, Trust and Other (e.g. cultural, legislation).
2. Discussions in workshops: the measures were discussed in workshops in five different countries — Ireland, Germany, France, Hungary and Spain. Detailed notes summarizing input given at each workshop were made. The workshop results have been thoroughly reviewed by agricultural and climate experts from CE Delft.
3. Summary of main findings: the main findings were summarized, including the potential recommendations for reforming the CAP. The results of the study are presented in this report.

1.5 Outline

The report is structured as follows:

- A short summary on GHG emissions in agriculture in Europe is given in Chapter 2 to illustrate the importance of agricultural in tackling climate change.
- In Chapter 3 an overview of the ten measures is given, with a short summary of the measure, costs, mitigation potential, co-benefits and trade-offs. The response to the measures, and particularly the barriers to implementation in the particular countries, collected in the workshops, are summarized. We end this chapter with conclusions, as insights.
- In Chapter 5 a short overview of the proposed CAP 2020 regulation is given for some background information.
- In Chapter 6 we list some reasons for optimism about the proposed CAP post 2020 regulation and some reasons for pessimism, based on the information gathered in the workshops about barriers and a study of the CAP post 2020 regulation.
- In Annex A the ten measures are elaborated on, in Annex B the factsheets on the measures are included.

1.6 Disclaimer

The information and conclusions expressed in this report do not necessarily reflect the opinion of the European Environmental Bureau and Birdlife.

2 Agricultural greenhouse gas emissions in Europe

In this chapter a very succinct overview of the development and the different sources of greenhouse gas (GHG) emissions from agriculture is given, both for the EU and for the five countries in which workshops were held.

Three GHG emissions are emitted in agriculture:
- **Methane (CH_4)**: CH_4 is emitted from animal manure and in livestock production through enteric fermentation in ruminants. Around 44% of agricultural emissions are related to enteric fermentation, around 15% to manure management.
- **Nitrous oxide (N_2O)**: emission of N_2O from soils is affected by a lot of different factors, among which are land management, synthetic fertilizer use and use of animal manure, as well as soil characteristics and climate. Around 37% of agricultural emissions are related to agricultural soils.
- **Carbon dioxide (CO_2)**: CO_2 is emitted from soils when soil organic matter decreases. It is also emitted through use of fuel consumption, and upstream in energy use for industrial processes, e.g. for production of fertilizer.

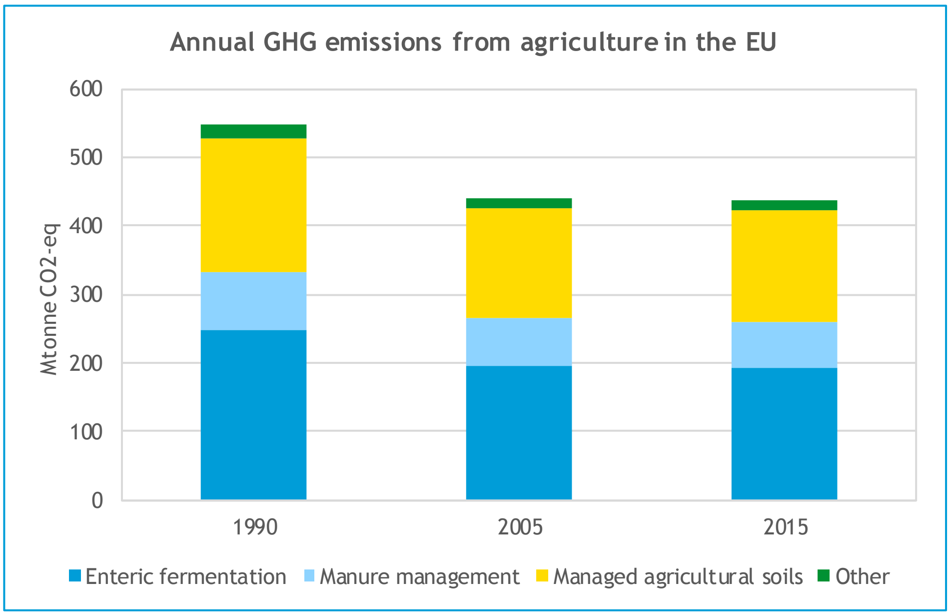
These emissions are reported under different sectors in the GHG inventory reports, the main ones of which are agriculture and LULUCF:
- **Agriculture**: this includes direct emissions from agriculture; mostly CH_4 and N_2O. These GHG emissions from agriculture in the EU are primarily (~99%) related to agricultural soils, manure management and enteric fermentation (as shown in Figure 1).
  Land use, land use change and forestry (LULUCF): this category is a net sink; carbon is absorbed. This is, however, due to increase in forest land. Net emissions from cropland and grassland (directly related to agriculture) are positive; soil organic matter is decreasing for these lands.

Also relevant for the food system, including processes upstream and downstream from agriculture:
- **Energy**: this includes fuel combustion for energy production and transport.
- **Industrial processes and product use**: e.g. production of fertilizer.

As shown in Figure 1 total emissions in agriculture have gone down between 1990 and 2015, by about 20%. Not much progress has been made in agriculture since; agricultural emissions decreased until 2012, but have been increasing again since 2012. In 2015 agricultural emissions were at the same level at 10 years earlier (EEA, 2017).

Overall, including all sectors, emissions in the EU28 have dropped between 1990 and 2015 by around 22% (EEA, 2017). As shown in Figure 1, emissions from agriculture dropped between 1990 and 2005, by around 20%, but the difference between 2005 and 2015 is negligible. *Gross value added* of the agricultural industry fluctuated in that period, but the values for 2015 and 2005 are roughly the same (EC, 2018a). This means that environmental efficiency gains, in terms of gross value added per unit of CO_2 eq. emission have not taken place.

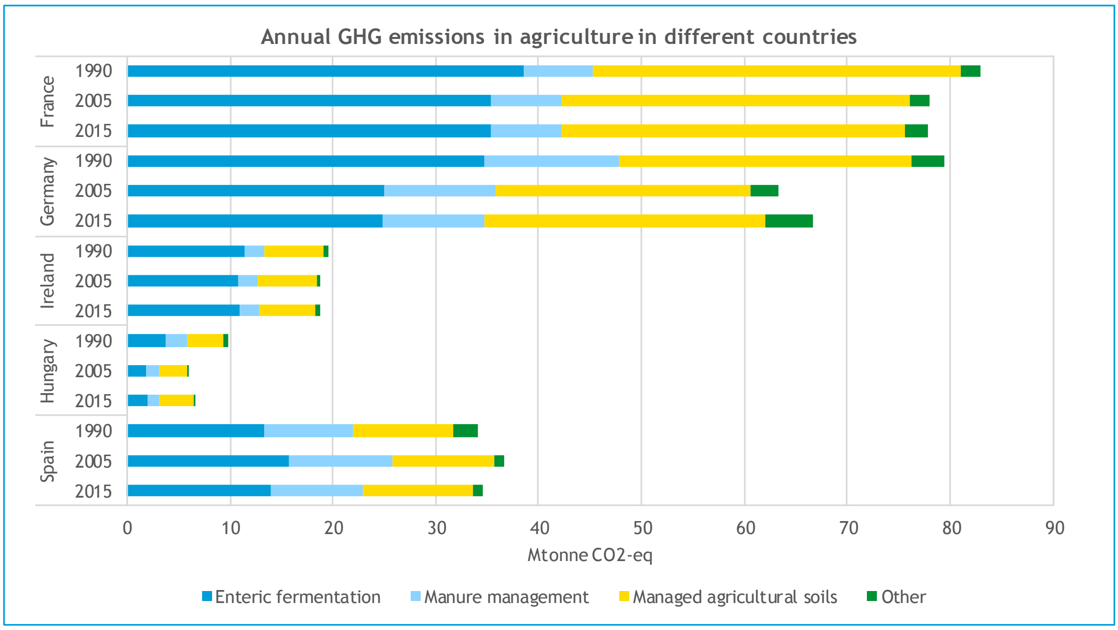
Figure 1 – Annual GHG emissions from agriculture in the EU (current composition (EEA, 2017)



Category 'other' includes: rice cultivation, field burning of residues, liming and application of other carbon containing fertilizers.

The respective countries in this study show roughly the same development: emissions in 2015 are (somewhat) lower than in 1990. In France and Ireland emissions in 2005 are almost equal to emissions in 2015, whereas in Germany and Hungary emissions actually increased between 2005 and 2015. In Spain emissions decreased between 2005 and 2015, but this was preceded by an increase between 1990 and 2005.

Figure 2 – Annual GHG emissions in agriculture in the five countries in which workshops were held; France, Germany, Ireland, Hungary and Spain



Source: (Eurostat, 2016).

3 Climate change mitigation measures in agriculture

The ten mitigation measures included in the analysis and discussed in the workshops are shortly described below. The goal of the chapter is to provide background information. For more elaborate information we refer to the background documents used for this overview (see Annexes). First an introduction to the measures is given (Section 3.1), then summaries of the costs, CO_2 eq. emission reduction potential and co-benefits of the measures (Section 3.2) are given, followed by a summary of the trade-offs related to each of the measures (Section 3.3).

3.1 Introduction climate change mitigation measures

The ten measures are further elaborated on in Annex A, which includes a short description, and information found on cost-effectiveness, mitigation potential, and environmental trade-offs and co-benefits. Both the set of measures and the information given on the measures are not meant to be comprehensive, but rather be a basis for the discussions about barriers in different countries.

Manure storage management

By covering manure stores, possibly in combination with passive ventilation, emissions of methane and nitrous oxide are reduced. Covering of both manure slurry tanks and solid manures stores is mandatory in some European countries but potential for implementation still exists in other European countries.

Anaerobic digestion of manure

Like natural (fossil) gas, biogas consists of methane and produces CO_2 when burned for energy or heat production. However, the CO_2 emissions from biogas are considered short cyclic (the CO_2 was recently absorbed by plants). Therefore biogas from manure can reduce fossil energy inputs and lower GHG emission. Additionally, anaerobic digestion reduces emissions from manure storage when storage time is shortened.

Animal management

Improving efficiency in animal husbandry can lead to a reduction in GHG emissions because of a reduction of inputs needed per produced product. In other words, the emission intensity is reduced. As part of this mitigation measure we include fodder optimization, improving livestock health and sexed semen.

Fodder optimization

Farm animals are often fed diets with more crude protein than they need. This is done to safeguard against a loss of production from a protein deficit through inaccurate analysis and/or formulation of the diet. Restricting diets to the required amounts of nitrogen (N) can limit the amounts excreted without affecting animal performance. Excretion can also be reduced by changing the composition of the diet to increase the proportion of dietary N utilised by the animal; for example, by optimizing the balance of N to carbohydrate in ruminant diets or by reducing the proportion of rumen-degradable protein.

Improving livestock health

Livestock health can be improved with preventive and curative measures. This leads to GHG emission reduction by increasing the production efficiency.

Sexed semen

Dairy cows currently produce offspring with dairy breed bulls, of which 50% is male.
Dairy breeds are not adapted for beef production and therefore all male calves and surplus female calves are slaughtered young. When using sexed semen to produce dairy cows, 90% female offspring is produced. The remaining offspring can then be bred with meat breed bulls making them suitable for meat production. This reduces both surplus calve production and the necessity for a suckler herd for beef cows.

Soil carbon conservation and sequestration

By maintaining soil carbon land use does not lead to GHG emissions. When soil carbon content is increased, a net carbon sink is created. As part of this mitigation measure we include: reduced or no tillage, maintaining soil cover, leaving crop residues on the soil surface.

Synthetic fertilizer management

By managing synthetic fertilizer inputs into agricultural systems GHG emissions from soil (nitrous oxide emissions) as well as emissions from synthetic fertilizer production can be reduced.
As part of this mitigation measure we include: matching synthetic fertilizer application with crop requirements (nitrogen management) and application of nitrification inhibitors to slow down the conversion of ammonium to nitrate and reduce the formation of N_2O.

Organic fertilizer management

By using organic fertilizer and biological fixation of nitrogen, GHG emissions from soil are lower than when synthetic fertilizer is used. Furthermore, emissions in the supply chain are reduced due to a lower use of synthetic fertilizers. Organic fertilizers such as compost, digestate and sewage sludge compost are considered here.

Switch in agricultural product

GHG emissions of certain agricultural products are higher than for other products which can fulfil the same function in our diet. A switch from a product with a high footprint to a lower footprint product could have a significant impact on the GHG emissions of European agriculture. An example is a shift from intensive livestock farming to crop production (vegetable protein products for human consumption).

Land-based livestock farming

Shift from intensive livestock farming to extensive livestock farming (which includes a smaller number of livestock per farm) reduces GHG emissions. This includes higher grass and roughage content in feed, and sourcing feed inputs (roughage, concentrates) locally. The focus of this mitigation measure is on dairy/cattle farms. Land-based livestock farming is also possible for chicken and pork farms but in those cases the GHG mitigation potential is likely to take place mostly outside the European Union, because of a reduction in import of feedstuffs such as soy.

Agroforestry

Carbon stock in and on soil is different for different agricultural systems. Agroforestry comprises of systems in which woody perennials are used on the same land as crops and or animals. In agroforestry additional carbon is stored, relative to grasslands or monocrops systems. Agroforestry can also help restore degraded land and ecosystems, which can help with climate change adaptation. Under this mitigation measure we consider the shift from crop farming to agroforestry.

Conversion to other use

Some lands used for agriculture emit greenhouse gases because of the management necessary to make them suitable for agriculture (e.g. drained peatlands). Different management practices help conserve soil carbon, but necessitate a change in purpose (e.g. peatland for grazing to restored peatland). Also, land-use change, from e.g. agriculture to forest, creates a carbon sink (sequestration). Under this mitigation measure we include both restoration of peatland and wetland (including wet meadows and paludiculture) as well as afforestation of arable land.

