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MEASURES AT FARM LEVEL TO REDUCE GREENHOUSE GAS EMISSIONS FROM EU AGRICULTURE

NOTES

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AGRICULTURE AND RURAL DEVELOPMENT

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FOREWORD

This document was requested by the European Parliament's Committee on Agriculture and Rural Development (COMAGRI).

It contains **two notes**, drawn up within the framework of the **Workshop** on 'Measures at farm level to reduce greenhouse gas emissions from EU agriculture', which was held on 21 January 2014, during a COMAGRI meeting in Brussels.

Note 1 was drawn up by Jordi Domingo, Eduardo De Miguel, and Blanca Hurtado (Fundación Global Nature, Spain), and Nicolas Métayer, Jean-Luc Bochu and Philippe Pointereau (Solagro, France).

Note 2 was drawn up by Sylvain Pellerin, Laure Bamière and Lénaïc Pardon (INRA, France).

NOTE 1

This document was requested by the European Parliament's Committee on Agriculture and Rural Development.

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NOTE 1

Abstract

Agriculture plays a key role in mitigating climate change. Mitigation measures at farm level have been shown to be effective, and the new CAP reform should help increase their potential. Nevertheless, a precise definition of and approach to these measures is needed in order to ensure that mitigation options at farm level are able to fulfil European mitigation commitments over the coming years.

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CONTENTS

LIST OF ABBREVIATIONS

ACCT	AgriClimateChange Tool
AEM	Agri-environmental measure
BD	Birds Directive (Directive 2009/147/EC)
C	Carbon
CA	Conservation Agriculture
CAP	Common Agricultural Policy
CC	Cross-Compliance
CH_4	Methane
CO_2	Carbon dioxide
DM	Dry matter
EAFRD	European Agricultural Fund for Rural Development
EFA	Ecological focus areas
ETS	Emissions Trading Scheme
EU	European Union
HA	Hectare
GHGE	Greenhouse Gas Emissions
GHG	Greenhouse Gas
HD	Habitats Directive (Directive 1992/43/EC)
JRC	Joint Research Centre (EU)
kWp	Kilowatt-peak
LULUCF	Land use, land use change and forestry

N	Nitrogen
ND	Nitrates Directive (Directive 91/676/EC)
NEC	Directive on National Emission Ceilings for certain pollutants (Directive 2001/81/EC)
NVZ	Nitrates Vulnerable Zones
N_2O	Nitrous oxide
MS	Member States
RDP	Rural Development Programme
UAA	Utilised Agricultural Area
WFD	Water Framework Directive

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Background

GHGE reduction and adaptation to climate change are major challenges that European agriculture will have to face over the coming years. Agriculture accounts for 10.1 % of the total GHGE in the EU-28 (excluding LULUCF), which corresponds to 464.3 million tCO_2e. Despite a decreasing trend in GHGE from the agricultural sector registered during the last decade, the EU and the MS will have to adopt further mitigation measures specifically focused on the farming sector in order to fulfil their global climate commitments. More than half the emissions are related to agricultural soils, one third to enteric fermentation and one sixth to manure management. In addition, croplands, which occupy more than half the territory of the EU, can stock massive reserves of carbon by putting in place agronomic measures and/or agro-ecological infrastructure that help reduce the amount of CO_2 in the atmosphere.

CAP reforms over the years have tried to deal with challenging environmental problems. In that sense, since 2010 it has been stated that the new CAP should support climate action while at the same time ensuring that economic, territorial and other environmental challenges are dealt with. The new CAP structure offers the possibility of including climate action instruments in both Pillar 1 and Pillar 2, but in some cases the impact of such measures is still uncertain. Nevertheless, agriculture will probably be a key sector in the mitigation of climate change and the new CAP will probably be one of the most important opportunities for the EU-28 to tackle the climate change issue.

Aim

The aim of this study is to provide a comprehensive analysis of the impact of mitigation options at farm level, in order to provide decision-makers with recommendations and policy-relevant advice, particularly within the framework of the new CAP reform. The measures included in this report are based on practical experience at farm level. Key information is provided for each proposed measure, regarding the impact on the European cropland scenario, GHG reduction estimation, technical and monitoring feasibility, implementation costs, constraints and synergies with other environmental challenges. Nine relevant case studies carried out within the framework of the AgriClimateChange project are included in the annexes to illustrate the benefits of the most effective measures. In a final conclusion and recommendations section, a table showing prioritisation of the mitigation measures at farm level is included, which is based on the criteria mentioned.

GENERAL INFORMATION AND BACKGROUND

KEY FINDINGS

- Climate change is one of the most important challenges for the EU, and agriculture is a key sector.
- The LIFE+ AgriClimateChange project (LIFE+09 ENV/ES/000441) has provided practical and updated information about mitigation options at farm level.
- Mitigation measures at farm level need to be included in European, national and regional regulations to fulfil the EU-28 commitments and recommendations concerning climate change mitigation.
- The new CAP reform includes several instruments that can significantly help mitigate climate change, but a more precise approach to the mitigation measures at farm level is required.
- The flexibility that the MS have in devising and implementing the CAP could make the fight against climate change more effective, but could also lead to a decrease in the mitigation potential expected for this policy. Special attention will be required in this respect.

The AgriClimateChange Project

Curbing GHGE and adapting to climate change are major challenges that European agriculture, like other sectors, will have to face over the coming years. Promoting farming practices that combat climate change is a powerful tool to improve climate conditions and also to preserve nature and increase the agriculture sector's viability.

The LIFE+ AgriClimateChange project (LIFE+09 ENV/ES/00441) was implemented simultaneously in four European countries (France, Germany, Italy and Spain) between September 2010 and December 2013. Its objective was to determine and support the farming practices that best contribute to mitigating climate change at farm level.

The key issues concerning this project were as follows:

- A **software tool was designed,** based on the partners' previous experience: the ACCT (AgriClimateChange Tool). It evaluates energy consumption, GHGE and carbon storage at farm level. This tool is intended to be used throughout the European Union.
- **120 farms were assessed** using this software: 24 in France, 24 in Germany, 24 in Italy and 48 in Spain. Taking into account the results obtained in the assessments, action plans were drawn up. These **action plans were specifically designed for each farm and submitted to the farmers**.
- **Farmers were supported during the voluntary implementation of the action plans** for three years/two farming campaigns. Progress and results achieved were monitored using the assessment tool.

- **Quantitative results and lessons learnt during that period with farmers were transformed into global mitigation proposals** at farm level and presented to several European, national and regional authorities.

- **Communication and awareness-raising activities** focused on key stakeholders (farmers, farmer unions, professional associations or consumers) were implemented.

More information about the results can be found on the project's website: www.agriclimatechange.eu

GHGE from agriculture

Agriculture accounted for 10.1 % of the total GHGE in the EU-28 (excluding LULUCF), which corresponds to 464.3 million tCO_2e. Between 1990 and 2011, non-CO_2 emissions from agriculture decreased by 23.1 %, mainly due to the diminishing cattle numbers, better manure management in some countries, the progressive adoption of more effective farming practices, the reduction in the amount of nitrogen added to soils and the financial and economic crisis. Regulatory instruments not specifically focused on climate change also had an indirect influence on this decreasing trend (Eurostat, 2013).

Countries with larger agricultural economies generally have higher levels of GHGE, although no general pattern can be found. France and Germany together accounted for around one third of the EU-28 GHGE from agriculture and the combined emissions of the United Kingdom, Spain, Poland and Italy accounted for an additional third of the total. Agricultural emissions from 11 countries of the EU-28 are above the average European emissions (Eurostat, 2013).

Despite the decreasing trend in GHGE, the EU and the MS will have to adopt further mitigation measures that include the farming sector in order to fulfil the global climate commitments. A good example is the EU Roadmap for moving to a low carbon economy, that recommends a decrease in GHGE for this sector of 36 to 37 % for 2030, and a more ambitious one (42 to 49 %) for 2050 (EU Roadmap for 2050).

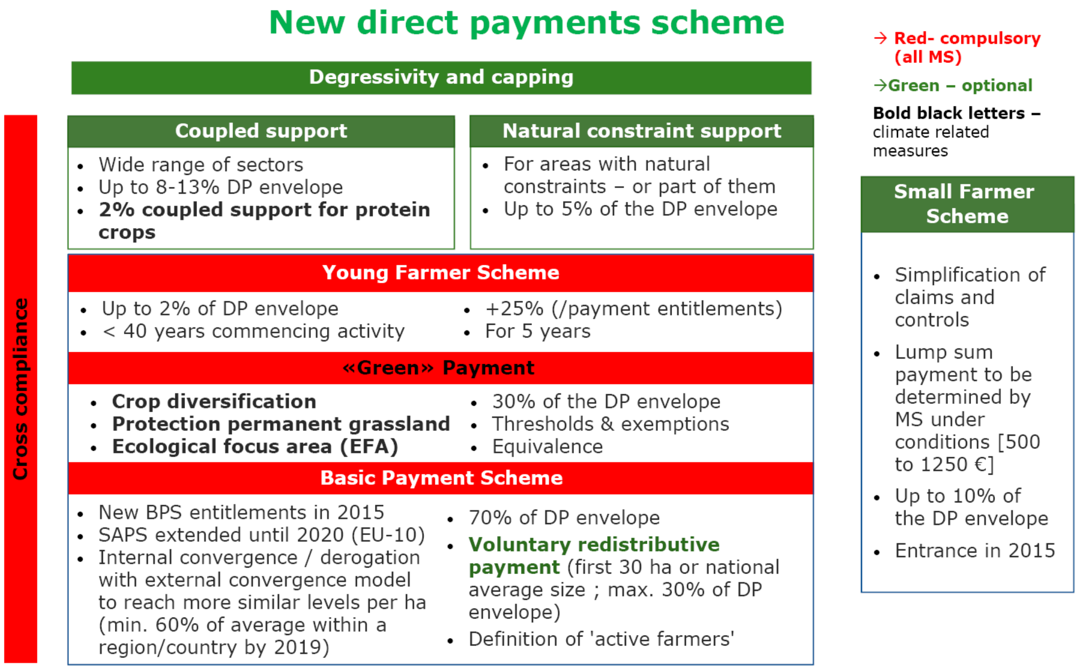
A preliminary overview of the GHGE sources from European agriculture shows that more than half the emissions are related to agricultural soils, one third to enteric fermentation and one sixth to manure management. The other sources of emissions (burning of residue and rice cultivation) are non-significant contributors. Nitrous oxide (N_2O) is the main GHG related to agricultural soil emissions, essentially due to microbial transformation of nitrogen in the soil (nitrification, denitrification). This concerns nitrogen mineral fertilisers, manure spreading and nitrogen from crop residues incorporated into the soil or lixiviation of surplus nitrogen. Enteric fermentation releases methane (CH_4), which is a natural part of the digestive process for ruminants. Both N_2O and CH_4 are also produced during manure storage (decomposition).