3.2 Costs, CO_2 eq. emission reduction potential and co-benefit of mitigation measures

In the following table per mitigation measure an overview is given of:
- costs, including cost-effectiveness (€/tonne CO_2 eq. reduced) where known;
- CO_2 eq. emission reduction potential per year;
- co-benefits, other than GHG emission reduction, that could occur when implementing a measure.

Most of the information given in table is based on the original factsheets, which were used as a basis for the discussions in the workshops. During the workshops, some additional aspects came up. These are shown in italics in the table.

Table 1 - Summary of costs, CO_2 eq. emission reduction potential and co-benefits related to the ten measures

Measure	Costs	CO_2 eq. emission reduction potential Mtonne CO_2 eq. per year unless otherwise indicated	Co-benefits
Manure storage management	€ 60-200 per m^2 or € 15,000-45,000 per slurry pit. Costs for solid manure stores unknown. Cost-effectiveness: € 5-15 per tonne CO_2 eq. reduced.	100-225 kg CO_2 eq. per LSU[1]	— Improved air quality — Higher N efficiency — Reduced input dependency synthetic fertilizer
Anaerobic digestion of manure	€ 1-2 million upfront investment. Can be cost-effective when biogas can be sold a premium level.	~600 kg CO_2 eq. per animal EU28 potential: — Farms >100 LSU ~60 — Farms > 200 LSU: ~10	— Improved air quality — Higher N efficiency — Reduced input dependency: synthetic fertilizer and fuel
Animal management	Both fodder optimization and improving livestock health can be cost-effective.	EU28 potential: — Fodder optimization: 0.8-2.3 — Improving health: 2.3-23 — Sexed semen: 1.4-5	— Improved water, air and soil quality: lower N and P in manure — Human health benefits — Improved animal welfare
Soil carbon conservation and sequestration	Economic benefits because of decreased costs of ploughing. Start-up phase may result in temporary losses. Leaving crop residues could lead to losses in case these are currently marketed.	EU28 potential: — Reduced/no tillage: 2.3-31 — Soil cover: 110-190 — Crop residues: 14-280	— Land is more resilient to the effects of climate change — Reduced risk of erosion — Increased water quality because of reduction in nitrate leaching — Reduced input dependency: fuel
Synthetic fertilizer management	Low costs for nitrogen nutrient management. Nitrification inhibitors approx. € 125/ha.	EU28 potential: — Nitrogen management: 2.4-24 — Nitrification inhibitors: 47-140	— Increased water and soil quality — Improved air quality — Reduced input dependency: synthetic fertilizer
Organic fertilizer management	Cost reduction due to reduced synthetic fertilizer costs. Increased margin of biological nitrogen fixation € 75-80/ha. Cost reduction of application of organic fertilizer dependent on availability and price of organic fertilizers.	EU28 potential biological fixation (incl. fertilizer production): 140-290 Emission reduction of organic fertilizer application depends on C:N balance in the soil	— Improved water quality and air quality — Improved soil quality — Improved biodiversity — Reduced input dependency: synthetic fertilizer

[1] If the reduction potential is described per LSU this means that it is per livestock unit. This is a unit that makes it possible to aggregate livestock from different species. E.g. a dairy cow producing milk for a year is 1 LSU, while a breeding sow (pig) is 0.5 LSU.

Measure	Costs	CO_2 eq. emission reduction potential Mtonne CO_2 eq. per year unless otherwise indicated	Co-benefits
Switch in agricultural product	Requires investments and may mean loss of previously made investment costs.	Emission reduction depends on demand	— Increased water and air quality — Reduction in per capita land-use — Human health benefits — Reversed carbon leakage
Land-based livestock farming	Requires investments and may mean loss of previously made investment costs. Reduction in feed costs.	Emission reduction depends on demand	— Reversed carbon leakage — Better economic perspective — Reduction in food-feed competition — Reduced input dependency: feedstuffs — Reduced risk of fire *(Workshop Spain)*
Agroforestry	Requires investments and may mean loss of previously made investment costs. Decrease in yield in short term but increase in the medium/long term.	EU28 potential: 28-170	— Improved air quality — Improved water quality — Improved soil quality — Improved flood management and resilience to climate change — Improved pest control — Improved biodiversity
Conversion to other use	Conversion costs and management costs. *However, reduced costs of management of drained wetland/peatland (Workshop Ireland).*	EU28 potential: Restoration of peatland and wetland: 0.2-1.2 Afforestation of all arable land: 280-350	— Improved soil quality — Improved water and air quality — Improved climate change resilience — Improved biodiversity

Note: Aspects identified in the workshops are listed in italics.

Note: More elaborate information on the measures can be found in Annex A, including sources for shown information.

3.3 Trade-offs to take into account for optimal policy results

From an environmental and social perspective, trade-offs give valuable information about the potential side effects of measures, and therefore the additional aspects which need to be taken into account when designing policy. Trade-offs were included in the factsheets. Trade-offs from the initial factsheets, as well as additional ones identified in the workshops are listed in Table 2.

It is possible that a measure contributes to realizing a reduction in GHG emissions in one part of the system, while at the same time increasing GHG emissions in another part (within or outside the agricultural system). For example: Afforestation reduces emissions, which is accounted for in the LULUCF sector, not in the agricultural sector. Furthermore, the benefit depends on the soil type; on peat soils the reduction may be counteracted by increased emissions from those soils. In this report, when discussing measures, it is assumed that they are implemented correctly, and that there is a net benefit (reduction of emissions) in the economy as a whole. This illustrates the necessity to take a systems perspective when mitigation potential is discussed.

Table 2 – (Potential) trade-offs identified in the analysis of climate mitigation measures and mentioned in the workshops

Aspect	Trade-off	Applies to measure(s)
Long-term change	Measures aiming towards (more) intensification and/or specialization may delay, complicate or prevent future emission reduction and more systemic changes. In other words, such measures might lock the sector in a system that would at some point reach its reduction limits (lock-in effect). *Measure does not bring a solution for the agricultural system as a whole, i.e. it does not necessarily reduce emissions from agricultural production and could lead to intensification of remaining agricultural areas (Workshop France).* *Measure may delay systemic change in moving from synthetic to organic fertilizers (Workshop Hungary).*	Manure storage management, Anaerobic digestion, Animal management *Conversion to other use.* *Synthetic fertilizer management*
Carbon leakage	A shift at farm-level does not mean a EU-wide shift. Carbon leakage could occur if demand does not change and less efficient production elsewhere fulfils demand. A holistic approach and life cycle perspective on a systemic level is needed to gain insight into such an effect.	Switch in agricultural product, Land-based livestock farming, Agroforestry, Conversion to other use.
Air quality	NO_x, PM and NH_3 emissions may increase dependent on manure/digestate handling and air treatment at the anaerobic digester. May increase ammonia emissions.	Anaerobic digestion Synthetic fertilizer management
Human health	When using antibiotics as curative treatment instead of preventive controls the risk for antimicrobial resistance increases.	Animal management
Production loss	Reduced or no tillage can lead to yield reduction for e.g. winter cereals and maize, no influence on other crops. In the adaptation phase production loss may occur because of fine-tuning nutrient application.	Soil carbon conservation and sequestration Synthetic fertilizer management, Organic fertilizer management
Biodiversity	Reduced or no tillage can lead to increased herbicide use for root crops having an adverse effect on biodiversity. In case of non-native trees too close to semi-natural woodland habitats, biodiversity can decrease. *Biodiversity could decrease if afforestation occurs with monoculture. Important to also include shrubs, etc. (Spain/France).*	Soil carbon conservation and sequestration Agroforestry, Conversion to other use Conversion to nature
Competition	Use of crop residues competes with demand for residues for other purposes e.g. feed. Use of non-wastes could lead to additional food and feedcrop production used in the anaerobic digester when co-digesting. This food/feedcrop could then not be used for its original purpose.	Soil carbon conservation and sequestration Anaerobic digestion

Aspect	Trade-off	Applies to measure(s)
Soil quality & water quality	Certain types of nitrification inhibitors lead to soil acidification and/or salinization. Possible reduction in water and soil quality due to additional heavy metals and other pollutants still present in organic fertilizers. Rewetting of peatland can increase nitrogen and phosphorus leaching, especially when fertilizers have been applied to the land before.	Synthetic fertilizer management Organic fertilizer management Conversion to other use
Animal welfare	*Systems may optimize on output, not on animal health and animal welfare (France).*	*Animal management*
Flood risk	*Risk of flooding if wet meadows are afforested (France).*	*Conversion to other use*

Note: Trade-offs identified in the workshops are listed in italics.

Note: More elaborate information on the measures can be found in Annex A, including sources for shown information.

4 Barriers to implementation of climate mitigation measures

In Section 4.1 the barriers to implementation of the climate mitigation measures are summarized. As trade-offs are important to take into account for optimal policy result, these are summarized in Section 3.2. An evaluation of the measures is presented in Section 4.3.

4.1 Overview of barriers to implementation gathered in the workshops

In Table 3 the barriers to implementation of the different climate mitigation measures are elaborated on. Not all barriers are sensible in all situations; for example, local soil and weather characteristics, or lack of other local sources of income may make implementation of measures or change of practices unfeasible or may make measures less attractive from a climate mitigation point of view. Barriers to obtaining effective results are therefore not included in Table 3. In Annex A the measures are elaborated on, including a list of barriers mentioned per measure.

Four types of barriers, with questions like the following, were explored in stakeholder meetings in five different countries:

Financial *Are subsidies available if necessary? Are there benefits for the farmer?*
Knowledge *Is information available? Are additional skills necessary?*
Trust *Will trade-offs harm the farm(er)? Is there access to experienced farmers*
Other *How will the measure impact the workload?*
In the category other, barriers identified related to time, culture, legislation and lobby.

Table 3 – Overview of barriers to implementation of climate mitigation measures, gathered from the five workshops

Type of barrier	Barrier	Applies to measure(s)
Financial	Investment costs for manure covers can be expensive, especially for small farms.	Manure storage management
	A sexed semen scheme is expensive, especially for small farms. For large farms it may be cost-efficient.	Animal management (sexed semen)
	Machinery for conservation agriculture is expensive, only feasible for larger farms.	Soil carbon conservation and sequestration
	Only profitable for large farms in some European Member States (e.g. Germany). Obtaining funding can be difficult due to restrictive requirements (e.g. in Spain).	Anaerobic digestion
	High costs for monitoring (especially difficult for small farms) and equipment for precision farming.	Synthetic fertilizer management (nitrogen management)
	High purchasing costs of nitrogen inhibitors.	Synthetic fertilizer management (nitrogen inhibitors)
	Stranded assets: When moving away from a type of agriculture to a new agricultural product or by converting to nature, early investments may become obsolete.	Switch in agricultural product Conversion to other use
	Return on investment time for agroforestry can be high, therefore may not be attractive if not fully subsidized.	Agroforestry
	Current compensation for conversion to other use, specifically nature, is often not enough.	Conversion to other use
Knowledge	Lack of technical expertise on how to run an anaerobic digester.	Anaerobic digestion
	Lack of data, knowledge gaps on impact of endemic diseases on production loss in animal husbandry. Lack of knowledge of impact of antibiotic use reduction.	Animal management (animal health management)
	Lack of data, knowledge gaps on e.g. perceived necessity to till the ground and management of weed and associated crops.	Soil carbon conservation and sequestration
	Lack of information on impacts of current practices (e.g. over-fertilization).	Synthetic fertilizer management (nitrogen management)
	Lack of knowledge on use, effectiveness and risks of organic fertilizer products.	Organic fertilizer management
	Lack of information on local options (locally adapted species) and influence on yields.	Agroforestry
	Farmers lack cost-benefit information.	Manure storage management
	Uncertainty about whether nitrification inhibitors can be used in crop farming for food, whether they have been and need to be added to the CODEX list for food additives.	Synthetic fertilizer management (nitrification inhibitors)
Trust	Low social acceptability, because of safety reasons.	Manure storage management Anaerobic digestion
	Low acceptability because of perceived low cost-effectiveness.	Manure storage management
	Consumer (of food product) acceptance of nitrification inhibitors is low.	Synthetic fertilizer management (nitrification inhibitors)

Type of barrier	Barrier	Applies to measure(s)
	Low acceptance of alternative/organic fertilizer/soil enhancement products (e.g. health risk related to use of sewage sludge).	Organic fertilizer management
Other: Time	Time needed for conversion.	Synthetic fertilizer management (nitrogen management)
Other: Lobby	Strong lobby for use of synthetic fertilizers.	Synthetic fertilizer management (nitrogen management) Organic fertilizer management
Other: Cultural	Cultural: shift from farmland to 'forest' is unacceptable to many farmers.	Agroforestry
	Lack of innovation drive, farmers see no need for change	Agroforestry Manure storage management
	Cultural: 'loss of land' is unacceptable to many farmers.	Conversion to other use
Other: Legislation	Current legislation promotes intensification and large-scale livestock farming.	Switch in agricultural product Land-based livestock farming

4.2 Evaluation of climate mitigation measures

In Table 4 the ten measures are listed, along with a relative evaluation of the costs, GHG mitigation potential, co-benefits, trade-offs and barriers. From this summary it seems that most measures have different types of barriers. Financial barriers are often presented, but usually accompanied by knowledge or other barriers. Translated to policy: this means that solely focussing on financing is not enough. Additional policy is needed to overcome the knowledge and other barriers. Overcoming such barriers is more of an ongoing process. In terms of difficulty, these may therefore be more difficult to overcome than financial barriers as they relate to culture and time investments of the farmers implementing the measures.

Table 4 – Evaluation of measures; costs, CO_2 potential, co-benefits, trade-offs and barriers

	Costs	GHG mitigation potential	Co-benefits	Trade-offs	Barriers
Manure storage management	-	++	+	-	Financial, Knowledge, Trust
Anaerobic digestion of manure	+/-	++	+	--	Financial, Knowledge
Animal management					
Fodder optimization	+/-	+	++	-	-
Improving livestock health	+/-	+	++	-	Knowledge
Sexed semen	-	+	+	-	Financial
Soil carbon conservation and sequestration					
Reduced or no tillage	+	+	++	--	Knowledge, Financial
Maintaining soil cover	+	++	++	-	Knowledge, Financial
Crop residues on soil surface	+/-	++	++	--	Knowledge, Financial
Synthetic fertilizer management					
Nitrogen management	+	+	++	-	Knowledge,

	Costs	GHG mitigation potential	Co-benefits	Trade-offs	Barriers
					Financial, Other
Inhibitors	-	+	+	--	Financial, Trust, Other
Organic fertilizer management					
Biological nitrogen fixation	+	+++	+++	-	Knowledge
Organic fertilizers	+/-	+++	+	--	Knowledge, Trust, Other
Switch in agricultural product	-	+++	+++*	-	Financial
Land-based livestock farming	+/-	++	++*	-	Financial, Trust
Agroforestry	+/-	+++	+++*	-	Knowledge, Financial, Other
Conversion to other use	-	+	+++*	--	Financial, Other

Note: Scores are comparable per column, not per row.
Green colored cells indicate: the darker the green the more attractive.
Purple colored cells indicate: the darker the purple the less attractive.
* Systemic benefits if no carbon leakage takes place.

4.3 Insights related to implementation of climate mitigation measures

Three main overarching insights were identified in the analysis of climate mitigation measures and the discussions during the workshops:

1. **Insight 1: There is a lack of long-term vision translated to consistent policy**
   - Member States are currently not asked to put in place a long-term climate strategy for agriculture on a systemic level. Furthermore, the EU does not have a long-term strategy on the future of a sustainable European agricultural system. Long-term consistent policy helps stakeholders work towards a common goal. Lack of long-term consistent policy creates uncertainty, a fear of investment and slow change. Farmers are risk averse: If current practices work (with regard to production), the need for change is not felt at an individual level. Farmers tend to be unwilling to take risks and are often not innovative, possibly in part because of the lack of long-term consistent policy. Farmers may only change current practices if they receive a subsidy. Also, if support is in place but is ended, farmers may quit (implementing) the more sustainable practice. Innovators and early adopters may be penalized, if support is discontinued. In conclusion, farmers need certainty (through e.g. policy) that the new practice is attractive long-term.
   - Measures may not be implemented unless 100% subsidized, because of lack of funds at a local level. Most of the benefits of a measure may be societal and environmental, with uncertain benefits for the farmer, as with for example agroforestry. Governments should weight the societal and environmental benefits against the costs of implementation. Translating this to a long-term vision and policy on a systemic (national) level, can help farmers make the transition to a more sustainable system. This links to Insight 3: measures which need supplementation by local funds may not be implemented in poorer regions, with smaller farms, which could contribute to climate mitigation.

- Ownership: during both the workshops in Ireland and Hungary it was mentioned that the farmer and the landowner are not necessarily the same person. This may make it difficult to implement measures: if a landowner can find a farmer to lease his/her land as is, there is no direct incentive for the landowner to implement measures. At the same time: if the farmer does not own the land, there is no direct incentive to implement measures if subsidies are not allocated directly to the farmer, and if measures may only start giving a return on investment after the lease is up.

Insight 2: Measures may push towards intensification/scaling up/efficiency on a product level, but not on a systemic level
- Certain measures are only relevant for (large-scale) intensive livestock systems. Implementing those measures may improve efficiency, but on a systemic level emissions may still increase (with a growing livestock sector).
- Applying for funding may be difficult, in terms of knowledge needed and bureaucracy. Smaller farms may not have the resources (human) to go through these processes.
- Implementing precision methods, using software and big data are more feasible for larger farms with more resources (financial and human). This also links to Insight 3.

Insight 3: There is a lack of information, knowledge and access to relevant data, which influences small and large farms differently
- Information on costs vs. benefits and necessity of implementation of measures is missing, and/or not widely known by farmers.
- When information and/or knowledge is available, it may only be available to those (larger) farms which can afford software and tools.
- Lack of information and knowledge does not only apply to the implementation phase, but also to the phase in which farmers apply for support: bureaucratic requirements are intense, which is a problem especially for smaller farms which may be more willing to implement more sustainable practices.

5 Background: Proposed CAP post 2020

On June 1 2018 the European Commission published the proposal (2018/0216) for a *Regulation of the European Parliament and of the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD)*. This proposal repeals the earlier CAP regulations (1305/2013 and 1307/2013). It is to come into effect January 1, 2021 (EC, 2018b).

Objectives

The proposal states that the CAP payments supplied to Members States under the regulation *“shall contribute to the environmental- and climate related objectives of the Union”*.

In Article 6 of the proposal the specific objectives explicitly related to sustainability are:
- (d) Contribute to climate change mitigation and adaptation, as well as sustainable energy;
- (e) Foster sustainable development and efficient management of natural resources such as water, soil and air;
- (f) Contribute to the protection of biodiversity, enhance ecosystem services and preserve habitats and landscapes.

One specific objective links to consumption and sustainability:

– (i) Improve the response of EU agriculture to societal demands on food and health, including safe, nutritious and sustainable food, food waste, as well as animal welfare.

CAP Strategic Plan

All Member States should make a CAP Strategic Plan, in which they present the interventions which will be taken to reach the specific objectives listed above. The plan should include quantitative targets and milestones, for which a common set of result indicators are given. The indicators include Impact Indicators, Result Indicators and Output Indicators.

Member States need to review their progress annually, presented in an Annual Performance Report. In this report Member States should report on realised output and on the contribution to achieving the goals set for the entire period.

Structure of the proposed CAP post 2020 & payments

The basic structure of the CAP has not changed: there are **direct payments** through the European Agricultural Guarantee fund (**EAFG**), also referred to as **Pillar 1**, and payments through the European Agricultural Fund for **Rural Development** (**EAFRD**), also referred to as **Pillar 2**. Budgets for EAFG and EAFRD are supplemented by additional funding from Horizon Europe, for support of research and innovation.

In order to get income support under Pillar 1, farmers should fulfil certain minimum standards, the **Good Agricultural and Environmental Conditions (GAEC)**. This is called **conditionality**.

The proposal reduces direct payments per farmer (in Pillar 1/EAGF), compared to the current CAP; between 25-75% for farmers receiving between € 60,000 and € 100,000 annually, and by 100% for the amount exceeding € 100,000 annually[2]. Total spending, however, is expected to increase in Pillar I and decrease in Pillar II (Matthews, 2018).

There is a certain **flexibility** to payments: up to 15% of direct payments (Pillar 1) can be transferred to rural development (Pillar 2), and vice versa. For interventions addressing climate change, a higher percentage can be transferred from Pillar 1 to Pillar 2. In the proposed regulation, Member States can choose to adopt 'eco-schemes' within Pillar 1. These schemes should be voluntary and go beyond the requirements and standards under conditionality.

Payments meant for rural development (EAFRD or Pillar 2) are not meant to cover 100% of the costs of interventions. The minimum coverage by CAP payments is 20%, and depending on the region, this can increase to 43 to 70%. For less developed regions the co-financing percentage is lower, meaning local authorities need to contribute less, relative to more developed regions. Payments transferred from Pillar 1 to 2 addressing environmental and climate objectives are exempted from this regulation, which makes it possible to still finance EAFRD interventions fully by EU payments.

[2] Labour costs are deductible.

6 Climate mitigation and the renewed CAP

The analysis of climate mitigation measures in agriculture, the identification of co-benefits, trade-offs and barriers, the discussion of all these issues in five workshops and the analysis of the proposal for the new CAP resulted in three insights (Section 4.3). There are a number of reasons for optimism about the new CAP related to these insights (Section 6.1), but there are also a number of reasons for concern (Section 6.2). In Section 6.3 we given some general recommendations for a stronger focus on sustainability in the agricultural sector and the CAP post 2020.

6.1 Reasons for optimism about the proposed CAP and climate mitigation

There are a number of reasons to be optimistic about the proposed renewed CAP and its influence on climate change mitigation by the agricultural sector. This list is not complete, but is based on the evaluation of barriers, trade-offs and co-benefits in this study.

Reason for optimism #1: Member States need to make a CAP Strategic Plan. In this plan they lay out their plan in contribute to the EU's goals, and the specific interventions with which they are planning to achieve those goals. Member States need to address how they are going to contribute to the specific environmental and climate objectives of the EU. Furthermore, the Plan should include an explanation of how interventions in agriculture will contribute to established national targets, e.g. on climate change.

Progress needs to be reported annually by Member States, in annual Performance Reports. If reported values deviate > 25% from the set target for that year, the Commission may ask for an 'action plan' including 'intended remedial actions and expected timeframe'.

Impact Indicators, Result Indicators and Output Indicators are given by the Commission, for example for climate change the following indicators are mentioned (among others):
- **Impact indicator**: Contribute to climate change mitigation: Reducing GHG emissions from agriculture. Progress on impact indicators is not included in the annual performance reports.
- **Result indicator**: Reducing emissions in the livestock sector: Share of livestock units under support to reduce GHG emissions and/or ammonia, including manure management.
- **Output Indicator**: Number of ha (agricultural) covered by environment/climate commitments going beyond mandatory requirements.

The annual performance reports focus on Output and Results Indicators (see also 'reason for concern #1).

Reason for optimism #2: The GAECs (Good Agricultural and Environmental Conditions) are set at a higher level than in the 2014-2020 CAP. GAECs addressing climate change have been added. Maintenance of soil organic matter through ban on burning arable stubble was kept in place, and maintenance of permanent pasture and protection of carbon-rich soils through appropriate protection of peatland and wetland have been added. Related to water quality, the condition to use the Farm Sustainability Tool for Nutrients was added. Related to soil quality, crop rotation was added. Finally, related to biodiversity and landscape, a ban on converting or ploughing permanent pasture in Natura 2000 sites was added.

Figure 1 shows a summary by Alan Matthews (Matthews, 2018) of the GAEC standards of the proposed post 2020 CAP compared to the current GAEC standards (Figure 3). GAECs may have a primary goal, but may impact the environment in different ways/influence different environmental aspects. There are several standards which influence climate directly or indirectly, specifically a focus on retaining carbon in the soil through GAEC 1, 2, 3, 6, 7 and 10.

Figure 3 – Current GAEC standards compared to proposed GAEC standards in the CAP post 2020

Proposed change in GAEC standards in the CAP post 2020 legislative proposals

2014-2020 GAEC standards	Proposed post 2020 GAEC standards
Climate change	**Climate change**
	GAEC 1 Maintenance of permanent pasture
	GAEC 2 Protection of carbon-rich soils through appropriate protection of peatland and wetland
GAEC 6 Maintenance of soil organic matter through ban on burning stubble	GAEC 3 Maintenance of soil organic matter through ban on burning stubble
Water	**Water**
GAEC 1 Establishment of buffer strips along water courses	GAEC 4 Establishment of buffer strips along water courses
GAEC 2 Where use of water for irrigation is subject to authorisation, compliance with authorisation procedures	
GAEC 3 Protection of groundwater against pollution	
	GAEC 5 Use of Farm Sustainability Tool for Nutrients
Soil protection and quality	**Soil protection and quality**
GAEC 5 Minimum land management reflecting site specific conditions to limit erosion	GAEC 6 Minimum land management under tillage to reduce risk of soil degradation including on slopes
GAEC 4 Minimum soil cover	GAEC 7 No bare soil in most sensitive period
	GAEC 8 Crop rotation
Biodiversity and landscape	**Biodiversity and landscape**
GAEC 7 Retention of landscape features, a ban on cutting hedges and trees during the bird breeding and nesting season, and as an option, measures for avoiding invasive plant species.	GAEC 9 Maintenance of non-productive features and area, including a minimum share of agricultural area devoted to non-productive features or areas, retention of landscape features, a ban on cutting hedges and trees during the bird breeding and nesting season, and as an option, measures for avoiding invasive plant species.
	GAEC 10 Ban on converting or ploughing permanent grassland in Natura 2000 sites

Sources: Annex III of Regulation No 1306/2013 and Annex II of draft CAP Strategic Plan Regulation

Reason for optimism #3: In Article 6 of the proposed regulation, specific mention is made of societal demands, including health and sustainable food (objective i). The link to consumption is interesting, because it is very well possible to improve diets both in health aspects as well as on sustainability. This mention opens the possibility for a more systemic approach of the CAP, in which the whole supply chain including the consumer is included. This objective is mentioned for the different subsectors as one of the objectives which could be chosen to pursue.

Reason for optimism #4: Moving payments from Pillar 1 (EAGF) to Pillar 2 (EAFRD) is possible; up to 15% can be transferred from one pillar to the other. Transfers from Pillar 1 to Pillar 2 are allowed to exceed the 15% when there are used for environmental or climate measures. Furthermore, if payments are transferred from Pillar 1 to Pillar 2, 100% of the expenditure may be covered by EAFRD payments.

6.2 Reasons for concern about the proposed CAP and climate mitigation

There are, however, also a few reasons for concern. This list is not complete, but is based on the evaluation of barriers, trade-offs and co-benefits in this study.