Agriculture emits very little carbon dioxide (CO_2), although assessments including direct energies consumed by agriculture as well as indirect CO_2 emissions from processing of inputs at farm level showed that this gas can represent between 10 and 20 % of the total GHGE. In addition, croplands, which occupy more than half the territory of the European Union, can stock massive reserves of carbon by putting in place agronomic measures and/or agro-ecological infrastructure that help reduce the amount of CO_2 in the atmosphere.

The new CAP, agriculture and climate change

The Council and the European Parliament reached an agreement in September 2013 on a CAP reform package that ensures a fully operational new CAP for 2015. CAP reforms over the years have tried to deal with challenging environmental problems. In that sense, since 2010 it has been stated that the new CAP should support climate action while at the same time ensuring that economic, territorial and other environmental challenges are dealt with. Climate action comprises both mitigation and adaptation measures, to be adopted through new policy instruments such as green payment, enhanced cross-compliance, new rural development measures or mandatory allocation of budget for climate and environmental purposes. The current situation of the new CAP is shown in Figure 1 and Figure 2.

Figure 1: New CAP structure (direct payments)



New direct payments scheme

→ Red- compulsory (all MS)

→Green – optional

Bold black letters – climate related measures

Degressivity and capping

Cross compliance

Coupled support
- Wide range of sectors
- Up to 8-13% DP envelope
- **2% coupled support for protein crops**

Natural constraint support
- For areas with natural constraints – or part of them
- Up to 5% of the DP envelope

Young Farmer Scheme
- Up to 2% of DP envelope
- < 40 years commencing activity
- +25% (/payment entitlements)
- For 5 years

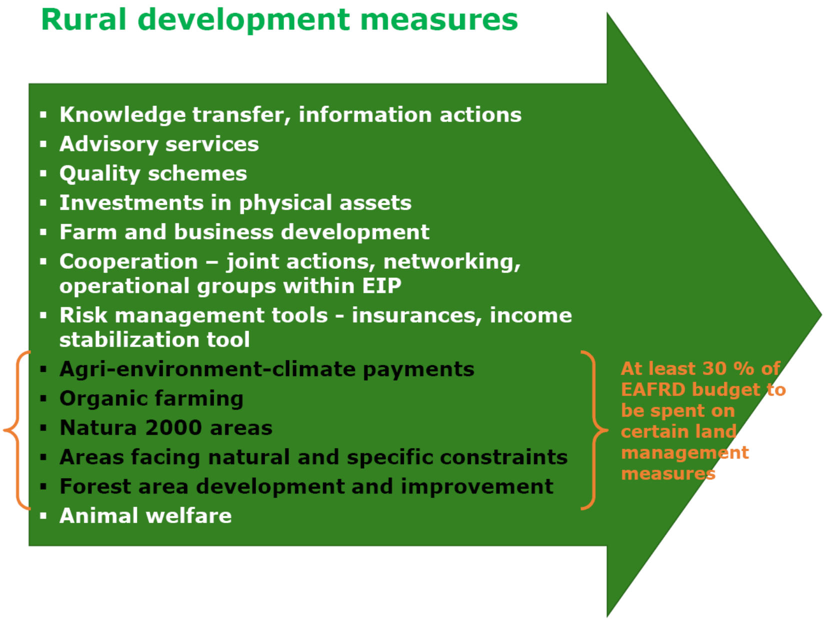
«Green» Payment
- **Crop diversification**
- **Protection permanent grassland**
- **Ecological focus area (EFA)**
- 30% of the DP envelope
- Thresholds & exemptions
- Equivalence

Basic Payment Scheme
- New BPS entitlements in 2015
- SAPS extended until 2020 (EU-10)
- Internal convergence / derogation with external convergence model to reach more similar levels per ha (min. 60% of average within a region/country by 2019)
- 70% of DP envelope
- **Voluntary redistributive payment** (first 30 ha or national average size ; max. 30% of DP envelope)
- Definition of 'active farmers'

Small Farmer Scheme
- Simplification of claims and controls
- Lump sum payment to be determined by MS under conditions [500 to 1250 €]
- Up to 10% of the DP envelope
- Entrance in 2015

Source: European Commission.

Figure 2: New CAP structure (rural development)



Rural development measures

- Knowledge transfer, information actions
- Advisory services
- Quality schemes
- Investments in physical assets
- Farm and business development
- Cooperation – joint actions, networking, operational groups within EIP
- Risk management tools - insurances, income stabilization tool
- Agri-environment-climate payments
- Organic farming
- Natura 2000 areas
- Areas facing natural and specific constraints
- Forest area development and improvement
- Animal welfare

At least 30 % of EAFRD budget to be spent on certain land management measures

Source: European Commission.

Climate-related measures can be found in both Pillars. Mitigation measures to be included in Pillar 1 will have a major impact as they will be linked to direct payments, thus enabling a significant increase in mitigation measures throughout the EU. As an example, enhancing cross-compliance with additional requirements or some of the greening measures will ensure an effective fight against climate change. On the one hand, certain aspects that are still not defined in Pillar 1, such as the greening equivalency measures to be devised with MS, could be very effective in enhancing the mitigation potential at farm level. But on the other hand, they could decrease the positive impacts of this Pillar on the climate if the approach and the calculation of the measures are not appropriate. The new structure of Pillar 2 ensures that at least 30 % of the EAFRD budget in each Member State will be allocated to climate and environmental actions. Six measures have been included to ensure that climate action is also linked to rural development strategy.

One of the main features of this new CAP reform is the flexibility the MS have when devising and implementing it (defining greening equivalency measures, EFA measures, transferring funds between Pillars and drawing up their RDP). This flexibility represents an opportunity to tailor this policy to their national and regional context, but may again weaken the climate approach pursued by the EU institutions.

Agriculture will probably be a key sector in the mitigation of climate change and the new CAP the most important opportunity the EU will have to tackle the climate change issue. Nevertheless, some of the defined CAP measures will have to be fine-tuned in order to increase their mitigation potential. **Another immediate challenge is to ensure that mitigation measures to be proposed/devised by or in cooperation with the MS have at least the same impact on GHG mitigation as the existing ones**. This report intends to transfer the lessons learnt during the AgriClimateChange project concerning mitigation measures at farm level, and aims to suggest a new approach to certain measures included in the new CAP reform.

1. OVERVIEW OF THE MITIGATION PROPOSALS

KEY FINDINGS

- The implementation of mitigation measures at farm level, preserving farmers' competitiveness, has proved to be feasible and an effective strategy to fight climate change.
- A precise approach to mitigation measures is needed in the new CAP reform and in further national/regional regulatory developments to ensure fulfilment of the future European climate commitments.
- Mitigation measures at farm level are cross-cutting actions with parallel benefits such as improving competitiveness, providing a better knowledge of the farms, tackling other environmental challenges, etc.
- Informing and supporting farmers is essential for successful and effective implementation of these measures at farm level. The farming community is not always aware of the important role it plays or the parallel benefits behind the mitigation measures, nor does it always have the skills to develop the proposed measures.
- Training farm advisers and farm advisory system staff is another key issue to increase the benefits of mitigation measures at farm level.
- Most of the mitigation measures at farm level depend on further CAP development at national/regional level. This flexibility the MS have in devising and implementing the new CAP could improve the effectiveness of this mitigation approach, but could also weaken this policy.

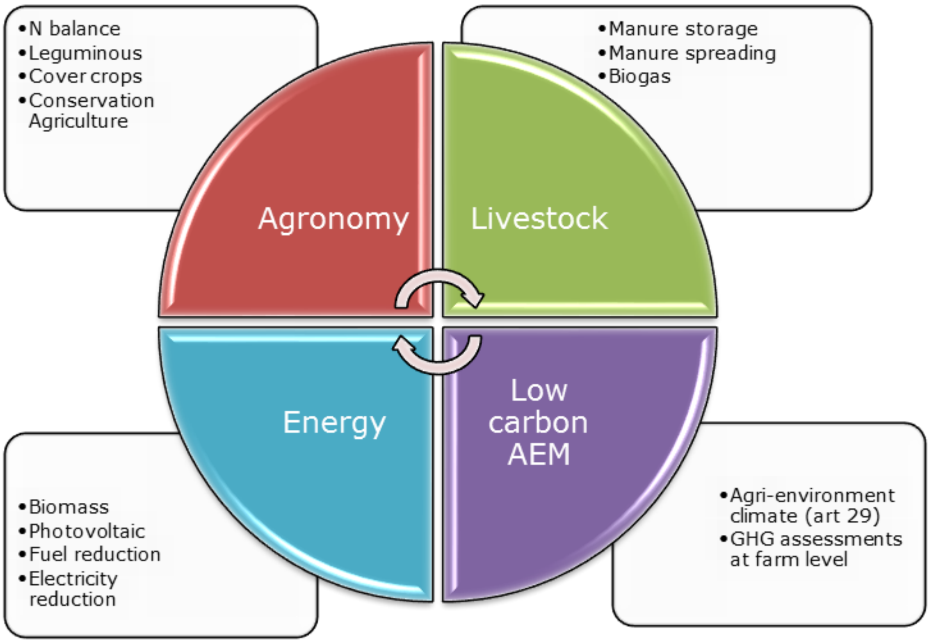
In the following chapters, 12 mitigation measures at farm level are described in detail. For each measure the following aspects are analysed:

- **Description of the measure:** describes how the measure should be implemented.
- **Target:** proposes and justifies a realistic target scenario for 2020.
- **Farming systems concerned:** explains to which types of farming production the measure can be applied.
- **GHGE reduction potential:** justifies why the described measure has been selected and quantifies the mitigation impact with maximum accuracy (where possible), taking into account not only the impact per unit, but also the potential implementation scenario in the EU. The calculations for mitigation potential are based on Eurostat data (agricultural statistics) and emission factors from the Carbon Calculator (JRC) or ACCT.
- **Environmental synergies:** identifies the cross-cutting benefits of the measure and underlines European directives or regulations that could benefit from the implementation of this measure.
- **Priority CAP option:** justifies, in the authors' opinion, the CAP instrument for which the measure would be the most effective in terms of mitigation.
- **Other CAP options:** explains for which other instruments of the new CAP this measure could be effective.