Reason for concern #1: There is no Strategic Plan for the EU as a whole. The proposal gives individual Member States room to be more ambitious. The EU as a whole does not, however, put down a vision for a sustainable agricultural system. Just as having a national vision helps farmers make choices, a EU vision helps Member States in making choices.
The proposed regulation puts more emphasis on addressing environmental and sustainability issues. These are, however, only monitored indirectly. Member States set targets based on Results Indicators, which are used as basis for the annual report of the Commission to the European parliament. An example of such a Result Indicator is '*the share of agricultural land under commitments to reducing emissions, maintaining and/or enhancing carbon storage'* (the only 'core indicator' related to climate change which is included in the report of the Commission to European Parliament).

The EU is working on further integrating climate action into the EU budget; more specifically, a target of 25% of EU expenditure contributing to climate objectives is propose by the commission (EC, 2018c).
In the CAP post 2020 proposal it is stated that is it expected that 40% of the overall CAP budget ('overall financial envelope') will contribute to reaching climate objectives. As no monitoring on Impact indicators (example of Impact Indicator: '*reducing GHG emissions from agriculture'*) takes place, it will be difficult to assess cost-effectiveness of the CAP budget on reaching climate objectives, while it will go a long way to contributing to the budgetary climate action goal.

Reason for concern #2: The Strategic Plan is a only a plan. In Article 92 of the proposal, aptly named *"Increased ambition with regard to environmental – and climate related objectives"* the following is stated: "Member Stated shall aim to make, through their CAP Strategic Plans (…), a greater overall contribution to the achievement of the specific environmental- and climate-related objectives". 'Shall aim to make' does not sound very ambitious, even though the objectives of the proposed CAP and the elements to be included in the plan could be interpreted that way.

In the Annual Performance Reports, Member States only have to report on their progress on Output and Results Indicators. This means Member States do not necessarily monitor on impact i.e. actual reduction of GHG emissions, and a systemic perspective may be lacking. Actual emission reductions are not included as targets monitored in the MS's Annual Performance Reports, or in the Commission's performance information presented to the European parliament. For the objective regarding climate change mitigation, only the Result Indicator about carbon storage in soils an biomass mentioned above is included for the Commissions annual report (EC, 2018c).

Reason for concern #3: The minimum GAECs depend on local/regional conditions.
This implies that they are different for different Member States and different regions within Member States. The standards are, however, not solely based on environmental characteristics. Member States should define the standards for their particular situation. Aspects like the soil and climatic conditions should be taken in account, but also for example existing farming conditions and farming practices. It is mentioned that Member States may define additional national standards. This is concerning as it may lead MS to interpret conditions and effects differently, and lead to MS try and take environment into account as little as possible to gain a competitive advantage.

6.3 Recommendations for CAP post 2020

This list is not complete, but is based on the reasons for optimism and reasons for concern identified based on the evaluation of barriers, trade-offs and co-benefits in this study.

1. **Quantitative GHG emission targets for agriculture at national level**
   A major condition for the Strategic Plan to contribute to sustainability long-term is that the Plan includes a long-term vision and goals with quantitative targets *on a systemic level*. This is especially important for the impact of agriculture on climate change.
   We recommend that the plan includes targets for 2030 and 2050 for the total amount of GHG emissions from agriculture (Impact Indicator) and how reductions compared to the current situation will be achieved. This can be split into two parts: how different subsectors can be more efficient and effective in terms of GHG emissions per kilogram of product (Result Indicator) *and* how the sum of all subsectors will be reduced over time to reach the targets (Impact Indicator). How both will be achieved should therefore be elaborated on in the Strategic Plan. In the intervention strategy (Article 97) only mention is made that targets for specific result indicators should be set.
   Putting down a long-term vision and goals helps decide whether interventions only contribute to efficiency, or also to reaching the national targets. It also helps identify whether interventions may lead to lock-ins. Do interventions help to reduce GHG emissions short term, but make it more difficult to reach the long term goals because it becomes more difficult to change? If setting GHG emission targets would be mandatory, it could be evaluated whether all Strategic Plans combined coincide with the targets at EU level.

2. **Focus on other environmental aspects, besides climate change**
   Solely focussing on climate change may lead to trade-offs, or underestimation of benefits of interventions. Climate action is an important goal in the CAP post 2020. So are other environmental aspects. It is very important to take a broader (than climate) view on sustainability. For example, measures like manure management and anaerobic digestion may push towards intensification. This could involve trade-offs like creating a lock in which makes systemic change more difficult in the long term. On the other hand, measures like soil carbon conservation and sequestration and organic fertilizer management have co-benefits like improved climate resilience because of better water drainage and soil moisture conservation. Delivering such additional services could be part of eco-schemes.

3. **Putting down a long-term vision creates security for farmers**
   Not only are a long-term vision and goals necessary to ensure reaching national targets. It is also necessary to give farmers the certainty that their investments will be worthwhile, and that if they decide to be relatively early adopters, they will not be out-competed by their neighbours.

4. **A shift in focus from agriculture to food**
   The primary goal of agriculture is of course to produce the food we eat. Therefore, aiming to make our food more sustainable by solely focussing on production, is taking a limited view. In article 6 of the proposal the following specific objective is presented: *Improve the response of EU agriculture to societal demands on food and health, including safe, nutritious and sustainable food, food waste, as well as animal welfare.* (EC, 2018b). It is not mentioned as one of the objectives for which an intervention strategy should be included in the CAP Strategic Plan. Attention for sustainability of our diets, and policy to steer us into a more sustainable direction, can help reduce the

footprint of our diet. Furthermore, such policy can simultaneously create a market (national and possibly EU) for more sustainable products.

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A Summary of measures

A.1 Manure storage management

15% of the direct European (EU28) agricultural GHG emissions (in CO_2 eq.) are related to manure management (in 2015, (EEA, 2017)). Better management of manure storage can play an important role in reducing these GHG emissions. Mitigation options include:
- covering manure slurry tanks incl. passive ventilation (mandatory in some European countries);
- covering solid manure stores with an airtight cover (mandatory in some European countries);

By covering manure stores, possibly in combination with passive ventilation, emissions of methane and nitrous oxide are reduced (Dalgaard, et al., 2011).

Current application

33% of European livestock holdings had storage facilities for manure in 2010. Difference are big within the European Union, for example in Austria, Slovakia, Sweden and Switzerland almost all holdings had manure facilities while in Bulgaria and Cyprus this was rarely the case (Eurostat, 2013).

Covering of manure storage is mandatory in e.g. Germany, Lithuania, the Netherlands and Denmark (AMEC & Bio Intelligence Service, 2014) while this is not the case in Ireland, Spain, Hungary and France. In 2010 in the EU28 only 14% of the holdings with manure storage facilities for solid manure has a cover while 69% of the holdings with storage facilities for slurry has a cover (Eurostat, 2013).

Applicability

This measure is applicable in European Member States where manure storage facilities are in place but where covering of manure storage is not (yet) mandatory.

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 5 - Summary - Manure storage management

Aspect	
CO_2 eq. emission reduction	Covering manure slurry tanks with cover with passive ventilation (Dalgaard, et al., 2011): – 200 kg CO_2 eq./LSU pig; – 165 kg CO_2 eq./LSU cow. Covering solid manure stores with airtight cover (Dalgaard, et al., 2011): – 225 kg CO_2 eq./LSU pig.; – 100 kg CO_2 eq./LSU cow. LSU = livestock unit. This is a unit that makes it possible to aggregate livestock from different species. E.g. a dairy cow producing milk for a year is 1 LSU, while a breeding sow (pig) is 0.5 LSU.
Costs	Cover costs for slurry tank covers are between 60 and 200 €/m^2 or between 15,000 and 45,000 € per slurry pit (European Parliament, 2014). The cost difference depends on the cover type.

Aspect	
	Cost-effectiveness: 5-15 €/tonne CO_2 eq. reduced (PBL & ECN, 2017). Cost-effectivity describes the costs of reducing GHG emissions. It includes all financial costs and benefits. Cost-effectiveness does not state anything about who will pay the costs or reap the benefits. Cover costs for solid manure stores: Unknown.
Trade-offs	— May prevent systemic change: Measures increasing efficiency of intensive animal husbandry may postpone systemic change in some regions. — Risks pushing for specialization and intensification and increasing livestock in regions that already have high livestock density (Workshop France, Workshop Germany).
Co-benefits	— Better air quality and reduced odour because of reduction in particulate matter and ammonia emissions when covering manure (WUR, 2017) (SRUC, et al., 2017). — Higher nitrogen efficiency because of higher nitrogen content in manure. Less ammonia is emitted (European Parliament, 2014). — Reduced dependency on inputs because of lower synthetic fertilizer use.
Barriers	— Financial: Storage covers are perceived as expensive (Workshop Hungary), especially for small farms (Workshop Germany). Large farms may not always get public support (Workshop France). — Knowledge: Farmers lack cost-benefit information (Workshop France). — Trust: It is indicated is that the cost-effectiveness of the measure is not good. Furthermore, implementation may not always be acceptable to residents, because of safety (Workshop France).

A.2 Anaerobic digestion of manure

15% of the direct European (EU28) agricultural GHG emissions (in CO_2 eq.) are related to manure management (in 2015, (EEA, 2017)). Anaerobic digestion can play an important role in reducing these emissions.
By producing biogas from manure, energy inputs in the supply chain/system are reduced. The CO_2 emissions from using biogas are short cyclic (the CO_2 was recently absorbed by plants), therefore the emission from using biogas it in boilers or in transport are not counted as fossil CO_2 emissions. Besides reducing energy inputs emissions from manure storage can also be reduced due to anaerobic digestion if manure storage time is shortened.

Current application

Anaerobic digestion of manure is currently mainly applied in Germany, UK, Italy and Czech Republic.
In most other European countries anaerobic digestion is not commonly applied.

Applicability

Anaerobic digestion is applicable to all types of manure, as long as the right process parameters are applied.

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 6 – Summary – Anaerobic digestion

Aspect	
CO_2 eq. emission reduction	— Anaerobic digestion at all EU28 farms > 200 LSU: 9.1-12.4 Mton CO_2 eq./year (Pérez Domínguez, et al., 2016); — Anaerobic digestion at all EU28 farms > 100 LSU: 60 Mton CO_2 eq./year (European Parliament, 2014); — 645 kg CO_2 eq./LSU pig (Dalgaard, et al., 2011); — 590 kg CO_2 eq./LSU cattle (Dalgaard, et al., 2011). *LSU = livestock unit. This is a unit that makes it possible to aggregate livestock from different species. E.g. a dairy cow producing milk for a year is 1 LSU, while a breeding sow (pig) is 0.5 LSU.*
Costs	An anaerobic (co-)digester adopted for on farm use: between 1,000,000 and 2,000,000 € in upfront investment (European Parliament, 2014). The digestion can be cost-effective (from a farmer's perspective) when the produced biogas can be sold at a premium or when both heat and electricity from utilization of biogas in a combined heat and power (CHP) installation can be sold. The cost-effectiveness is highly dependent on national policy (national subsidies) (Commission of the European Communities, 2009). Additional costs for use of gas on own farm for example when upgrading to green gas, application in CHP installation or when amending a tractor to be able to drive on gas. Co-digestion is only feasible when the digestate can be used on the farm, when manure and digestate have a value (price), and there is no excess of phosphorus. Otherwise, costs of transport likely exceed benefits. The straw needed for anaerobic co-digestion is scarce in Hungary (Workshop Hungary), making co-digestion not very suitable in Hungary.
Trade-offs	— Depending on manure and digestate handling: possibly higher ammonia emissions to air (SRUC, et al., 2017) leading to a decrease of local air quality. — Depending on air treatment from anaerobic digester: higher local NO_x and particulate matter emissions (SRUC, et al., 2017) leading to a decrease in air quality. — Use of non-waste for co-digestion: In case of co-digestion, use of non-wastes could lead to additional food and feed production (WUR, 2017). — Less carbon is added to the soil when using digestate for fertilization than when using raw manure (Alterra, 2008). To maintain soil carbon content additional measures may have to be taken. — May prevent systemic change: Measures increasing efficiency of intensive animal husbandry may postpone systemic change in some regions.
Co-benefits	— Increased local air quality: Biogas can be used in own machinery (usually using diesel), which results in reduction of PM_{10} and NO_x emissions on-farm. — Higher nitrogen content in digestate than in manure digestion leads to a higher anorganic N-content which is more readily available to crops (Alterra, 2008). This means the efficiency of the fertilizer product is improved. — Reduced dependency on inputs: Higher nitrogen content leads to lower fertilizer use and biogas use in own machinery or use of biogas in CHP reduces need for external energy sources.

Aspect	
Barriers	— Financial: The investment costs are high (Workshop France) making anaerobic digestion only profitable (if at all) for large farms (Workshop Germany). Obtaining of funding is difficult due to restrictive requirements (Workshop Spain). — Knowledge: Lack of technical expertise on how to run an anaerobic digester and lack of support in developing this expertise (Workshop France, Workshop Hungary). — Trust: Low social acceptability, because of safety reasons (Workshop France).

A.3 Animal management

Improving efficiency in animal husbandry can lead to a reduction in GHG emissions because of a reduction of inputs needed per produced product. As part of this mitigation measure we include fodder optimization, improving livestock health and sexed semen.

Fodder optimization

Farm animals are often fed diets with more crude protein than they need, to safeguard against a loss of production from a protein deficit through inaccurate analysis and/or formulation of the diet. Restricting diets to only the required amounts of N can limit the amounts excreted without affecting animal performance. Excretion can also be reduced by changing the composition of the diet to increase the proportion of dietary N utilised by the animal; for example, by optimizing the balance of N to carbohydrate in ruminant diets or by reducing the proportion of rumen-degradable protein

Improving livestock health

Livestock health can be improved with preventive and curative measures. This leads to GHG emission reduction by increasing the production efficiency per fodder intake.

Sexed semen

Dairy cows currently produce offspring with dairy breed bulls, of which 50% is male.
Dairy breeds are not adapted for beef production and therefore all male calves and surplus female calves are slaughtered young. When using sexed semen to produce dairy cows 90% female is produced.
The remaining offspring can then be bred with meat breed bulls making the remaining offspring suitable for meat production. Reducing both surplus calve production and the necessity for a suckler herd for beef cows.

Current application

Measures for better animal management have already been put in place in most farms in France.

Applicability

- Fodder optimization: In the case that land-based livestock farming is used, such as in Ireland, it is more difficult to steer food intake than in the case of intensive livestock farming.
  Fodder optimization is therefore mostly suitable in intensive livestock farming.
- Improving livestock health is limited by available land in case of land-based farming. At a certain point the herd-size is too big for healthy land-based farming.

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 7 – Summary – Animal management

Aspect	
CO_2 eq. emission reduction	**Fodder optimization** — 0.01-0.12 tonne CO_2 eq./1,000 heads of cattle/year (Ricardo, 2016); — EU28 potential 0.8-2.3 Mton CO_2 eq. per year (IEEP, 2017). **Animal health management** — 0.14-0.68 tonne CO_2 eq./1,000 heads of livestock/year (Ricardo, 2016). Very little studies are available on GHG emission reduction potential due to livestock health improvement. Therefore, the study cited made an estimate on a reduction of 1 to 10% of the baseline emissions from enteric fermentation and manure management from national inventory reports. The range shown here is the lowest end of this range (1% of the lowest baseline emission in one member state) to the highest end of this range (10% of the highest baseline emission in one member state). — EU28 potential 2.3-23.0 Mton CO_2 eq. per year (IEEP, 2017). **Sexed semen** — 6.0-21.0 tonne CO_2 eq./1,000 heads of cattle/year (Ricardo, 2016). The range is reflected by an assumption of “a range of 1 to 3.5% of baseline emissions, where the baseline is CH_4 emissions from enteric fermentation and all GHG emissions from manure management in the 2012 national inventory reports” (2014 submission) (Ricardo, 2016). - EU28 potential 1.4-5.0 Mton CO_2 eq. per year (IEEP, 2017).
Costs	— Costs for fodder optimization depend on the extent to which the diet will be changed from the current practice, but can be cost-effective (Commission of the European Communities, 2009). — Improving livestock health can be cost-effective if the costs are lower than the economic benefit of increased productivity (Ricardo, 2016). Costs that should be considered to improve livestock health are e.g. veterinary service and advice. Benefits are improved farm yields. — Sexed semen is relatively more expensive and despite improving the quality of beef calves and reducing the number of calves being send directly to slaughter, it will not change the proportion between beef/diary calves and will thus not lead to cost reduction (Ricardo, 2016).
Trade-offs	— Potential increases in antimicrobial resistance in livestock due to antibiotics use (SRUC, et al., 2017). This could pose a human health risk. National policy can have an important influence on antibiotics use. As seen in the Netherlands, antibiotics use can be substantially reduced when mandatory. Antibiotics are necessary in case of certain diseases, but other preventive measures may have a better outcome systemically. — May prevent systemic change: Measures increasing efficiency of intensive animal husbandry may postpone systemic change in some regions. — Risks pushing for specialization and intensification (Workshop France). — Systems may optimize on output, not on animal health and animal welfare (Workshop France).
Co-benefits	— Measures that improve feed conversion lead to a reduction in the amount of phosphorus and nitrogen excreted and possibly ending up in nature per kilogram of product produced. This increases the water quality (SRUC, et al., 2017). The same emission reduction also leads to increased air and soil quality.

Aspect	
	— Positive effect on human health because of a reduction in livestock carried diseases such as salmonella (SRUC, et al., 2017). — Increased animal welfare; less disease when improving animal welfare.
Barriers	**Animal health management** — Knowledge: Lack of data, knowledge gaps on impact of e.g. endemic diseases on milk production (loss) in animal husbandry (Workshop Ireland). **Sexed semen** — Financial: A sexed semen scheme is expensive, especially for small farms. For large farms it may be cost-efficient (Workshop Germany).

A.4 Soil carbon conservation and sequestration

Emissions (of N_2O) from agricultural soils are responsible for 37% of the direct European (EU28) agricultural GHG emissions, measured in CO_2 eq. (in 2015, (EEA, 2017)).
GHG emissions can occur due to soil disturbance. Carbon sequestration due to soil conservation can play an important role in reducing GHG emissions and can create a net carbon sink. Mitigation options include:
- minimizing soil disturbance by reduced or no tillage;
- maintaining soil cover to reduce fallow period (cover crops, catch crops);
- leaving crop residues on the soil surface.

Besides these options also the introduction of hedgerows, wooded banks and cash crops help reduce fertilizer input by sequestering nutrients. The latter is discussed in Factsheet 6 (Organic fertilizer management) and hedgerows and wooded banks in Factsheet 9 (agroforestry).

Current application

Soil carbon conservation and sequestration is pushed for by actors in France.

Applicability

Reduced or no tillage

Reduced or no tillage is applicable in all climate zones but is especially useful in dry regions (Ricardo, 2016). The quantity of sequestration will vary depending on the crops grown and the soil type. Soil types specifically suitable are "[…] light (i.e. course) soils and soils high in $CaCO_3$" (Ricardo, 2016).

Maintaining soil cover

Most effective "in areas with a large area of annual crop production and with light-textured free-draining soils" (Ricardo, 2016).

Crop residues

C sequestration depends on: initial soil C content, gap between content and potential soil C capacity (dependent on clay content, greater potential for clay soils), amount of residue that can be retained (dependent on soil type and climate (more potential in regions with adequate rainfall/irrigation), C:N ratio of the residue (small C:N ratio favours sequestration) (Ricardo, 2016).

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 8 - Summary - Soil carbon conservation and sequestration

Aspect	
CO_2 eq. emission reduction	**Reduced or no tillage** — 0.0059-0.0359 tonne CO_2 eq./hectare/year (Ricardo, 2016); — Total EU28 potential between 2.3-31.0 Mton CO_2 eq. per year (IEEP, 2017). **Maintaining soil cover** — 0.88-1.47 tonne CO_2 eq./hectare/year (Ricardo, 2016); — Total EU28 potential between 110-190 Mton CO_2 eq. per year (IEEP, 2017). **Crop residues** — 0.11-2.2 tonne CO_2 eq./ha/year (Ricardo, 2016); — Total EU28 potential 14-280 Mton/year (IEEP, 2017).
Costs	**Reduced or no tillage** Economic benefits of reduced or no tillage are likely because of decreased fuel costs for ploughing. Additional costs could however occur due to loss of crops in the start-up phase and increased herbicide use (Ricardo, 2016) (Teagasc, 2012) (Workshop France). **Maintaining soil crops** “Adding cover/catch crops may increase gross margin by € 16.60/ha or decrease gross margin by € 270/ha, but on average it is estimated that gross margin in the short term will decrease by € 174.50/ha” (Ricardo, 2016). **Crop residues** Loss of other income if plant residues were originally sold between € 20-150/ha/year (Ricardo, 2016). Higher prices only occur in regions where residues are in demand. For example: in regions were residue streams are used as feed or in stables.
Trade-offs	**Reduced or no tillage** — Yield reduction for winter cereals and maize. No influence on other crops (Ricardo, 2016). — Increased herbicide use in root crops such as potatoes and carrots because of increased vulnerability to weeds at the start of the growth season (Teagasc, 2012). This can have an influence on biodiversity. **Crop residues** May conflict with efforts to use residues at biomass for energy production (Commission of the European Communities, 2009), increased use of fungicides.
Co-benefits	— Land is more resilient to climate change because of better drainage and water retention and soil moisture conservation (Hawken (ed.), 2017) (Ricardo, 2016); — Increased soil quality: reduced risk of erosion (Ricardo, 2016), better soil structure better nutrient retention; — Reduction in nitrate leaching and thus increased water quality (Hawken (ed.), 2017). — Lower/no fuel use (Hawken (ed.), 2017).
Barriers	— Financial: Machinery for conservation agriculture is expensive and applying for subsidies is only feasible for larger farms (Workshop Spain). — Knowledge: Lack of data, knowledge gaps on e.g. perceived necessity to till the ground (Workshop Spain) and management of weed and associated crops (Workshop Hungary, Workshop France). Providing tools for farmers is important (Workshop Ireland, Workshop Germany, Workshop Hungary, Workshop Spain).

A.5 Synthetic fertilizer management

By managing synthetic fertilizer inputs into agricultural systems GHG emissions from soil (nitrous oxide emissions) as well as emissions from synthetic fertilizer production can be reduced.
As part of this mitigation measure we include: matching synthetic fertilizer application with crop requirements (nitrogen management) and application of nitrification inhibitors to slow down the conversion of ammonium to nitrate and reduce the formation of N_2O.

During the Irish workshop it was mentioned that protected urea is much better from a financial perspective than nitrification inhibitors. We do not further describe protected urea, but application of protected urea would fall under this mitigation measure.

Current application

Management of nitrogen addition to soil is applied all over Europe, but does not always occur as effective as possible. Nitrification inhibitors are only applied to a very limited extend.

Applicability

Nitrogen management can be applied in all cases where synthetic nitrogen fertilizer is applied. Application of nitrogen management could be more efficient if it is combined with other management systems, such as water management.

Nitrification inhibitors can be used whenever nitrogen fertilizer is used. "The effectiveness of nitrification inhibitors (specifically DCD) depends largely on temperature, moisture, and soil type.
For example, the longevity of DCD decreases with increasing soil temperature." (Ricardo, 2016)

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 9 - Summary - Synthetic fertilizer management

Aspect	
CO_2 eq. emission reduction	**Nitrogen management** — 0.033-0.159 tonne CO_2 eq./hectare/year from soil emissions (reduction of nitrous oxide emissions) (Ricardo, 2016) and 0.08 tonne CO_2 eq./hectare/year because of a reduction in nitrogen fertilizer production (Hawken (ed.), 2017); — The range is reflected by the assumption of "a range of 1.0 to 10.0% of baseline emissions, where the baseline is N_2O emissions from managed soils in the 2012 national inventory reports (2014 submission)" (Ricardo, 2016); — Total reduction around 2.4-24 Mton CO_2 eq./year for the EU28 (IEEP, 2017). **Nitrification inhibitors** — 0.003-0.017 tonne CO_2 eq./hectare/year (Ricardo, 2016); — Total EU28 potential is between the 47-140 Mton CO_2 eq. per year (IEEP, 2017).
Costs	**Nitrogen management** Low costs if there is no opportunity cost from output loss. New equipment might be needed but this is counterbalanced by reduction in fertilizer costs (Hawken (ed.), 2017).

Aspect	
	Nitrification inhibitors The costs of nitrification inhibitors are high and they do not lead to additional economic benefits such as yield increase (IEEP, 2017). Costs are approximately 125 €/hectare (Ricardo, 2016).
Trade-offs	**Nitrogen management** — In the adaptation phase there is a possibility for reduction in production. This could lead to an increase in production elsewhere (with associated impacts). — May delay systemic change in moving from synthetic to organic fertilizers (Workshop Hungary). **Nitrification inhibitors** — Certain types of nitrification inhibitors can lead to soil acidification (Pérez Domínguez, et al., 2016) and salinization (Dietz, et al., 2010); — Reduced air quality: May increase ammonia emissions (EC, 2016). No evidence on whether degradation products of nitrification inhibitors have an influence on soil/ecosystem quality (IEEP, 2017).
Co-benefits	— Improved water quality and soil quality because of reduction in nitrate leaching (WUR, 2017) (Hawken (ed.), 2017) (SRUC, et al., 2017); — Nitrogen management: Improved air quality because of reduction in ammonia, NO_x and particulate matter emissions at the farm (Hawken (ed.), 2017); — Lower impact of supply chain: lower synthetic fertilizer use (Hawken (ed.), 2017).
Barriers	**Nitrogen management** — Financial: High costs for monitoring (especially difficult for small farms) (Workshop Spain, Workshop Ireland, Workshop Hungary) and equipment for precision farming (Workshop France); — Knowledge: Lack of knowledge on the necessity for this measure due to the lack of knowledge about impacts of overfertilisation (Workshop France); — Other: Time needed for conversion (Workshop Ireland); — Other: Strong lobby for use of synthetic fertilizers (Workshop Ireland, Workshop France, Workshop Spain). **Nitrogen inhibitors** — Financial: High costs for purchasing nitrogen inhibitors (Workshop France); — Trust: Consumer acceptance of nitrification inhibitors is low (Workshop Ireland); — Other: Before nitrification inhibitors can be used in crop farming they need to be added to the CODEX list for food additives (Workshop Ireland).

A.6 Organic fertilizer management

By using organic fertilizer and biological fixation of nitrogen GHG emissions from soil are lower than when synthetic fertilizer is used. Furthermore, emissions in the supply chain are reduced due to a lower use of synthetic fertilizers. Applicability depends on the crop rotation, and the susceptibility to diseases and plagues. Organic fertilizers such as compost, digestate and sewage sludge compost are under consideration. Direct injection of manure slurry is used in agriculture to decrease ammonia emissions. This does, however, not decrease GHG emissions. Therefore injection of manure slurry is not considered.