- **Difficulty for farmers:** provides an overview of the difficulties farmers face when implementing the measure from a technical point of view (not only technological limitations but also knowledge constraints).
- **Monitoring feasibility:** explains the feasibility of monitoring the implementation or progress of this measure in order to envisage the difficulties European, national and/or regional Authorities will have to face if the measure is included in any regulation.
- **Implementation costs:** explains the calculation of the benefits and/or costs associated with implementing the measure. The cost in euros is detailed if there is consistent information that can be used for all the EU countries. If the calculation of the costs depends on too many variables and factors, meaning consistent information cannot be ensured, an estimated cost is provided (negative, low, medium or high implementation cost).
- **Constraints:** describes the general constraints envisaged according to the authors' experience for implementation of the measure on a wide scale.

The suggested measures have been classified into 4 different categories related to the sources of GHG emissions: agronomy, livestock, energy and a specific agri-environmental measure (Figure 3). Before analysing each of the measures in detail, a summary table is provided (Table 1).

Figure 3: Proposed mitigation measures at farm level by category



Source: AgriClimateChange project.

Table 1: Summary of the proposed mitigation measures at farm level

	Name	GHGE potential	Target	Farming system concerned	Implementation costs	Other environmental synergies	Main CAP option	Difficulty for farmers	Monitoring feasibility
Agronomic measures	Nitrogen balance	High	<50 kg N/ha	All, except greenhouse, housed animals	Neutral / negative	ND, WFD, NEC, HD	CC	Easy	High
	Introduction of leguminous plants on arable land	Medium	>10% in cereals & >40% for temporary grassland	Arable land	Low / neutral	ND, WFD, HD & BD	Greening: crop diversification & EFA	Medium	Easy
	Conservation Agriculture	High	20% of the cropland	Cropland	Low / medium	Soil, WFD, HD	Greening equivalency	High	High
	Cover crops	High	100% of the cropland Permanent crops	Cropland and permanent crops	Low / medium	ND, WFD, Soil, HD, Pesticides	CC in NVZs	Medium / high	High
Livestock measures	Manure storage	Low -	Cover slurry pit	Livestock, especially pigs & cattle	Medium / high	NEC	Cross-compliance	Easy	Easy
	Manure spreading	Low	Liquid manure	Livestock, especially pigs & cattle	Low	NEC	Cross-compliance	Easy	Easy
	Biogas	High +	Manure	Livestock	Medium / high	NEC	Investment	High	Easy
Energy measures	Biomass	Low	Fuel substitution	Farms with heat needs	Medium	20/20/20, HD	Investment, AEM	Medium	Easy
	Photovoltaic	Medium	On farm roofs	All farms	Medium / High	20/20/20	Investment	Easy	Easy
	Fuel reduction	Medium	10% fuel reduction	All farms	Low	20/20/20	INF, AS	Easy	Easy
	Electricity reduction	Low	5 to 30% electricity reduction	Dairy, cold rooms, irrigation, processing	Low	20/20/20	Investment	Easy	Medium
AEM	Low carbon AEM	High	Maintain and encourage farms with low level of GHG emissions	All farms over 20 ha of UAA	Low	All	Agri-Environment Climate	Easy	Easy

Source: AgriClimateChange project.

2. DESCRIPTION OF THE MITIGATION MEASURES

2.1. Nitrogen balance

Description of the measure: an annual consolidated N balance (post-harvest) at farm level should become a mandatory tool. Pre-season nitrogen balances have proven to be ineffective. This approach highlights the scope for progress at farm level. The method requires annual data at farm level about the nitrogen inputs per category (quantities of mineral fertilisers, manure and grazing-related nitrogen, quantities of nitrogen fixed by leguminous species). Yields and surfaces for each crop (cereals, fruits, grasslands, etc.) are needed in order to calculate the annual output of nitrogen at farm level. The annual nitrogen surplus is calculated using the difference between inputs and outputs of nitrogen at farm level.

Target: a maximum surplus of N leaching of 50 kgN/ha at farm level is proposed as a realistic measure, as this was the average amount of N leached in the EU-27 in 2008 (Eurostat, Annex 1). However, there are huge differences between MS. Thus, the proposed target would mean a convergence of the N leaching levels throughout the EU.

Farming systems concerned: nearly all the farming systems in the EU, except non-grazing animals (no surface/farmland linked to the N balance) and greenhouse production for which specific methods need to be defined.

GHGE reduction potential: high, through direct and indirect emissions of N_2O from soils. The processing of mineral N fertilisers also has important consequences on climate change due to CO_2 and N_2O emissions. The potential scenario for the implementation of this measure is 63 million ha (12 MS exceed an average of 50 kgN/ha) in the EU-28, which corresponds to a reduction of 2.26 million tonnes of N (-23 % of the mineral N fertilisers used in the EU-28 in 2009). The mitigation potential could be about 21.5 million tCO_2e/year, which corresponds to the emissions from the manufacturing of mineral N fertilisers and the spreading on soils (a higher mitigation potential could be achieved by taking into account indirect emissions from soils).

As seen in AgriClimateChange, it is quite feasible for farmers to have an N balance under 30 kgN/ha due to a continuous decrease in the nitrogen surplus over time (Annex 2, case study 1). At European level, this threshold would mean a reduction of 4.33 million tonnes of N (-44 % of the mineral N fertilisers used in the EU-28 in 2009). The mitigation potential could be about 41.3 million tCO_2e/year, which corresponds to the manufacturing of mineral nitrogen fertilisers and the spreading on soils.

Implementation cost: this is a neutral measure (costs are compensated by savings), or even a negative one. No cost is envisaged for large cropland surfaces as the cost of an N balance calculated by a farm adviser will generally be compensated by the economic savings on fertilisers. The purchase of mineral fertilisers is a consistent annual expenditure for farmers (8 % of the intermediate inputs, Eurostat). The price of one unit of mineral nitrogen is about EUR 1.5; a decrease of 10 kgN/ha would cover the price for the adviser.

Environmental synergies: reduction of N leaching and pressure would improve biodiversity, water and air quality (ND, NEC Directive, WFD, Habitats Directive).

Priority CAP option: N balance at farm level should be included as a complement in cross-compliance (Pillar 1) to ensure that the mitigation impact of such a significant GHGE source is increased. In addition, the MS also have the possibility to implement financial instruments such as nitrogen taxes, which have already been tested in some countries (Norway, Sweden, Denmark or the Netherlands).

Other CAP options: options in Pillar 2 are available through innovation and research or farm advisory systems, but their impact will be lower.

Difficulty for farmers: easy, as data for calculating annual N inputs and outputs are known by farmers and farming advisers.

Monitoring feasibility: difficult, as this is a measure based on annual farm assessments and results, and not on previous calculations. Several steps should therefore be taken in advance, for example, defining accounting methodologies and accepted evidence to assess the nitrogen inputs.

Constraints: as this measure is result-based (requiring calculation of the N balance once the harvest is finished), European, national and regional administrations are in general quite reluctant to approach it this way. A limit on the maximum amount of N used is preferred. Nevertheless, this approach does not solve the methodological problems (control is still needed), and the huge diversity of varieties, climates and expected yields mean the measure is very difficult to devise (it is, in fact, converted into a large list of measures). Similar farming schemes based on farming assessments and results, such as the one suggested, have been implemented successfully, for example in Switzerland.

As regards acceptance by farmers, there is a still a strong correlation in farmers' minds between fertilisers and yields, so training should be given to overcome this problem.

2.2. Introduction of leguminous plants on arable land

Description of the measure: leguminous species can fix atmospheric N through symbiosis with bacteria in nodules of the root system. Sowing leguminous species on arable land would improve the fertility of the farm's agro-system. For cereal crops, this can be done by sowing protein crops on their own or by intercropping (mixed with other species). On temporary grasslands, leguminous fodder species can be sown alone or combined with grass species. Protein crops (peas, lupins, faba beans, soya beans, lentils, chick peas, vetches) are now grown on only 1.8 % of the arable land in the EU, whereas they are grown on about 8 % of the arable land in Australia and Canada (The environmental role of protein crops in the new common agricultural policy, 2013). The MS most involved in the production of protein crops are Spain (22 % of the surface), France (21 %) and Italy (12 %). As regards temporary grasslands, 34 % of the surfaces are composed only of leguminous crops (clover, alfalfa, sainfoin, vetch, etc.).

Target: the objective is to have at least 10 % of leguminous crops in the UAA of the farms (excluding grassland surfaces). For temporary grasslands, the objective is to plant leguminous species on at least 40 % of the total surface.
Farming systems concerned: all arable land in the EU-28.

GHGE reduction potential: high, through a decrease of direct N_2O emissions from soils (substitution of mineral nitrogen fertilisers) and CO_2 emissions from processing and transportation of external feedstuffs used on the farms. A potential of 7.4 million ha for protein crops could enable the EU to achieve its 10 % objective. A 35 kgN/ha reduction in mineral fertilisation for the next crop would be available thanks to the biological N fixation. As regards temporary grasslands, 7.2 million ha could potentially be planted with leguminous species, corresponding to 40 % of the surface available. A 25 kgN/ha reduction could be achieved for mineral fertilisation. Thus, a reduction potential of 439 million kg of N could be achieved for leguminous species on both temporary grasslands and arable land, which represents 4.4% of the mineral N fertilisers used in the EU-28 in 2009. This equals a mitigation potential of 4.1 million tCO_2e/year covering the manufacturing of mineral N fertilisers and the spreading on soils.

Farmers involved in the AgriClimateChange project have also implemented this measure. For example, in a case study included in Annex 2 (case study 1), it is demonstrated that introducing 16 % of protein crops into the total UAA of a crop farm enables the total GHGE at farm level to be reduced by 15 %.

Implementation cost: the introduction of protein crops would generate savings in inputs (fertilisation, fungicides and soil tillage) as well as a gain in gross margin for the next crop. However, there would be a loss of profitability for the farmer between protein crop and cereal crop gross margin. It should be understood that this last calculation is based on the current scenario of high cereal prices, which of course may change in the coming years. Nonetheless, this would be an inexpensive measure.

For temporary grasslands, this measure could be neutral or even entail a negative cost for farmers. The estimation of the implementation cost is calculated taking into account the cost of purchasing the seeds and sowing, and subtracting the mineral N saved.

Environmental synergies: this measure would have a positive impact on the implementation of the ND and WFD by reducing N leaching. It has also been proven that leguminous crops can benefit wildlife in Natura 2000 areas (such as endangered steppe birds in Spain), thus helping to implement the Habitats and Birds Directives. It would also reinforce the traceability of protein crops for breeding farms if more proteins were produced directly on farms. Self-sufficiency for livestock farms and more independence regarding feedstuffs could be another benefit.

Priority CAP option: the introduction of leguminous crops has already been mentioned in several documents as a suitable measure in the greening (Pillar 1). More specifically, in the measure "Crop diversification", leguminous crops can play a very important role, providing not only the expected diversity in the production systems, but also the aforementioned benefits. For EFAs, the introduction of leguminous species into temporary grassland has already been suggested, as they generate habitats that support wildlife.

Other CAP options: other options are possible in Pillar 2, for example the Natura 2000 payments or organic farming (in which these species are usually used to enhance soil fertility) payments. As usual, horizontal measures such as the Farm Advisory System and innovation and research should address this measure.

Difficulty for farmers: medium, as no specific sowing machinery is required but farmers would need to improve their skills in order to manage these new crops.

Monitoring feasibility: easy, through the annual CAP declaration of surfaces.

Constraints: in the case of cereals, the high price of wheat during the past few years certainly makes it difficult to convince farmers to move towards introducing leguminous plants. Compensation payments through greening could be a way to overcome these constraints. Other commercial strategies (such as giving added value to leguminous edible plants, related, for example, to nature conservation or Nature 2000 sites conservation) could increase the final price of the yield and become an attractive option for farmers. Training and information would be needed to inform farmers of the potential benefits (better diets for animals, better soil conservation, etc.).

2.3. Conservation Agriculture

Description of the measure: no-tillage is a cultivation technique involving one-pass planting. Soil and residues from the previous crop (mulch or stubble) are disturbed as little as possible (no ploughing). The machines used are normally equipped with coulters, row cleaners, disk openers, in-row chisels or roto-tillers. These penetrate the mulch, opening narrow seeding slots (2–3 cm wide) or small holes, and place the seeds and fertilisers into the slots. We consider that no-tillage should not be limited only to the use of the described machinery, as this approach leads only to a reduction in fuel consumption (and thus CO_2 emissions). When no-tillage machinery is approached in a wider agronomic sense, it has to include other agronomic practices such as cover crops and long crop rotation. Cover crops and long crop rotation enable a better control of weeds, thus reducing the use of pesticides compared with the no-tillage approach alone. Both cover crops and long crop rotation further improve the content of nitrogen in soils and organic matter, and the annual increase of C stocks in soils. If this wider approach is used, the amount of herbicide used does not systematically increase under conservation agriculture. However, a maximum threshold for herbicides can be set to limit this disadvantage and to increase the environmental effectiveness of this measure.

Target: at present, only 1.295 million ha are cultivated under CA in Europe (European Conservation Agriculture Federation, 2011), mainly in Finland, France, Italy, Spain and the United Kingdom. ECAF estimated that 30 % of the arable land in Europe would be suitable for adaptation to CA practices. Thus, the objective would be to reach 20 % of the EU-28 arable land for 2020, which corresponds to 19.55 million ha.

Farming systems concerned: all kinds of croplands.

GHGE reduction potential: GHGE reduction in this measure is related to the CO_2 emissions avoided due to fuel savings made in comparison with conventional systems (-50 litres/ha/year). Carbon sequestration in the soil is due to the combination of direct seeding with cover crops and long crop rotation (+1.13 tCO_2e/ha).

Compared to conventional tillage, additional N_2O emissions may occur under direct seeding (+1 kg $N\text{-}N_2O$/ha), and have been taken into account for the calculation of the mitigation potential. Thus, there is a reduction potential of 16.0 million tCO_2e/year.

Several pilot farms in the project were using conservation agriculture. Annex 2 (case study 1) shows that direct seeding combined with cover crops is the most effective measure to fight against climate change on a crop farm (reduction in GHGE and increase in the carbon stock). Over a 10-year period, the farm included in the case study has doubled the organic matter content in its soils.

Implementation cost: this measure requires specific investment in direct-seeding machinery. According to the no-tillage approach suggested in this report, the cost of purchasing seeds for cover crops also needs to be taken into account. Nevertheless, an average fuel saving of 50 % in comparison with conventional tillage is usually assumed, so it can be considered as a low-cost measure for large farms when the system is fine-tuned. The average cost of a suitable direct seeding machine for a 100 ha farm (suitable for this investment; for smaller farms, other formulas should be used) is EUR 50 000. With an amortisation period of 8 years, the annual cost is EUR 62/ha. Assuming a cost of EUR 8/ha for cover crops implementation, the measure would cost EUR 70/ha/year. Economic savings derived from fuel reduction (EUR 45/ha) and N fertiliser optimisation (20 KgN/ha = EUR 20) would lead to a total implementation cost of EUR 5/ha/year. In the farm used as an example (1,000 ha) this would mean EUR 5 000.

Environmental synergies: apart from the reduction in fuel consumption and N fertilisers, an increase in organic matter content in the soil (higher fertility) and a reduction in the working time per ha for field operations have been demonstrated. Numerous results reinforce and confirm evidence showing that no-tillage can reduce springtime run-off and erosion, provided the soil is sufficiently covered (with mulch, green manure, catch crops, etc.) and its biological activity is significant. The increase in the organic carbon stock is mainly located in the upper soil layer (the first 10 cm). The process continues until a new balance is reached between accumulation and destruction in the upper soil layer. It should be pointed out that ploughing once no-tillage techniques have been implemented can cause the rapid disappearance of all the positive effects of organic carbon in soils, which is why no-tillage has to be maintained over time to store carbon durably in the soil. This agronomic measure would improve the implementation of the WFD and directives related to Natura 2000.

Priority CAP option: this measure should be included as a greening equivalency measure under a certification scheme that ensures that direct seeding is linked as required to cover crop implementation and long rotations.

Other CAP options: an investment measure in Pillar 2 would be another option to facilitate the purchase of specific machinery, but we insist that linking no-tillage to investment measures would be a narrow approach and would decrease the GHGE reduction potential. Farm Advisory Systems and information are needed to make farmers aware of the benefit of this technique and train them in the use of new machinery and the suggested approach.

Difficulty for farmers: difficult, because in order to be successful, non-tillage should be combined with cover crops and a diversified rotation. Farmers would need to improve their agronomic skills with the help of qualified advisers. A transition period is necessary, especially for farmers who are still using full tillage (reduced tillage should be tried before no-tillage).

Monitoring feasibility: difficult, if approached with cover crops and long rotations, as it requires inspections. That is why we suggest a certification scheme system for no-tillage.

Constraints: the lack of knowledge would possibly be the most important constraint, as this measure proposes the combination of three different agronomic measures. Direct seeding is progressively being adopted by farmers due to fuel saving advantages, but direct seeding is just a part of this very effective mitigation measure.

2.4. Implementation of cover crops

Description of the measure: cover crops are crops planted to restore soil fertility and quality, contributing simultaneously to better management of water, weeds, pests, diseases, biodiversity and wildlife in agro-ecosystems (includes catch crops, cover crops, green manure, wild vegetation). The objective is to prevent N flushing, catch atmospheric N when using leguminous plants, improve soil conditions, avoid erosion, etc. In general, all the types of cover crops described improve the quality of soils in the short/mid-term, reducing the need to use N fertilisers that lead to N_2O emissions. This measure is especially suitable for tree crops in all European climates with a parallel benefit of reducing herbicide spraying, resulting again in the reduction of CO_2 emissions (please note that this assumption cannot be extended to arable land). An example of this situation from the AgriClimateChange project is illustrated in Annex 2 (case study 7).

Furthermore, intertillage is an agronomic practice that involves the use of catch crops (such as beans, clover or peas) that cover the bare soil after other crops. Intertillage practices, when they involve legumes, replace a significant amount of synthetic N fertiliser due to the N atmospheric fixation. Finally, they all contribute to increasing C storage in soils in the long term.

Target: in 2010, 25 % of the arable land in the EU-28 was left as bare soil (Eurostat), which corresponds to about 26.1 million ha. Annex 3 shows the huge variations between MS in the percentage of bare soil in the total arable land. The objective is to use cover crops on 100 % of the EU-28 cropland.

Farming systems concerned: all the cropland in the EU-28.

GHGE reduction potential: high, due to the decrease in direct and indirect N_2O emissions from soils. The potential farming scenario for this measure in the EU-28 is the total number of arable and permanent crops, thus the potential impact is very high.

For arable land, CO_2 emissions from additional fuel for sowing and destruction are taken into account (9 litres of fuel/ha), as well as the increase in the carbon stock in the soil and the saving of mineral nitrogen fertiliser when using cover crops (10 kgN/ha). A mitigation potential of 17.1 million tCO_2e could be achieved.

No consistent information has been found to identify the EU-28 permanent crops that are already using cover crops. Taking into account that the situation between MS is quite variable across Europe for vineyards or orchards, an estimative increase baseline of 30 % is proposed and used for the calculations. This offers a potential of 3.2 million ha in which cover crops could be used, which corresponds to a reduction potential of 5.7 million tCO_2e/year when considering only the additional carbon sequestration.

In total, increasing the use of cover crops on arable land and permanent crops could lead to a reduction potential of 22.8 million tCO_2e/year.

Implementation cost: the implementation of cover crops could lead to an increase in machinery operation and seed purchase on the farm. Due to the diversity of agronomic techniques and other issues relevant to the implementation of this measure, such as climate, farm size, kind of cover plants used, etc., it is impossible to give a standard cost per ha. In general terms, the cost of additional machinery operation and seeds purchased would have to be deducted from the fertiliser savings, but the final result is highly variable. In general terms it can be considered as a low to medium cost measure.

Environmental synergies: from an agronomic point of view, the main interest for farmers in implementing this measure is related to the improvement of soil structure, which leads to higher organic matter content, increased fertility, reduced N needs and higher resilience to droughts and erosion. A wider environmental approach will show that this also creates habitats that benefit biodiversity and functional connectors between protected areas and/or endangered species, enhances the potential for biological control of pests and diseases, significantly reduces soil erosion and, when managed correctly, can lead to water saving on the farm.

Priority CAP option: for arable land, the cover crops measure can be regarded as an EFA option (Pillar 1). Permanent crops are excluded from greening, so to avoid the exclusion of permanent crops from this measure, an agri-environmental-climate payment (Pillar 2) could be envisaged for cover crops used in permanent crops.

Other CAP options: the organic farming measure and Natura 2000 areas are measures where cover crops could be included and partially funded. In the first case, it is common practice among organic farmers and, in the second case, it is a practice that can improve biodiversity. This topic should be included in the Farm Advisory Systems in order for the measure to be implemented correctly.