Current application

Organic fertilizer management is applied especially in organic farming all over Europe. Numbers on the extent to which this applied are not known, but organic farming occurred on 6.7% of the utilised agricultural area in 2016 in EU28 (Eurostat, 2017).

Applicability

Organic fertilizer management is suitable for every type of cropland but the exact type of organic fertilizer or species to use for biological nitrogen fixation differs per soil type and soil quality. Biological nitrogen fixation might be more difficult on grassland used for livestock farming.

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 10 - Summary - Organic fertilizer management

Aspect	
CO_2 eq. emission reduction	**Biological nitrogen fixation** — 0.006-0.042 tonne CO_2 eq./hectare/year (Ricardo, 2016). Effectiveness of biological nitrogen fixation varies in the EU due to different kinds of legumes that can be grown per region and the speed at which legume grow. Legume use can lead to complete replacement of nitrogen fertilizer use, while when using clover estimates show a reduction of 60-80% nitrogen fertilizer use (Ricardo, 2016). — Total EU28 reduction 140-290 Mton CO_2 eq./year (IEEP, 2017). **Organic fertilizers** — Extend of emission reduction depends on C:N balance in the soil (Favoino and Hogg, 2008). C:N < 20-15: Nitrogen is not completely taken up in the soil, on the other hand, if C:N > 20-30 nitrogen is less available for plant growth; — Emission reduction is achieved because of sequestration of carbon in the soil, of reduced use and production of synthetic fertilizers (Favoino and Hogg, 2008).
Costs	**Biological nitrogen fixation** Increased margins due to increased profitability of crops and decreased need for fertilizers (Commission of the European Communities, 2009). Increased margin is between € 75 and € 80 per hectare for legumes (IEEP, 2017). **Organic fertilizers** Cost reduction due to reduced synthetic fertilizer costs. Net cost reduction depends on availability relatively cheap organic fertilizers. New EU legislation makes it easier to use waste-based fertilizers (EC, 2016).
Trade-offs	**Overall** In the adaptation phase there is a possibility for reduction in production. This could lead to an increase in production elsewhere. **Organic fertilizers** Reduced water and soil quality: Possible reduction in water and soil quality due to additional heavy metals and other pollutants still present in organic fertilizers (STOWA, 2014). Legislation on application of organic fertilizers differs per country.
Co-benefits	— Improved water quality and soil because of reduction in nitrate leaching because of reduced necessity for nitrogen fertilizers when using biological nitrogen fixation (WUR, 2017) (IEEP, 2017). — Improved air quality because of reduction in ammonia and particulate matter emissions at the farm because of reduced necessity for nitrogen fertilizers when using biological nitrogen fixation (SRUC, et al., 2017). — Reduced dependency on external inputs: synthetic fertilizer (SRUC, et al., 2017). — Improved soil quality: Soil fertility increases when using legumes (SRUC, et al., 2017) and using organic fertilizers (Alterra, 2008) (Favoino and Hogg, 2008). — Increased biodiversity (SRUC, et al., 2017).

Aspect	
Barriers	**Biological fixation** — Knowledge: Lack of knowledge on use and effectiveness of legumes and clover (Workshop France). **Use of organic fertilizers** — Knowledge: Lack of knowledge on risks of organic fertilizer products of digestate (Workshop France), sewage sludge (Workshop Hungary, Workshop France) and manure (Workshop Germany); — Trust: Acceptance of alternative/organic fertilizer/soil enhancement products (think health risk due to use of sewage sludge). (Workshop Hungary, Workshop France); — Other: Strong lobby for use of synthetic fertilizers (Workshop Ireland, Workshop France, Workshop Spain).

A.7 Switch in agricultural product

GHG emissions of certain agricultural products are higher than for other products which can fulfil the same function in our diet. A switch from a product with a high footprint to a lower footprint product could have a significant impact on the GHG emissions of European agriculture. An example is a shift from intensive livestock farming to crop production (vegetable protein products for human consumption). In this climate change mitigation measure we consider the switch from the production of feed for livestock to the production of products, such as beans, that can provide protein directly to humans.

Current application

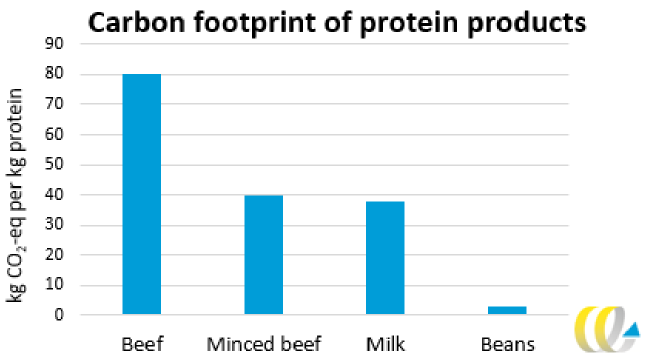
No explicit policy is developed in Europe on a switch in agricultural product, and limiting the production of feed for livestock.

Applicability

This measure is in principle applicable in all cases where feed for intensive livestock farming is grown in Europe. The measure is less applicable to land used for land-based livestock farming. For example in the case of Ireland the choice has been made to use land for land-based livestock farming because the land is not suitable for crop farming (clay land in combination with high amounts of rainfall). Furthermore grassland stores carbon, this carbon sink will be reduced when converting from pastureland to cropland.

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 11 – Summary - Switch in agricultural product

Aspect	
CO_2 eq. emission reduction	Emission reduction depends on demand for animal products, not so much on the supply side.  Source: CE Delft database.
Costs	— Cost of change at farm: A switch in agricultural product requires investments and may mean loss of previously made investment costs in the 'old' agricultural practice (stranded assets). — Cost of change in system: A systemic change requires a change in demand. Also, stakeholders in the product supply chain may have stranded assets (e.g. butchers, processing plants) (SRUC, et al., 2017).
Trade-offs	— Crop production requires more pesticides than livestock production on farm. This could lead to a decrease in water quality (SRUC, et al., 2017). Pesticide use in the whole system could be lower, because of a lower demand for feed crops (with associated input use). — A shift at farm-level does not necessarily mean a shift EU-wide. Carbon leakage could occur if the demand does not change (less efficient production elsewhere fulfils demand).
Co-benefits	— Increased air quality: Reduced nitrogen pollution, odour, ammonia emissions (SRUC, et al., 2017); — Increased water quality: Reduced nitrogen and phosphorus leaching (SRUC, et al., 2017); — Reduction in per capita land-use (SRUC, et al., 2017); — Human health benefits: A diet lower in animal products than the current EU diet has health benefits. (SRUC, et al., 2017) (Gezondheidsraad, 2015); — Reversed carbon leakage if inefficient intensive farms are replaced with more efficient farms elsewhere.
Barriers	— Financial: When moving away from a type of agriculture to a new agricultural product, early investments will become obsolete. These are stranded assets. (Workshop France). — Knowledge: Crop farming is knowledge intense, to be able to compete on the world market a farmer would need to re-school for the change to be possible (Workshop Ireland). — Other: Legislation, current national legislation is promoting intensification and large-scale livestock farming (workshop Hungary).

A.8 Land-based livestock farming

Shift from intensive livestock farming to extensive livestock farming (which includes a smaller number of livestock per farm) reduced GHG emissions. This includes higher grass and roughage content in feed, and sourcing feed inputs (roughage, concentrates) locally. The focus of this mitigation measure is on dairy/cattle farms. Land-based livestock farming is also possible for chicken and pork farms but in those cases the GHG mitigation potential is likely to take place mostly outside the European Union, because of a reduction in import of feedstuffs such as soy. Since the focus of this study is on agricultural GHG emissions in the EU dairy and cattle farming is considered under this mitigation measure.

Current application

Ireland currently focusses mainly on cattle farming on the basis of grassland, a limited quantity of fodder is imported for dairy/cattle farming. On the other hand, the Netherlands imports almost all of its fodder for dairy/cattle farming and livestock farming is therefore only to a limited extend land-based. Other European countries fall somewhere in between these countries in terms of land-based livestock farming.

Applicability

Application of land-based livestock farming is not possible in all European Member States and is mainly dependent on climate and soil conditions. For example in Hungary water scarcity hinders the expansion of grazing area and thus implementation of land-based livestock farming.

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 12 – Summary – Land-based livestock farming

Aspect	
CO_2 eq. emission reduction	Emission reduction depends on demand for animal products, not so much on the supply side. Emission reduction per kg product may be higher, whereas emissions per farm or hectare will be lower. Additional carbon benefits could be provided by different grass management: carbon sequestration by adding legumes and clover (see factsheet ‘Organic Fertilizer Management’ - also includes other environmental co-benefits).
Costs	— Cost of change at farm: A switch in agricultural practice requires investments and may mean loss of previously made investment costs in the ‘old’ agricultural practice (stranded assets); — More grassland for grazing means higher costs (Commissie Grondgebondenheid, 2018); — Feed costs: Costs for feed inputs and feed treatment (of roughage) will decline (Commissie Grondgebondenheid, 2018).
Trade-offs	A shift at farm-level does not necessarily mean a shift EU-wide. Carbon leakage could occur if the demand does not change (less efficient production elsewhere fulfils demand).
Co-benefits	— Reduction in food-feed competition (Commissie Grondgebondenheid, 2018). No food crops will be used as feed. The feed mix is composed of grass, agricultural by-products and by-products from the food processing industry which cannot be used for food products.

Aspect	
	— Reversed carbon leakage if inefficient intensive farms are replaced with more efficient farms elsewhere. — Potentially higher price for products from extensive systems. See Factsheet 6 (Organic Fertilizer Management) for benefits associated with diversifying grassland for grazing. — Extensive livestock helps to prevent fire, reduced risk of fire (Workshop Spain).
Barriers	— Financial: When moving away from a type of agriculture and converting to nature, early investments will become obsolete. These are stranded assets. Furthermore absence of economic aid for transition (Workshop Hungary) or first pillar aid (Workshop France). — Trust: Perceived risk of loss of income (Workshop France). — Other: Legislation, current national legislation is promoting intensification and large-scale livestock farming (Workshop Hungary).

A.9 Agroforestry

Carbon stock in and on soil is different for different agricultural systems. Agroforestry comprises of systems in which woody perennials are used on the same land as crops and or animals. In agroforestry additional carbon is stored, relative to grasslands or monocrops systems. Agroforestry can also help restore degraded land and ecosystems, which can help with climate change adaptation. Under this mitigation measure we consider the shift from crop farming to agroforestry.

Current application

Stimulation for agroforestry is in place in Ireland, but the current scheme is not interesting enough for farmers. Changes are underway. Agroforestry is in place also in France and Spain. Exact numbers on the extend of current application are not available.

Applicability

Agroforestry is in principle applicable on all arable land. However the practical applicability depends on the local climate (e.g. steppe climate in Hungary might not suitable for agroforestry) and the current use of the land (e.g. incompatibility of agroforestry with intensive livestock farming).

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 13 - Summary - Agroforestry

Aspect	
CO_2 eq. emission reduction	— 0.15-0.88 tonne CO_2 eq./tonne/ha/year due to carbon sequestration. Additional CO_2 emission reductions depend on the type of agroforestry (Ricardo, 2016). — EU28 potential: 28-170 Mton/year (IEEP, 2017). The quantity of carbon sequestered during agroforestry is highly dependent on the exact type of agroforestry used. Differentiating factors include the type of crop species, the type of tree species, the frequency of crop rotation, the land division between crops and trees as well as other managing factors (Ricardo, 2016). The 0.15-0.88 tonne CO_2 eq./tonne/ha/year due to carbon sequestration gives an estimate of the range of carbon sequestration per hectare in the EU28. There is a maximum to the

Aspect	
	time period during which carbon sequestration will occur, the time-period depends on the type of trees utilized and the type of soil on which agroforestry is applied.
Costs	Cost of change in agricultural practice: Significant changes in agricultural practice require initial investment (Ricardo, 2016) and may mean loss of early investment costs in the 'old' agricultural practice (stranded assets). — Change in yield: Decrease in the short term: Lower yields in initial phase (Ricardo, 2016); — Change in yield: Increase in the medium/long term (Ricardo, 2016).
Trade-offs	— Negative effects on biodiversity can occur when non-native trees are used close to semi-natural woodland habitats (Ricardo, 2016). — Potentially lower yields in initial phase (Ricardo, 2016), which could lead to carbon leakage: A shift at farm-level does not mean a EU-wide shift. Carbon leakage could occur if demand does not change and less efficient production elsewhere fulfils demand.
Co-benefits	— Improved air quality: Reduction in NO_x, PM and NH_3 downwind of emission sources (filtration capability of the forest) as well as reduced emissions from fertilizer use (SRUC, et al., 2017). — Improved water quality: Root net of multiple species prevents run-off of nitrate and reduces use of agrochemicals because of presence of natural enemies of pests (SRUC, et al., 2017) (Ricardo, 2016). — Improves soil quality: reduction of soil erosion (Ricardo, 2016) (SRUC, et al., 2017) (FAO, 2017) and more diverse soil microbial communities and improved soil fertility (Ricardo, 2016) (FAO, 2017). — Flood management: Potential improvement due to buffer strip effect (SRUC, et al., 2017) and improvement in soil moisture (Ricardo, 2016). A buffer strip effect means that floods are held back by forest that is shielding off e.g. inhabited areas. — Improved pest control in comparison to conventional monoculture crop farming (Ricardo, 2016). — Improved resilience to climate change, compared to monocultures (Ricardo, 2016) (FAO, 2017). — Biodiversity increase: increased species diversity depends on type of tree species used and the intensity of the management (Ricardo, 2016).
Barriers	— Financial: Return on investment time for agroforestry is high, therefore not attractive if not fully subsidized (Workshop France, Workshop Ireland); — Knowledge: Lack of knowledge on locally adapted species (workshop France) and influence of implementation on yields (Workshop Ireland); — Other: Cultural, shift from farmland to 'forest' is unheard of (workshop Ireland, workshop France); — Other: Lobby, the forestry lobby will consider a land where enough trees are planted a forest, the foresters will then not allow any changes or switch in cultivation (e.g. crop type switch). Only plantations are often allowed (Workshop Hungary); — Other: Cultural, farmers do not want to develop further, innovation activity has declined (Workshop Hungary); — Other: Time, requires more/different, possibly more time-consuming management.