Difficulty for farmers: medium to difficult, as the implementation costs of cover crops and intertillage depend on several factors and do not necessarily represent a high cost for the farmer. The most important constraints for implementation do not refer to economic limitations but probably to other aspects, especially the lack of information among farmers concerning the benefits at farm level and insufficient knowledge and transfer of the agronomic techniques.

Monitoring feasibility: high, as it requires inspection or farm book control.

Constraints: cover crops and intertillage are well-known agronomic measures, but they are not widely used among the farming community. The aforementioned lack of information refers not only to the benefits of implementing this measure but also to the practical information needed to manage a cover crop that is extremely variable depending on the climate, geographical area, crop, annual condition, previous situation of the soil, etc.

2.5. Manure storage

Description of the measure: storage of cattle and pig slurry is a source of ammonia (NH_3) and methane (CH_4). Methane is one of the climate-active gases and ammonia is a precursor gas for nitrous oxide (N_2O). Therefore, the reduction of ammonia should be a target in active farming to combat climate change. Through the relatively simple measure of covering the liquid stored, emissions of methane and ammonia during storage could be greatly reduced. There are several possibilities for covering the liquid stored, depending on the size of the storage area and how often it is emptied. The most effective way to reduce emissions involves a solid cover such as a concrete or wooden top. Other covers, such as floating or perforated covers, tents or natural crusts, are less effective but also less expensive.

Target: to cover all the slurry pits and liquid manure facilities on EU-28 livestock farms. Around 75 % of the EU-28 holdings have covered storage facilities for liquid manure and slurry (Eurostat, 2010). Nevertheless, there are significant differences between countries, as, in some of them (Belgium, Denmark, Germany, the Netherlands, Slovakia), covering slurry pits and liquid manure is mandatory. Other countries (such as France, Italy and Spain) have a significant potential for progress.

Farming systems concerned: livestock, especially cattle and pig farms for which liquid manure systems are the most frequent.

GHGE reduction potential: covering liquid storage facilities with a rigid cover can decrease NH_3 emissions by 70 to 90 %; using a flexible cover can decrease them by 80 to 90 % (GGELS, JRC).However, manure storage in anaerobic conditions can increase CH_4 emissions. It is therefore necessary to burn the gases through a flare system. A GGELS study put forward a reduction potential of 17 000 tonnes of ammonia across the EU-27 by covering manure facilities. This equals a reduction of mineral nitrogen fertilisers equivalent to 0.09 million tCO_2e/year for the manufacturing process. Taking into account an increase of 0.04 million tCO_2e/year in the CH_4 emissions burnt, covering liquid manure facilities could lead to a reduction potential of 0.05 million tCO_2e/year.

Implementation cost: the implementation costs are related to investment on the farm. Depending on the cover type, the costs can be adapted to the farmer´s budget. A cover can cost around EUR 60/m^2 to EUR 200/m^2, i.e. around EUR 15 000 to EUR 45 000 for an average slurry pit, plus a flare system (EUR 20 000).

Environmental synergies: suitable manure storage could improve the N content of liquid manure thanks to the avoided N losses from NH_3 volatilisation. This measure is therefore directly linked to implementation of the NEC Directive. Covering the slurry storage pit would also reduce the emission of odours.

Priority CAP option: this measure should be included in cross-compliance to ensure its mitigation potential is increased. Some countries have already included it as a mandatory measure using other regulations. Cross-compliance would provide a common framework for this measure throughout the EU-28.

Other CAP options: another option would be to include this measure in the investment measures of Pillar 2.

Difficulty for farmers: easy, as guidance in constructing the slurry storage cover can be given by public/private agricultural advisers and private companies. As soon as the type of cover has been decided on and constructed, the farmer should not have to perform any additional work in this respect.

Monitoring feasibility: easy, as only one inspection is required.

Constraints: no constraints are envisaged for this measure.

2.6. Manure spreading

Description of the measure: the application of slurry close to the ground reduces the emissions of gases such as methane and ammonia, and also reduces odours. The state-of-the-art trailing machines, such as trailing hoses and trailing shoes, and the application methods involving shallow or deep injection can therefore be used. The second improvement to reduce gas emissions during slurry application involves incorporation into the soil at the time of application. Slurry should be incorporated as soon as possible after application. The weather during application should not be too hot or too windy.

Target: mandatory application of slurry close to the ground on all the EU croplands that use slurry as fertiliser.

Farming systems concerned: all the croplands that use slurry as fertiliser.

GHGE reduction potential: high potential, as it involves NH_3 emissions. Drip hose systems that allow the application of slurry close to the ground can decrease NH_3 emissions by 55 %. In addition, if liquid manure is injected directly into the soil, NH_3 emissions can be reduced by 95 % to 100 %. If solid manure is incorporated 4 hours after spreading, an 80 % reduction in NH_3 emissions can be observed (60 % if manure is incorporated 12 hours after spreading).

It has been demonstrated in a GGELS study that using techniques to reduce ammonia emissions during and after application of manure on arable lands or grasslands could lead to an average reduction potential of 350 000 tonnes of ammonia in the EU-27. This represents 1.8 million tCO_2e/year in the manufacturing process of mineral N fertilisers.

Implementation cost: adding rubber pipes to a spreading machine that is already on the farm in order to enable near-ground application costs EUR 1 200/m. Therefore, depending on the type of spreader, the total price would be around EUR 1 200 to EUR 3 600 per farm.

Environmental synergies: volatilisation of ammonia from liquid slurry leads to a loss of N. Therefore, reducing ammonia emission will lead to more N being present in the slurry. The farmer needs to add less purchased synthetic N fertilisers. By using a near-ground application technique, the emission of odours can also be reduced. For farms located in the neighbourhood of a village/city, the inhabitants would therefore be less disturbed by the smell. This measure will improve the implementation of the ND and NEC Directives.

Priority CAP option: cross-compliance already takes into account measures for manure spreading, and it should move towards including new obligations for the spreading of liquid manure to ensure results for climate change mitigation. Including this measure in cross-compliance would ensure a wide application and a significant mitigation impact.

Other CAP options: the investment measure in Pillar 2 would be another option, as a small investment is needed to adapt the machinery. Farm Advisory Systems will again play an important role, informing farmers about the need to adopt this measure and providing training in the use of the machinery.

Difficulty for farmers: easy, as no special skills are needed to use this adapted machinery.

Monitoring feasibility: difficult, as frequent inspection is required.

Constraints: no constraints are envisaged for this measure.

2.7. Biogas at farm level

Description of the measure: the fermentation of slurry, residues and other plants generates biogas, which is used to produce electricity. Due to the covering process the emission of methane and ammonia from manure storage can be avoided. Biogas technology is well developed, although continuous progress is made to improve its efficiency. In the opinion of the authors, biogas plants at farm level should be based on slurry, not on energy crops, to fight against GHGE from manure management.

Target: the objective would be to use all kinds of manure and farm residues to feed the biogas plants. Biogas plants are only used at farm level on a wide scale in Germany (with more than 7 000 biogas plants); therefore the target of 100 % of livestock farms could be extended to almost all the countries of the EU-28. To be more realistic, we will retain the GGELS study assumption, involving only farms above 100 livestock units.

Farming systems concerned: all livestock farms, especially cattle and pig farms and farms with arable land.

GHGE reduction potential: very high potential, as CH_4 emissions from manure storage are avoided and renewable energies are produced (electricity and heat valorisation). An average biogas plant at farm level (around 200 kWe, material used for fermentation around 7 tonnes) avoids the emission of 300 tCO_2e per year (Annex 2, case study 4 presents a biogas plant in Germany).

By installing biogas plants on every farm with more than 100 livestock units, a reduction potential of 60 million tCO_2e/year could be achieved, 50 % related to the manure storage reductions and 50 % related to the valorisation of renewable energies.

Implementation cost: this measure is probably one of the most expensive. A biogas plant adapted for a single farm would require an average investment of EUR 1 000 000-2 000 000.

Environmental synergies: the production of electricity generates heat, which can be used to warm up buildings and heat water. Other side-effects of biogas production are the reduced emission of odours from manure storage, as the fermenter and post-fermenter are covered, and the enhanced efficiency of fertilisers: organic N is transformed into mineral forms in the digestate, which benefits the N balance at farm level. The production of electricity and heat with biogas creates new sources of income for farmers. This measure is directly linked to the NEC Directive implementation as well as to the ND and WFD.

Priority CAP option: this measure should be related to investment measures, as investment is a major constraint.

Other CAP options: there is little room for other CAP instruments, as investments and income from electricity are the key factors in biogas plants. Energy programmes and prices for electricity production would need to be agreed upon at national level in order to make the implementation of biogas plants feasible.

Difficulty for farmers: difficult, as the system would have to be installed by experts. Once the infrastructure is ready, farmers would need several months of experience in order to get the best results.

Monitoring feasibility: easy, as only one inspection would be required.

Constraints: the most important constraint is the high cost of the infrastructure, but it is also very important to optimise the national regulatory framework, as the viability of the biogas plants, once built, will depend on the price agreed for the electricity produced, other related bonuses and the possibly of using gas or heat.

2.8. Use of biomass for heating needs

Description of the measure: every farm that requires heat for its activities, or simply to heat its buildings, can produce this heat from renewable energy such as wood or other biomass products. To implement this measure, the conventional boiler would need to be replaced by a new one able to be fed with wood. The raw material could sometimes be obtained on the farm (from forests owned, waste from pruning or other by-products such as olive pits). Otherwise, it could also be purchased. The boiler technology currently available enables a wide range of materials to be used. In the case of an internal source of biomass, it would be necessary to cut, harvest, process and store it in a proper building. Depending on the case, it may be necessary to adapt the heating system: if the new boiler is positioned in a different place, close to the wood storage area, a remote heating connector to reach the heat distribution circuit will need to be provided; otherwise, this should be left as it is.

Target: substitution of all the fossil fuel consumed in boilers by biomass (mainly wood, pruning waste or other wood by-products). It is difficult to set a target for this measure as there is no consistent information to identify the number of boilers on EU-28 farms (and also the boilers that have already been replaced by biomass boilers).

Farming systems concerned: the use of biomass to produce heat is very interesting because it can be applied to all farms that need heat for greenhouses, agricultural product processing, the management of certain animal barns (pigs), or simply for heating houses.

GHGE reduction potential: low potential for CO_2 emissions, related to the substitution of fossil fuels consumed on the farm for heating (usually liquid and gaseous fossil fuels, such as diesel, LPG, methane, butane). As an example, for each litre of fuel substituted by biomass, 3 $kgCO_2e$ are avoided.

Implementation cost: medium-cost measure, but difficult to calculate as the investment depends on whether or not the previous boiler can be adapted, the power of the new one purchased, the final use of the boiler, the kind of material to be used, etc. The main costs for implementing this measure are related to the substitution of the traditional fossil fuelled boiler with another special boiler capable of being fed with wood and biomass; the construction, if necessary, of the room to be used for wood storage; the adaptation of the heating system, if required; cutting, harvesting, processing of the raw material if it comes from within the farm.

Environmental synergies: apart from avoiding CO_2 emissions, the main benefit would be the reduction of fuel-related costs and independence regarding energy prices. This measure is directly linked to the EU climate and energy package (20-20-20 strategy).

Priority CAP option: this measure should be related to investment measures.

Other CAP options: agri-environment-climate payments could be another option to co-fund the investments needed, especially if they are linked to National Energy Saving Strategies (for example, *Plan de Performance Energétique* in France) or non-ETS mitigation programmes (such as the FES-CO_2 programme in Spain). Farm Advisory Systems will play a key role in informing, training and advising farmers during the implementation of this measure.

Difficulty for farmers: medium, as technical advice is needed for the substitution of the biomass boiler, wood supply (purchasing or cutting, harvesting, processing and storage), adapting the heating system if needed, constructing or adapting the boiler room, organising a storage system for the wood, supplying the wood, implementing a remote heating system, etc.

Monitoring feasibility: easy, as a brief inspection or invoice control for the fuel supply would be enough.

Constraints: no constraints are envisaged for this measure, except for the investment needed.

2.9. Photovoltaic installation

Description of the measure: farm buildings often have significant surface areas. Where there is exposition to solar radiation, photovoltaic panels could be installed to produce renewable electricity. Sometimes, electricity consumed from the grid could be replaced by the local renewable electricity produced (balance between the activity of the farm and the size of the installation).

Target: to use the maximum surface of suitable farm roofs, avoiding the use of land for the installations. It is very difficult to determine a realistic target for this measure, as it is not easy to assess the number of farms using electricity for which substitution with photovoltaic installations is feasible, or the number among them which already use photovoltaic installations to a certain degree. Thus, it is assumed in the calculations that at least 5 % of farm holdings in the EU could have suitable conditions in which to install 100 m^2 of photovoltaic panels.

Farming systems concerned: all farms with significant flat surfaces (every 1 kWp installed needs about 7-8 sq m for a mono- or polycrystalline panel), with the right exposure (oriented +/- 20° south) and inclination (15°-30°). Depending on the countries' conditions, the annual renewal of electricity production can vary from 79 kWh/m^2 in Finland to 150 kWh/m^2 in Malta.

GHGE reduction potential: low potential for CO_2 emission linked to the use of electricity on the farm, even if the emission factor per kWh is extremely variable among the MS (from 0.11 $kgCO^2e/kWh$ to 1.6 $kgCO_2e/kWh$). Electricity consumption for agriculture represented around 47 949 GWh in 2011 for the EU-27 (Eurostat), and the highest consumers were Germany, the Netherlands, Italy, Spain, the United Kingdom, France and Greece. Assuming that 5 % of the farms in the EU could install photovoltaic panels, and using an average productivity ratio per country for the calculations, a potential of around 5 367 GWh of renewed electricity could be obtained, representing 11 % of the current electricity needs for EU agriculture. This would lead to a reduction potential of 4.7 million tCO_2e/year.

In Annex 2 (case study 9), a relevant example in Italy about photovoltaic production in a cellar demonstrates the interest of energy independence at farm level.

Implementation cost: medium to high cost measure, but depending on the size of the photovoltaic installation. An average of EUR 1 500‑3 000 is needed for every kWp installed.

Environmental benefits: the main benefits would be the income from electricity production, reduced electricity costs and independence as regards energy prices. This measure could be linked to the EU climate and energy package (Strategy 20-20-20). Developing smart grids in agricultural areas could be very useful for several reasons: environmental monitoring, smart farming management for reducing resources and energy consumption.

Priority CAP option: this measure should be linked to investment measures.

Other CAP options: agri-environment-climate payments could be another option to co-fund the investments needed, especially if they are linked to National Energy Saving Strategies (for example, *Plan de Performance Energétique* in France) and a favourable regulatory framework that supports the use of renewable energies.

Difficulty for farmers: easy, as the technology of photovoltaic systems is very mature and enables the most suitable technical solution for each roof type to be used, and most technicians have photovoltaic knowledge.

Monitoring feasibility: easy, as authorisation to connect to the grid is required in order to install a photovoltaic plant.

Constraints: no constraints are envisaged regarding this measure.

2.10. Fuel reduction

Description of the measure: the fuel consumed by mobile machinery (tractors and other farming vehicles) can be reduced at farm level in several ways. In some countries, interesting initiatives have been implemented to test the tractors' engines (for example *"Banc d'essai tracteur"* in France), going beyond the theoretical measures published extensively in most countries and demonstrating that the average amount of fuel saved can be significant (in France, an average of 10–15 % reduction in fuel consumption was achieved after the tests). Eco-driving training for farmers has also been implemented in several countries, showing interesting results.

Finally, fuel reduction can result from the implementation of other sustainable farming practices that lead to the reduction or optimisation of work on the farm. Farm operations that lead to reduced tillage or no-tillage (see above CA including direct seeding) have to be encouraged to obtain fuel reduction. Using GPS technologies can also help to optimise fuel consumption (Annex 2, case study 3 in Italy). Using integrated production can also decrease the number of plant protection treatments required and reduce the use of tractors; using cover crops on tree farms can significantly reduce tillage and herbicide treatments, and again decrease the use of tractors. For livestock farms, it is quite frequent that half of the total fuel consumption is related to animal care in buildings (fodder distribution, mulch for animals, manure removal, etc.), thus, strategies designed to optimise machinery movements in livestock buildings and adjust tractor power in relation to the work done can help to reduce fuel consumption.

Target: a 10 % reduction in the fuel consumed for mobile machines, for the most-used tractors on the farms.

Farming systems concerned: all farms that use mobile machinery in the EU.

GHGE reduction potential: low to medium potential linked to CO_2 emissions from fossil fuels used mainly in mobile machines on the farm. In 2011, the agriculture energy consumption of the EU-27 was 12 065 000 tons of oil equivalent for liquid fuels (Eurostat), therefore a reduction potential of 3.3 million tCO_2e/year could be achieved.

Implementation cost: the average cost of engine tests for tractors in the aforementioned French experiment is EUR 130/tractor (which is not a real cost as it is partially granted). The cost of adjusting the tractor after the test results varies from EUR 20 to EUR 1 500, depending on the equipment; a cost that can be easily compensated with the average fuel reduction of 10-15 % achieved. In the French experiment, *"Banc d'essai tracteur"*, the testing equipment travels in a lorry to different regions of the country to ensure a maximum commitment by farmers. The investment cost for setting up the testing equipment can be significant, but the French initiative has been working for several years under public and public-private management. For eco-driving training financial limitations should not be a problem, as explained in the case study included in Annex 2. Finally, fuel-saving through best sustainable practices can be considered as a parallel benefit of implementation.

Other benefits: the added value of this measure is the reduction in expenditure for the farmer, especially in the current trend of rising petrol prices. This measure would be directly linked to the climate and energy package (Strategy 20-20-20).

Priority CAP option: all measures concerning the reduction of fuel consumption could be included in Pillar 2, in the investment measures (for experiments such as *"Banc d'essai tracteur"*) or in the Farm Advisory System (for measures such as eco-driving).

Other CAP options: agri-environment-climate payments could be another option to co-fund the investments needed, especially if they are linked to National Energy Saving Strategies (for example, the *"Banc d'essai tracteur"* experiment is linked to the *Plan de Performances Energétique* in France).

Difficulty for farmers: this measure is very easy to implement for farmers and probably one of the most popular, as fuel is one of the main consumption sources for farmers and its reduction is considered a priority.

Monitoring feasibility: engine tests are easy to monitor, as the farmers receive a document after the engine test. Monitoring could include presenting this document and/or the proof of modifications made to the tractors in order to increase efficiency.

Constraints: no constraints are envisaged for this measure. In fact, even though the measure has a low impact on the total emissions from agriculture, it could possibly be the one which is best accepted by the farming community.

2.11. Electricity reduction

Description of the measure: the potential of electricity reduction on dairy farms focuses on the milking process. Installed vacuum pumps reduce electricity needs during milking, pre-cooling milk systems reduce electricity consumption during milking (30 to 50 %), heat exchange systems allow the heat to be reused to heat rooms and water (70 to 90 % electricity reduction for hot water). On irrigated farms, irrigation can represent significant electricity consumption: adjusting the water quantities to the water needs of the plants with the help of tensiometric probes in the soil is a way to decrease water consumption and therefore electricity consumption. Substitution of pumping using fossil fuel with renewable energy systems could also be envisaged in this measure. Farms with processing activities often have opportunities to optimise their use of electricity: for heating needs, solar panels could be an option (Annex 2, case study 6). In addition, when cold rooms are used on the farm, the heat recovery potential could be studied.

Target: a reduction of 5 to 30 % of the total electricity consumption on the farm could be achieved. On dairy farms, electricity for the milk system usually represents 85 % of the total electricity consumption. The main sources of consumption are the milk tank and water heating; milk-cooling systems and heat exchangers are installed on half of the dairy farms.

Farming systems concerned: farms with significant electricity consumption such as dairy farms, irrigated farms, farms with processing activities or equipped with cold rooms.

GHGE reduction potential: low, depending on the type of farm and technology already in place. The reduction of electricity only concerns CO_2 emissions. In general, farms that are far from being effective can achieve more significant reductions than farms with high energy performance, which can only achieve low reductions.
For dairy farms in Europe, electricity consumption for the operation of the milk tank and the production of hot water has been estimated at 6 803 GWh, which represents 14 % of the total electricity consumption of EU-28 agriculture. Assuming that half the dairy farms are equipped with electricity-saving technologies (milk-cooling system and heat exchange on the milk tank), a mitigation potential of 1 million tCO_2e/year could be achieved.

Implementation cost: investment may vary quite significantly, depending on the equipment needed.

Environmental synergies: the main benefits for farmers are electricity savings and the decrease in the farm's energy dependence.

Priority CAP option: this measure should be linked to investment measures and/or national energy plans, as it has been in many European countries: an increase in electricity efficiency should be compulsory for newly built farms and replaced machines.

Other CAP options: not considered, although the Farm Advisory System would help explain to farmers the opportunities linked to energy reduction and the technologies available in each sector.