A.10 Conversion to other use

Some lands used for agriculture emit greenhouse gases because of the management necessary to make them suitable for agriculture (e.g. drained peatlands).
Different management practices help conserve soil carbon, but necessitate a change in purpose (e.g. peatland for grazing to restored peatland). Land-use change, from e.g. agriculture to forest, creates a carbon sink (sequestration). Under this mitigation measure we include both restoration of peatland and wetland (including wet meadows) as well as afforestation of arable land.

Current application

Conversion of agricultural land to nature occurs for example under the Natura 2000 scheme to protect biodiversity and threatened species. This means that conversion of agricultural land to nature has occurred, and still occurs to a limited extent in all of the five countries where workshops are held.

Applicability

In principle, restoration of peatland and wetland and afforestation is possible on all agricultural land in the European Union. Arable land in the EU is approximately 180 million hectares (IEEP, 2017). However, the practical applicability of course depends on a range of different factors including current economic importance of the area and local climate (e.g. steppe climate in Hungary not suitable for afforestation).

Summary: CO_2 eq. emission reduction, costs, trade-offs, co-benefits and barriers

Table 14 - Summary - Conversion to other use

Aspect	
CO_2 eq. emission reduction	**Restoration of peatland and wetland** — 1.3-8.2 tonne CO_2 eq./hectare/year (Ricardo, 2016). The quantity of GHG emission reduction is highly dependent on the current land-use and extend of the land change that has occurred (e.g. amount of water drainage) (Ricardo, 2016). The 1.3-8.2 tonne CO_2 eq./tonne/ha/year gives an estimate of the range of emission reduction per hectare in the EU28. — Total EU28 potential between 0.2-1.2 Mton CO_2 eq. per year (IEEP, 2017). **Afforestation** — 1.47-1.83 tonne/ha/year. Only carbon sequestration (Ricardo, 2016). The quantity of carbon sequestration is based on conversion from arable land to woodland, and depends on type of tree introduced (Ricardo, 2016). — EU28 potential: 280-350 Mton CO_2 eq./year (IEEP, 2017). The potential is for afforestation of all arable land. The values are for complete conversion of arable land to woodland (approx. 180 million hectares), this is of course not realistic, but does show the maximum potential.
Costs	**Restoration of peatland and wetland** – New economic use of restored peatland is possible by means of paludiculture providing economic benefits from crop production (Ricardo, 2016). Paludiculture is wet agriculture on wetland and peatlands that does not dry out the land. In Europe mostly applied with reeds. — Peatland conservation: 2,400-2,800 €/ha investment costs (PBL & ECN, 2017).

Aspect	
	— Financial benefit is that drains do not need to be managed anymore (Workshop Ireland). **Afforestation** — Conversion to nature can have high costs when current agricultural use of the land needs to be halted. Afforestation of prime agricultural land leads to a large reduction of agricultural production while afforestation of semi-natural grassland causes much less loss of existing income (SRUC, et al., 2017). — Afforested land might need management; recurring management costs (Ricardo, 2016). — Afforestation 1,976 €/ha for conversion (Ricardo, 2016). This is excluding costs for lost production, and solely refers to the investment costs for conversion. Depending on national policy, subsidies may be available (see (Department of Agriculture, Food and the Marine, 2015) for Ireland).
Trade-offs	**Overall** — Measure does not bring a solution for the agricultural system as a whole, i.e. it does not necessarily reduce emissions from agricultural production and could lead to intensification of remaining agricultural areas (Workshop France). **Restoration of peatland and wetland** — Rewetting of peatland sites can increase nitrogen and phosphorous leaching particularly in the early years of restoration. The risk is increased where fertiliser has been applied or where trees are felled during restoration (SRUC, et al., 2017). — Use of rewetted peatland for some paludiculture crops may conflict with biodiversity objectives (Ricardo, 2016). Some paludiculture crops might not be native species and therefore prevent native biodiversity restoration. **Afforestation** — Production displacement from the afforested area of agricultural land leading to increased production elsewhere, possibly in regions where GHG emissions per tonne of crop or per livestock unit are higher than in the EU (Ricardo, 2016). This is carbon leakage. — Negative effects on biodiversity can occur when non-native trees are used close to semi-natural woodland habitats (Ricardo, 2016). — Risk of flooding if wet meadows are afforested (Workshop France).
Co-benefits	**Restoration of peatland and wetland** — Increased soil quality: Reduced risk of erosion (Ricardo, 2016). — Improved water retention and storage (Ricardo, 2016). — Increased water quality: Reduction in pollution from fertilizer run-off after conversion from arable land or intensive grassland (Ricardo, 2016). — Increased biodiversity in surrounding areas (PBL & ECN, 2017) and in the restored area itself (Ricardo, 2016) (SRUC, et al., 2017) (PBL & ECN, 2017). **Afforestation** — Improved air quality: Reduction in NO_x, PM and NH_3 downwind of emission sources (filtration capability of the forest) as well as reduced emissions from fertilizer use (SRUC, et al., 2017). — Improved water quality: Afforestation of arable land can reduce nitrogen leaching (SRUC, et al., 2017) (Ricardo, 2016). — Improved soil quality: Reduced risk of erosion and more diverse soil microbial communities and improved soil structure (Ricardo, 2016).

Aspect	
	— Increased flood management: “There is evidence that trees (coniferous to a larger degree than broadleaved) use/intercept more water than shorter vegetation types Infiltration rates may be significantly enhanced (and thus runoff reduced) where grazed pasture is planted with woodland Floodplain woodland may lead to significant increases in flood storage and flood peak travel times” (SRUC, et al., 2017) (Ricardo, 2016). — Increased biodiversity depends on type of tree planted (SRUC, et al., 2017) (Ricardo, 2016). E.g. afforestation with one type of tree leads to lower biodiversity increase than when using multiple tree species.
Barriers	— Financial: Compensation for conversion to nature is currently too small (Workshop France, Workshop Hungary); — Other: Cultural, ‘loss of land’ is insurmountable (Workshop Ireland).

B Factsheets

MANURE STORAGE MANAGEMENT

Description

15% of the direct European (EU28) agricultural greenhouse gas emissions (in CO_2 eq.) are related to manure management. Better manure storage management can play an important role in reducing these emissions. Mitigation options include:

- **covering** manure **slurry tanks** incl. passive ventilation (mandatory in some EU countries);
- **covering solid manure stores** with an airtight cover (mandatory in some EU countries).

Co-benefits

Improved air quality and odour reduction
Reduction of PM and NH_3 emissions. [3][9]

Higher nitrogen efficiency
Higher nitrogen content in manure because less nitrogen is emitted as NH_3. [2]

Reduced dependency on inputs
Higher nitrogen content leads to lower synthetic fertilizer use.

Trade-offs

May prevent systemic change
Measures increasing efficiency of intensive animal husbandry may postpone systemic change in some regions.

Emission reduction

Slurry tank cover

- 200 kg CO_2 eq./LSU pig/yr [1]
- 165 kg CO_2 eq./LSU cow/yr [1]

Solid manure store cover

- 225 kg CO_2 eq./LSU pig/yr [1]
- 100 kg CO_2 eq./LSU cow/yr [1]

LSU = Livestock unit

Costs

All covers
New storage facilities can have large capital costs. [8]

Slurry tank cover, incl. ventilation
60-200 €/m^2 or € 15,000-45,000 per slurry pit. [2]
Cost-effectiveness: 5-15 €/tonne CO_2 eq. reduced. [11]

Barriers

Financial: Covers are expensive for small farms. Large farms may not get public support. [20]
Knowledge: Farmers lack cost-benefit information. [20]
Trust: Implementation not always acceptablet to surroundings because of safety. [20]

ANAEROBIC DIGESTION OF MANURE

Description

15% of the direct European (EU28) agricultural greenhouse gas emissions (in CO_2 eq.) are related to manure management. Anaerobic digestion can play an important role in reducing these emissions. Anaerobic digestion (AD) reduces emissions by:

- **Shortening manure storage** times, reducing emissions from storage.
- **Producing biogas,** which can be substituted for natural gas, or used to produce electricity and heat directly.

Co-benefits

Higher nitrogen efficiency
Higher anorganic nitrogen content in digestate, which is more readily available to plants. [(13)]

Reduced dependency on inputs
Higher nitrogen content leads to lower synthetic fertilizer use. Biogas could be used in own machinery.

Improved local air quality: Biogas can be used in own machinery (usually using diesel), which results in reduction of PM_{10} and NO_x emissions on-farm.

Trade-offs

Possible decrease in local air quality: NO_x, PM and NH_3 emissions may increase dependent on manure/ digestate handling and air treatment at the AD. [(9)]

Use of non-waste for co-digestion
In case of co-digestion, use of non-wastes could lead to additional food and feed production. [(3)]

May prevent systemic change: Measures increasing efficiency of intensive animal husbandry may postpone systemic change in some regions.

Emission reduction

- 645 kg CO_2 eq./LSU pig/yr [(1)]
- 590 kg CO_2 eq./LSU cow/yr [(1)]

EU28 farms > 200 LSU

- 9.1-12.4 megatonne CO_2 eq./yr in EU [(4)]

EU28 farms > 100 LSU

- 60 megatonne CO_2 eq./yr in EU [(2)]

LSU = Livestock unit

Costs

Investment cost: Anaerobic (co-)digester adopted for on farm use: € 1,000,000-2,000,000 to process manure for > 200 LSU.[(2)] Additional costs for use of gas on own farm (upgrading to green gas, alteration to equipment).

Cost-effectiveness: Highly dependent on national policy (national subsidies) and local conditions/ availability of infrastructure; whether produced biogas can be sold at a premium or whether produced heat and electricity can be sold. [(8)]

Barriers

Financial: High investment cost, only profitable for large farms. Difficult to attract funding.[(20)]
Knowledge: Lack of technical expertise on how to run AD and lack of support to develop. [(20)]
Trust: Implementation not always acceptable to surroundings because of safety. [(20)]

These factsheets are not meant to be comprehensive, but are meant to provide the basis for a discussion about climate change mitigation measures in agriculture.

ANIMAL MANAGEMENT

Description

Improving efficiency in animal husbandry can lead to a reduction in greenhouse gas emissions because of a reduction of inputs needed per produced product. Mitigation options include:

- Matching feed intake with animal requirements: **fodder optimization.**
- **Improving livestock health** with preventive and curative measures.
- **Sexed semen** for dairy replacement: Efficient production of dairy replacement cows leaves room for calves production specific for beef production. This reduces surplus calve production as well as the necessity for a suckler herd for replacement beef cows.

Co-benefits

Reduced human health risk
Reduction in livestock carried diseases. [9]

Improved air quality, water quality, soil quality
Reduction in NH_3, NO_x and PM emissions as well as phosphor and nitrate leaching per quantity of produced product. [9]

Improved animal welfare
Less disease when improving livestock health.

Trade-offs

Increased human health risk
When using antibiotics as curative treatment instead of preventive controls the risk for antimicrobial resistance increases. [9]

May prevent systemic change: Measures increasing efficiency of intensive animal husbandry may postpone systemic change in some regions.

Reduced animal welfare
Optimization on output not on animal welfare. [20]

Emission reduction

Fodder optimization
- 0.01-0.12 tonne CO_2 eq./1,000 cattle/yr [6]
- EU28: 0.8-2.3 megatonne CO_2 eq./yr [5]

Improving livestock health
- 0.14-0.68 tonne CO_2 eq./1,000 animals/yr [6]
- EU28: 2.3-23.0 megatonne CO_2 eq./yr [5]

Sexed semen
- 6.0-21.0 tonne CO_2 eq./1,000 cattle/yr [6]
- EU28: 1.4-5.0 megatonne CO_2 eq./yr [5]

Costs

Fodder optimization
Costs depend on the extent to which diet will change from current practice, but can be cost-effective. [8]

Improving livestock health
Cost-effective if costs are lower than the economic benefit of increased productivity. [6]

Sexed semen
Relatively expensive. [6]

Barriers

Financial: Sexed semen scheme is expensive esp.ecially for small farms. [20]
Knowledge: Lack of data and knowledge haps on impact of e.g. endemic diseases on milk production (loss) in animal husbandry. [20]

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SOIL CARBON CONSERVATION AND SEQUESTRATION

Description

37% of the direct European (EU28) agricultural greenhouse gas emissions (in CO_2 eq.) are related to agricultural soil management. Due to soil disturbance, greenhouse gas emissions can occur. Carbon sequestration due to soil conservation can play an important role in reducing emissions and can create a net carbon sink. Mitigation options include:

- minimizing soil disturbance by **reduced or no tillage;**
- **maintaining soil cover** to reduce the fallow period;
- leaving **crop residues** on the soil surface.

Co-benefits

Improved climate change resilience: Better water drainage and retention, soil moisture conservation.[7,6]

Improved water and soil quality: Reduction in nitrate leaching. [10]

Improved soil quality: Reduced risk of erosion [6], better soil structure, and nutrient retention.