Feasibility for farmers: easy, as the systems would be installed by experts, with no significant difficulties.

Monitoring feasibility: medium, as it depends on whether there is an investment or not, and on the kind of equipment purchased.

Constraints: no constraints are envisaged beyond the investment needs.

2.12. Low carbon agri-environmental measure

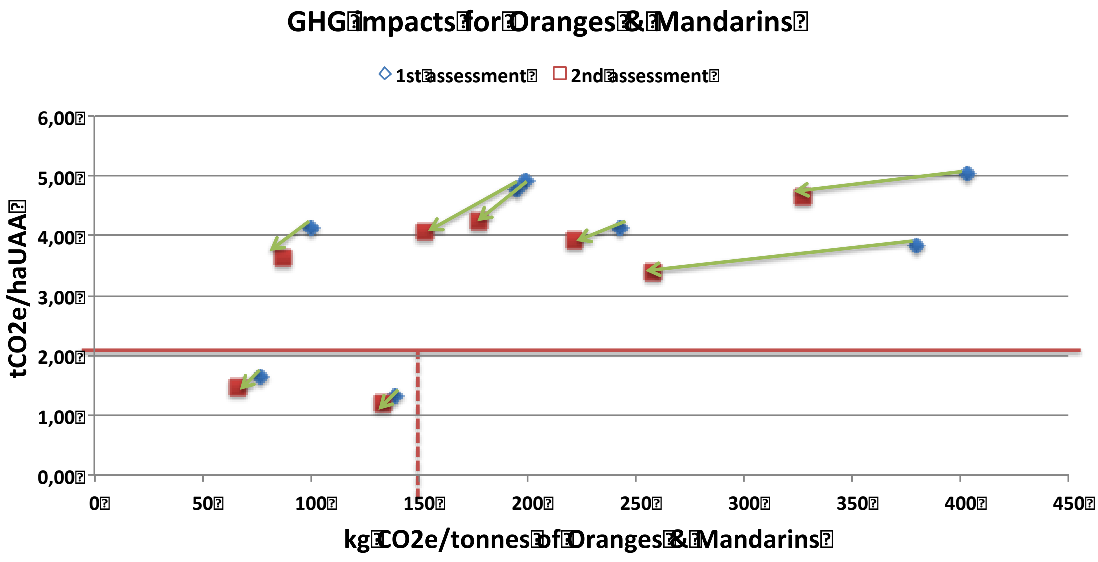
Description of the measure: according to the AgriClimateChange results, a great variation in GHGE has been observed between farming systems and even within a same farming system. These results are linked to farm practices but also to farmers' skills and interests. There are often several options for reducing GHGE on a farm, and implementing an AEM Climate system would enable farmers to be free to organise themselves in order to achieve effective results. Thus, this AEM can both maintain and encourage farms developing low carbon farming practices.

Target: all farms in the EU-28 with over 20 ha of UAA (this represents 12.3 % of the holdings in the EU-28 and 80.4 % of the total UAA).

Farming systems concerned: all farm systems in the EU-28.

GHGE reduction potential: all the aforementioned GHG measures in this report could be used, with the advantage of focusing on the most relevant ones at farm level, or focusing on the measures that farmers are ready to implement. Generally, drawing up an action plan at farm level can result in a GHGE reduction of at least 10 % (AgriClimateChange network of farms). Taking into account direct emissions from EU-28 agriculture and the UAA involved, a reduction potential of around 30 million tCO_2e could be achieved.

Figure 4: Progress made by orange and tangerine farms in implementing action plans including several mitigation measures



Source: AgriClimateChange project.

As shown in Figure 4, for a group of orange and tangerine farms, GHGE per ha of UAA can vary from around 1 to 5 tCO_2e/ha. These observations would be the same for other agricultural productions (dairy milk farms, cereals, olives, etc.) and significant progress can be made by implementing diverse measures that depend on farm possibilities, or sometimes just on the farmers' choice.

Assessment tools and action plans: several tools are available in Europe to correctly assess GHGE at farm level. ACCT is a specific tool developed during the AgriClimateChange project that combines GHGE, changes in the carbon stocks on the farm and the total energy consumption (direct and indirect energies). The complete version of ACCT is very useful in the aforementioned process of a low carbon AEM strategy and is sufficient enough to work with farmers and assess the GHGE reduction achieved through changes in farming practices or other measures implemented at farm level.

The JRC has also developed an EU-wide farm-level Carbon Calculator that is now available and could also be advisable for this purpose (http://www.solagro.org/site/476.html). In addition to these tools, national or regional initiatives have regularly led to the design of local GHGE assessment tools, and some of them would certainly also be suitable. The main limitation is access, because some of the tools are not free. It is obviously not conceivable to pay for such a tool in the low carbon AEM. These kinds of tools, which must be paid for, are often linked to carbon footprint initiatives, which are not the subject of the low carbon AEM. As the assessment's aim is not to calculate the carbon footprint, the accuracy of the GHGE calculations of ACCT or the Carbon Calculator is sufficient enough to show the GHGE reductions under the low carbon AEM.

From the authors' point of view, tools are very useful to identify the main challenges on a farm and suggest suitable measures to farmers, but this is just the first step in the process. Farmers are encouraged to obtain the support of a specialised adviser with wider skills (agronomic, livestock, energy, etc.) to help them develop the measures they are interested in. If a farmer carries out a self-assessment of -GHGE, the relevant measures will not automatically be indicated. The role of an adviser is essential to explain all the possible options to farmers, and then prioritise them in order to select the most suitable ones to be implemented.

The proposed AEM climate measure is an annual GHG assessment at farm level that could be run by a "certified" external adviser (expected workload: 1 day, divided into a half-day to collect data and a half-day to obtain results). The assessment must be carried out at farm level over a cultivation period (one crop season or year). It is the user who defines the beginning and the end of this period based on present agricultural production on the farm and the production cycles. Most of the required data are usually available in various farm documents: CAP statement, fertilisation plan, the farm accounts, invoices input, identification of the herd, etc. Most data could therefore be checked if verification is needed. The national authorities should determine a list of data, stating which are mandatory. For example, GHGE that are not linked to agricultural activities (processing, transportation of products, etc.) should be reported separately from the agricultural sources. Thus, farms that sell their products will not be placed at a disadvantage.

The farmer would have a 5-year period to implement some of the measures included in an action plan. At the end of this period, a second assessment would be made in order to verify that the GHGE ratio per ha has been reduced in a proportion corresponding to the initial objective.

Implementation cost: the cost should be based on the work of the adviser during this 5-year period. The time devoted to the advisory work is estimated to be between a minimum of 5 days/year and a maximum of 10 days/year. With an average daily rate of EUR 500, the final cost would be between EUR 2 500 and EUR 5 000.

UAA of the farm	20 ha	50 ha	100 ha	150 ha	200 ha
Advisory cost €	2500	3000	4000	4500	5000
AEM cost €/ha/year	25	12	8	6	5

Depending on the size of each farm, the annual AEM cost per ha could be low, between EUR 25/ha/yr for small farms and EUR 5/ha/yr for large farms.

Environmental synergies: an assessment at farm level always results in a better knowledge of the farm and many advantages therefore arise through farm level assessments. Economic improvements (money saving, better knowledge for future investments, added value for the product, etc.) as well as social benefits (improved effectiveness for certain tasks, optimisation of time, etc.) are frequent when supporting farmers in this kind of process. As this measure potentially includes all the measures mentioned in this document, there are also very significant parallel environmental benefits.

Priority CAP option: the measure proposed fits perfectly into the agri-environmental climate measure, which is not sufficiently defined in the current available documents.

Other CAP options: not envisaged, but there is probably no room to include this measure in Pillar 1 as many aspects of this measure should be implemented on a national or regional scale (definition of baseline references, priority of measures to be included in the AEM, inspection system, etc.). The Farm Advisory System should play a very relevant role in this measure as it could be the main support for farmers in the implementation and monitoring of the farms' progress.

Difficulty for farmers: easy, as data required for the assessment are available in various farm documents. Nevertheless, the assistance of an adviser with climate-friendly agricultural skills would be necessary due to the novelty of the method proposed.

Monitoring feasibility: easy, as the implementation of this measure requires several steps, such as defining national or regional references per farming system, defining the assessment tools, training Farm Advisory System personnel in this AEM, visits to the farms by said personnel, etc. Nevertheless, in some regions, similar farming schemes based on farming assessments and results have been implemented successfully.

Constraints: as a new and result-based measure, thus needing a complete new implementation protocol and post-harvest control, the national and regional administrations in charge of CAP implementation which have already been contacted regard this measure as complex. A possible way to overcome this situation would be to integrate this AEM climate module into other previous existing schemes, so that part of the protocol (tool, data input, inspection, etc.) would already be well established and would only have to be extended.

Maintaining farms with low carbon farming practices

As seen in the AgriClimateChange project, GHGE per ha can be quite variable inside a single farming system. Some of the farms already implement low carbon farming practices. Therefore, their reduction potential is probably low due to their low level of GHGE. In our opinion, the definition of national or regional references per farming system to determine low, medium or high emission levels is one of the core aspects of this AEM Climate.

A threshold must be determined for GHGE per ha and for the main farming systems (only annual gross GHGE, not a GHG balance), based on the reference group results. For example, it could be the lower quartile for the GHGE per ha (this means that a quarter of the farms are under this emission ratio). If the first assessment on a farm that is testing the AEM shows that this farm already has good results (GHGE/ha under the lower quartile), then a specific method should be applied: the priority for this kind of farm would not be the reduction potential objective but the verification in the final assessment of whether the GHGE/ha is still under the lower quartile at the end of the 5-year period.

3. PRIORITISATION OF MITIGATION MEASURES AT FARM LEVEL

In this section, the proposed measures are prioritised according to 3 aspects:

1. The global impact of the mitigation measure, thus taking into account the quantity of GHGE avoided per unit and the potential applicability in EU agriculture. This is done using the calculations developed in the description of each measure.

2. The feasibility for farmers, thus taking into account realistic measures that European farmers are able to implement. This information is detailed in the previous section and is based on the AgriClimateChange experience.

3. The implementation cost of the measure, which is also detailed in the previous section.

The following table includes the proposed mitigation measures in the left-hand column. Each measure is classified according to the implementation cost, from neutral to high. The mitigation potential impact measured in $MtCO_2e/yr$ is detailed (using a lighter or darker shade of orange depending on its importance) and the difficulty for farmers is also shown.