Reduced dependency on inputs: Lower/no fuel use. [7]

Trade-offs

Production loss: Reduced or no tillage can lead to yield reduction for e.g. winter cereals and maize, no influence on other crops. [6]

Biodiversity loss: Reduced or no tillage can lead to increased herbicide use for root crops. [10]

Competition for crop residue use: Use of crop residues competes with demand for residues for other purposes e.g. feed. [8]

Emission reduction

Reduced or no tillage
- 0.0059-0.0359 tonne CO_2 eq./ha/yr [6]
- EU28: 2.3-31.0 megatonne CO_2 eq./yr [5]

Maintaining soil cover
- 0.88-1.47 tonne CO_2 eq./ha/yr [6]
- EU28: 110-190 megatonne CO_2 eq./yr [5]

Crop residues
- 0.11-2.2 tonne CO_2 eq./ha/yr [6]
- EU28: 14 – 280 megatonne CO_2 eq./yr [5]

Costs

Reduced or no tillage
Economic benefits of reduced or no tillage because of decreased fuel costs for ploughing. Additional costs may occur due to production loss or increased herbicide use. [6][10]

Crop residues
Loss of other income if plant residues were originally sold between € 20-150/ha/yr [6], high(er) prices only occur in regions where residues are in demand.

Barriers

Financial: Machinery is expensive. Applying to subsidies is only feasible for large farms [20]
Knowledge: Lack of data, knowledge gaps on e.g. perceived necessity to till the ground and management of weed and associated crops. [20]

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SYNTHETIC FERTILIZER MANAGEMENT

Description

51% of the direct European (EU28) agricultural greenhouse gas emissions (in CO_2 eq.) are related to agricultural soil management. Optimization of synthetic nitrogen fertilizer application can play an important role in reducing these emissions. Mitigation options include:

- matching synthetic fertilizer application with crop requirements: **nitrogen management;**
- application of **nitrification inhibitors** to slow down the conversion of ammonium to nitrate and reduce the formation of N_2O.

Co-benefits

Increased water quality and soil quality
Reduction in nitrate leaching. [3][7][9]

Improved local air quality (nitrogen management)
Reduction in NH_3, NO_x and PM emissions at farm. [9]

Reduced dependency on inputs/lower impact of supply chain
Lower synthetic fertilizer use. [9]

Trade-offs

Possible production loss during adaptation
In the adaptation phase production loss may occur because of fine-tuning nutrient application.

Reduced soil quality
Certain types of nitrification inhibitors lead to soil acidification[4] and/or salinization. [12]

Reduced air quality
May increase ammonia emissions.[14]

Emission reduction

Nitrogen management

- 0.033-0.159 (soil) [6] and 0.08 (fertilizer production) [7] tonne CO_2 eq./ha/yr
- EU28: 2.4-24 megatonne CO_2 eq./yr [5]

Nitrification inhibitors

- 0.003-0.017 tonne CO_2 eq./ha/yr [6]
- EU28: 47-140 megatonne CO_2 eq./yr [5]

Costs

Nitrogen management
Costs of new equipment counterbalanced by reduction in fertilizer costs. [7]

Nitrification inhibitors
Costs ~€ 125/ha/yr. [6]
Expensive, does not lead to yield increase. [5]

Barriers

Financial: High cost for monitoring, equipment and purchase of nitrogen inhibitors. [20]
Knowledge: Lack of knowledge on impact of overfertilization, and thus necessity measure. [20]
Other: Strong lobby for use of synthetic fertilizers. [20]

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ORGANIC FERTILIZER MANAGEMENT

Description

51% of the direct European (EU28) agricultural greenhouse gas emissions (in CO_2 eq.) are related to agricultural soil management. Optimization of organic fertilizer application can play an important role in reducing these emissions. Mitigation options include:

- **biological fixation** of nitrogen by means of e.g. legumes and clover;
- **application of organic fertilizers** such as compost, digestate and sewage sludge compost.

Co-benefits

Improved water quality and local air quality: Reduction in nitrate leaching [3][5] and NH_3, NO_x and PM emissions at farm [9], because of reduction in fertilizer use when applying biological fixation.
Improved soil quality: Increased soil fertility when using legumes for nitrogen fixation[9] or using natural fertilizers. [13][16]
Improved biodiversity: Differentiation in crop use when using biological fixation. [9]
Reduced dependency on inputs and lower impact of supply chain: Lower synthetic fertilizer use. [9][16]

Trade-offs

Possible production loss during adaptation
In the adaptation phase production loss may occur because of fine-tuning nutrient application.

Reduced water and soil quality
Possible reduction in water and soil quality due to additional heavy metals and other pollutants still present in organic fertilizers. [17]

Emission reduction

Biological fixation (incl. fertilizer production)

- 0.006-0.042 tonne CO_2 eq./ha/yr [6]
- EU28: 140-290 megatonne CO_2 eq./yr [5]

Application of organic fertilizers

- Extend of emission reduction depends on C:N balance in the soil [16]
- Emission reduction because of sequestration of carbon in the soil, of reduced use and production of synthetic fertilizers [16]

Costs

Biological fixation
Benefits of € 75-80/ha [5] due to reduced fertilizer costs.[8]

Application of organic fertilizer
Cost reduction due to reduced synthetic fertilizer costs. Net cost reduction depends on availability of relatively cheap organic fertilizers.

Barriers

Knowledge: Lack of knowledge on use of legumes and clover and on risks of organic fertilzer products. [20]
Other: Strong lobby for use of synthetic fertilizers [20]

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SWITCH IN AGRICULTURAL PRODUCT

Description

Greenhouse gas emissions of certain agricultural products are higher than for other which can fulfil the same function in our diet. A switch from a product with a high footprint to a lower footprint product could have a significant impact on the greenhouse gas emissions of European agriculture.

This mitigation option includes:

- A shift from intensive livestock farming to crop production (vegetable protein products for human consumption).

Co-benefits

Increased water quality and air quality:
Reduction in nitrogen and phosphorus leaching, reduction of NH_3 emissions. (9)

Reduction in per capita land use (9)

Human health benefits: For EU average citizen, lower intake of animal products has health benefits. (9) (18)

Reversed carbon leakage: If inefficient intensive farms are replaced with efficient farms elsewhere.

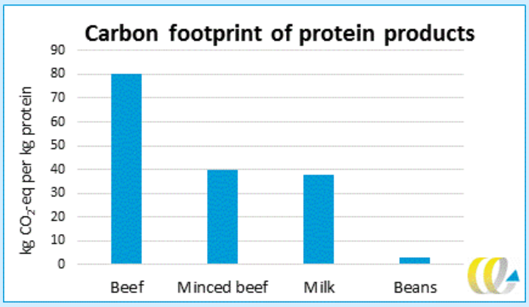
Trade-offs

Reduced water quality on farm
Crop production requires more pesticides than livestock production on farm. (9)

Risk of carbon leakage
A shift at farm-level does not mean a EU-wide shift. Carbon leakage could occur if demand does not change and less efficient production elsewhere fulfils demand.

Emission reduction

Emission reduction depends on demand. The carbon footprint differ substantially for protein-rich products:



Costs

Cost of change at farm
A switch in agricultural product requires investments and may mean loss of previously made investment costs in the ‘old’ agricultural practice (stranded assets).

Cost of change in system
A systemic change requires a change in demand. Also, stakeholders in the product supply chain may have stranded assets (e.g. butchers, processing plants). (9)

Barriers

Financial: Stranded assets, earlier investments become obsolete. (20)
Knowledge: Crop farming is knowledge intense, reschooling necessary. (20)
Other: Current national legislation is promoting large-scale livestock farming. (20)

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LAND-BASED LIVESTOCK FARMING

Description

Greenhouse gas (GHG) emissions from manure and enteric fermentation account from almost 50% of direct GHG emissions from agriculture in the EU. Therefore, a reduction in the number of livestock could have a significant impact on overall GHG emissions.

Options include:

- Shift from intensive livestock farming to extensive livestock farming (which includes a smaller number of livestock per farm). This includes higher grass and roughage content in feed, and sourcing feed inputs (roughage, concentrates) locally.

Co-benefits

Reversed carbon leakage: If inefficient intensive farms are replaced with efficient farms elsewhere.
Better economic perspective: potentially higher price for products from extensive systems and compensation for social/public services. [19]
Reduction in food-feed competition [19]

Reduced dependency on inputs (feedstuff) and lower impact of supply chain [19]

Reduced risk of fire [20]

Trade-offs

Risk of carbon leakage
A shift at farm-level does not mean a EU-wide shift. Carbon leakage could occur if demand does not change and less efficient production elsewhere fulfils demand.

Emission reduction

Emission reduction depends on **demand for animal products**, not so much on the supply side.
GHG emissions per kg product may be higher, whereas emissions per farm or hectare will be lower.

Additional carbon benefits could be provided by different grass management: carbon sequestration by adding legumes and clover (see factsheet 'Organic Fertilizer Management' - also includes other environmental co-benefits).

Costs

Cost of change in agricultural practice
A switch in agricultural practice requires investments and may mean loss of previously made investment costs in the 'old' agricultural practice (stranded assets).

More grassland for grazing means higher costs. [19]

Feed costs: Costs for feed inputs and feed treatment (of roughage) will decline. [19]

Barriers

Financial: Stranded assets, earlier investments become obsolete. [20]
Trust: Percieved risk of loss of income. [20]
Other: Current national legislation is promoting large-scale livestock farming. [20]

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AGROFORESTRY

Description

Carbon stock in and on soil is different for different agricultural systems. Agroforestry comprises of systems in which woody perennials are used on the same land as crops and or animals[15].
In agroforestry additional carbon is stored, relative to grasslands or monocrop systems.
Agroforestry can also help restore degraded land and ecosystems, which can help with climate change adaptation. This mitigation option includes:

- Shift from crop farming to agroforestry.

Co-benefits

Improved air quality: Reduction in NO_x, PM and NH_3 emissions. [9]

Improved water quality: Reduction in nitrate run-off and use of agrochemicals. [6][9]

Improved soil quality: Reduction in soil erosion, more diverse soil micobial communities and improved soil fertility. [6][9][15]

Improved flood management and resilience to climate change: Increased water retention. [6][9][15]

Improved pest control [6]

Improved biodiversity: Increased species diversity. [6]

Trade-offs

Potentially lower yields in initial phase [6], which could lead to carbon leakage
A shift at farm-level does not mean a EU-wide shift. Carbon leakage could occur if demand does not change and less efficient production elsewhere fulfils demand.

Loss of biodiversity
In case of non-native trees too close to semi-natural woodland habitats. [6]

Emission reduction

- 0.15-0.88 tonne CO_2 eq./ha/yr due to carbon sequestration [6]
- Additional CO_2 emission reductions depend on the type of agroforestry [6]
- EU28: 28-170 megatonne/yr [5] (total EU)

There is a maximum to the time period during which carbon sequestration will occur, the time period depends on the type of trees utilized and the type of soil on which agroforestry is applied.

Costs

Cost of change in agricultural practice
Significant changes in agricultural practice require initial investment [6] and may mean loss of early investment costs in the 'old' agricultural practice (stranded assets).

Change in yield: Decrease in the short term
Lower yields in initial phase. [6]

Change in yield: Increase in the medium/long term [6]

Barriers

Financial: Return on investment time is high, full subsidy needed to make attractive. [20]
Knowledge: Lack f knowledge on locally adaoted species and influence on yields. [20]
Other: Cultural, shift from farmland to "forest" is unheard of. [20]

CONVERSION TO OTHER USE

Description

Some lands used for agriculture emit greenhouse gases because of the management necessary to make them suitable for agriculture (e.g. drained peatlands). Different management practices help conserve soil carbon, but necessitate a change in purpose (e.g. peatland for grazing to restored peatland). Furthermore, land use change, from e.g. agriculture to forest, creates a carbon sink (sequestration). Mitigation options include:

- **restoration** of peatland and wetland;
- **afforestation** of arable land.

Co-benefits

Improved soil quality: Reduced risk of erosion and in case of afforestation improved soil structure. [6]

Improved water and air quality: Reduced nitrate and phosphorus runoff and reduced NH_3 and PM Emissions [9] (no fertilizer application).

Improved climate change resilience: Improved water retention and storage.[9][6]

Improved biodiversity: Increase in areas surrounding restored wetland [11] and within the afforested/ restored area. [6][9][11]

Trade-offs

Loss of production/production areas, leading to carbon leakage: If less efficient production elsewhere fulfils demand.

Temporary decrease in water quality: Rewetting of peatland can increase nitrogen and phosphorus leaching, especially when fertilizers have been applied to the land before. [9]

Biodiversity loss: When non-native trees are planted too close to semi-natural woodland habitats [6] or in case of monoculture. [20]

Flood risk when afforesting meadows [20]

Emission reduction

Peatland and wetland conservation and restoration (including improved drainage)

- 1.3-8.2 tonne CO_2 eq./ha/yr [6]
- EU 28: 0.2-1.2 megatonne CO_2 eq./yr [5]

Afforestation

- 1.47-1.83 tonne/ha/yr [6]
- EU28: 280-350 megatonne CO_2 eq./yr [5]

EU potential is the value for conversion of *all* arable land to woodland, approx. 180 million hectares.

Costs

Conversion costs

- Afforestation conversion: 2,000 €/ha [6]
- Peatland restoration: 2,400-2,800 €/ha [11]

Management costs

Recurring management costs of converted land [6], no management costs of drained wetland/peatland. [20]

New economic use of restored peatland

Restored peatland can be used for paludiculture, providing economic benefit from crop production. [6]

Barriers

Financial: Compensation for conversion to nature is currently too small. [20]

Other: Cultural: 'loss of land' is unacceptable. [20]

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