Table 2: Prioritisation of the mitigation measures at farm level according to the implementation costs and feasibility for farmers

GHGE potential (MtCO2e/yr)	Difficulty for farmers			
Implementation Cost	**Easy**	**Medium**	**High**	**Total**
Neutral / negative				
Nitrogen balance	21.5			21.5
Low				
Low Carbon AEM	30.0			30.0
Electricity reduction	1.0			1.0
Fuel reduction	3.3			3.3
Leguminous plants on arable land		4.1		4.1
Manure spreading	1.8			1.8
Low / medium				
Cover crops		22.8		22.8
Conservation Agriculture			16,0	16.0
Medium				
Biomass for heating		1.0		1.0
Medium / high				
Manure storage	0.1			0.1
Photovoltaic installation	4.7			4.7
Biogas			60,0	60.0
Total	**62.4**	**27.9**	**76.0**	**166.3**

At least 6 neutral or inexpensive measures can contribute in a very significant way to reducing GHGE from the agricultural sector, 2 of them being quite relevant: N balance and low carbon AEM. The advantage is that all these measures are easy (or average for leguminous plants) for farmers to implement.

Regarding the difficulty for farmers, 2 additional, easy-to-implement measures could be added to the previous ones: manure storage and photovoltaic installations. Nevertheless, these are medium- to high-cost measures. That means that the implementation of inexpensive and feasible mitigation measures would represent a relevant mitigation target and would include at least 8 measures involving different farming systems.

A more ambitious approach would be including as a mitigation priority the biogas, cover crops and conservation agriculture measures. For biogas plants, the main problem is that this depends on MS regulations and electricity grants; it is an expensive and difficult measure to implement. For conservation agriculture and cover crops, as approached in this report, the problem is not the cost (which remains moderate) but the skills farmers have to develop to be able to implement these measures and achieve the maximum mitigation potential. An effort to overcome these constraints would enable a significant agricultural mitigation potential to be reached.

In general terms, it can be concluded that **the implementation of mitigation measures at farm level in the EU can contribute quite significantly to reducing agricultural emissions.** The measures proposed include some which are **inexpensive and easy to implement for farmers, among which two in particular, N balance and low carbon AEM, would lead to significant reductions in agricultural GHGE**. More ambitious measures (such as biogas, cover crops and conservation agriculture), but which are also more expensive and difficult to implement, are possible and would lead to more relevant mitigation results. All the proposed measures can be included in the new CAP structure, although **a more precise definition of the mitigation measures will be needed in the future development of European, national and regional CAP-related instruments to ensure that the described results are achieved**. All the mitigation measures at farm level are **cross-cutting actions with parallel benefits, such as improving competitiveness, providing a better knowledge of farms and tackling other environmental challenges.**

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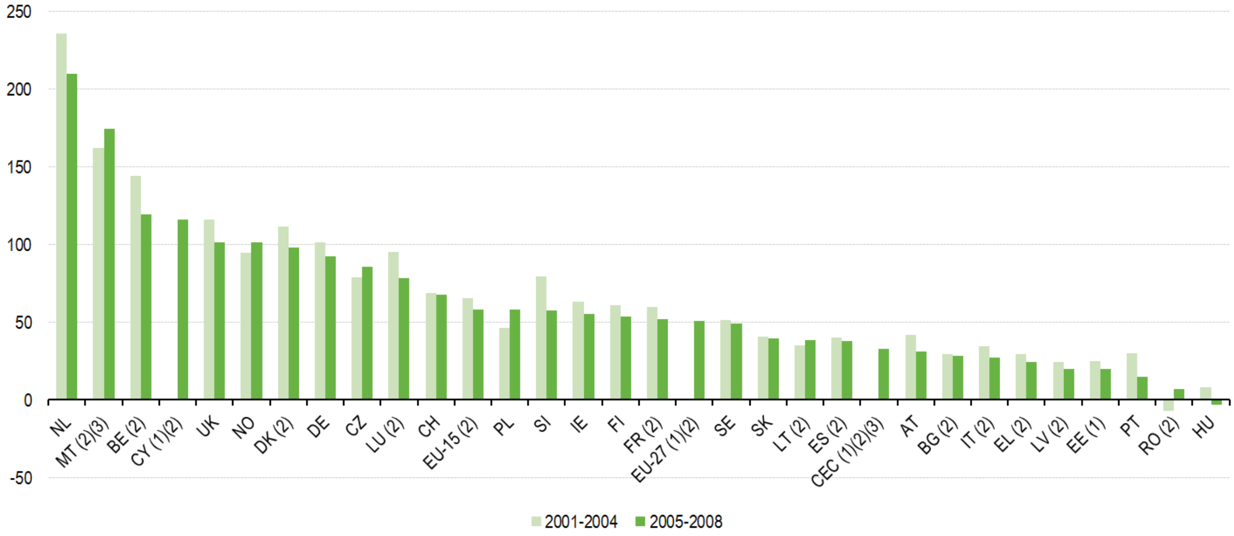
ANNEX 1: NITROGEN BALANCE

The indicator provides an indication of the potential surplus of nitrogen (N) on agricultural land (kg N/ha/year). It also provides trends on nitrogen inputs and outputs on agricultural land over time. It is measured by the following indicator: potential surplus of nitrogen on agricultural land (kg N/ha/year)

Data for the EU-27 could only be compiled for 2005-2008 (Eurostat). The gross nitrogen surplus for the EU-27 remained relatively stable between 2005 and 2008 with an estimated average of 51 kgN/ha. Data for the EU-15 was compiled for 2001-2008, showing that the nitrogen balance for the EU-15 was reduced between 2001 and 2008 from an estimated average of 66 kgN/ha in the period 2001-2004 to 58 kgN in the period 2005-2008. The gross nitrogen surplus of the central and east European countries is much lower than that of the EU-15, with an estimated average of 33 kgN per ha in 2005-2008. The average gross nitrogen surplus per ha was highest on average between 2005 and 2008 in countries in the north-west of Europe (Belgium, the Netherlands, Norway, the United Kingdom, Germany, Denmark) and the Mediterranean islands Malta and Cyprus, while many of the Mediterranean (Portugal, Italy, Spain, Greece) and central and east European countries belong to the group of countries with the lowest N surpluses (Figure 5).

Figure 5: **Nitrogen surplus (kgN/ha), average 2001-2004 vs 2005-2008, EU-27 (Eurostat)**



(1) Data not available for 2001-2004
(2) Eurostat estimations
(3) PL, RO, BG, CZ, HU, LV, LT, EE, SI, SK
(4) Average 2002-2004

Source: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agri-environmental_indicator_-_gross_nitrogen_balance

ANNEX 2: CASE STUDIES FROM THE LIFE+ AGRICLIMATECHANGE PROJECT

Nine case studies are included in this annex, to illustrate the impact of some of the measures proposed. The case studies were published in the AgriClimateChange Manual (2013) called "Climate-friendly agriculture. Evaluations and improvements for energy and greenhouse gas emissions at farm level in the European Union", which can be downloaded at the following link:
http://www.agriclimatechange.eu/index.php?option=com_docman&task=cat_view&gid=52&Itemid=79&lang=fr

It should also be noted that these measures have been implemented in the framework of the AgriClimateChange project, and have therefore been agreed upon and accepted by farmers. This section sets out a practical approach to the previous information in this report.

Case study 1: Crop system: long crop rotation, direct seeding and cover crops (Lauragais, France)

This cereal farm is located in the south-west of France (25 km south of Toulouse), in the agricultural region of Lauragais. Under the influence of the CAP, the local farms have progressively specialised in the production of durum and winter wheat as well as sunflower.

Description of the farm

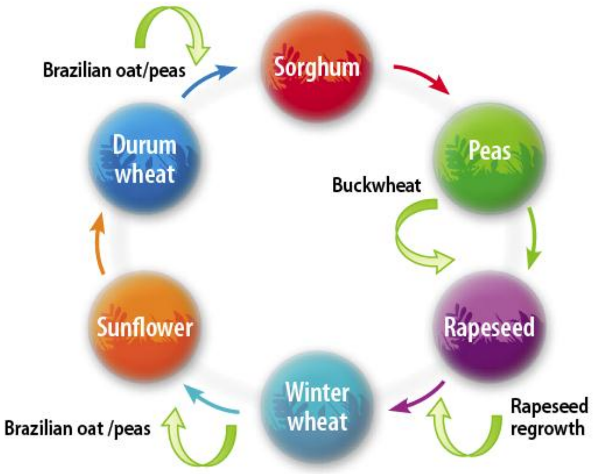
- 177 ha of rainfed cereals and protein-oil crops.
- 2 annual work units (2 brothers).
- clay-limestone soils and non-calcareous clay and sandy soils, 50 % of undrained waterlogged soils.
- 10 to 25 % cultivated slopes, strong erosion sensitivity.
- average annual rainfall of 638 mm, 200 days per year of wind (vent d'autan).
- peri-urban area: some plots near houses.

The two brothers soon realised the growing vulnerability of the initial cropping system, due to the low number of crops in the crop sequence: difficulty in ensuring a good crop establishment (climatic uncertainties and sensitivity to soil erosion) and economic risks due to price volatility. The agricultural system has been completely changed and the number of crops increased.

The main steps of change

The current cropping pattern of the farm

The resizing of farm plots into 6 areas of identical size has enabled the establishment of a balanced crop rotation composed of six main crops. Winter crops alternate with spring crops and cereals alternate with oilseeds and protein crops. Sown cover crops (oat, peas, buckwheat) or the crop regrowth (rapeseed) also enable higher soil coverage than before.

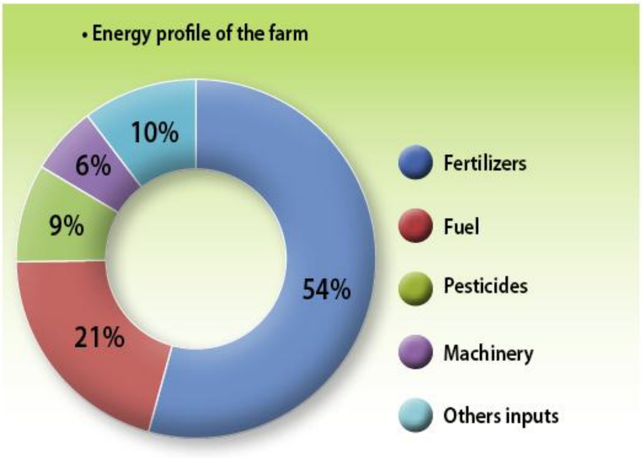


The current established crop rotation sequence has been progressively modified to obtain a succession of crops consistent with the local soil and climate conditions, while meeting the farmer’s agronomic and environmental objectives:

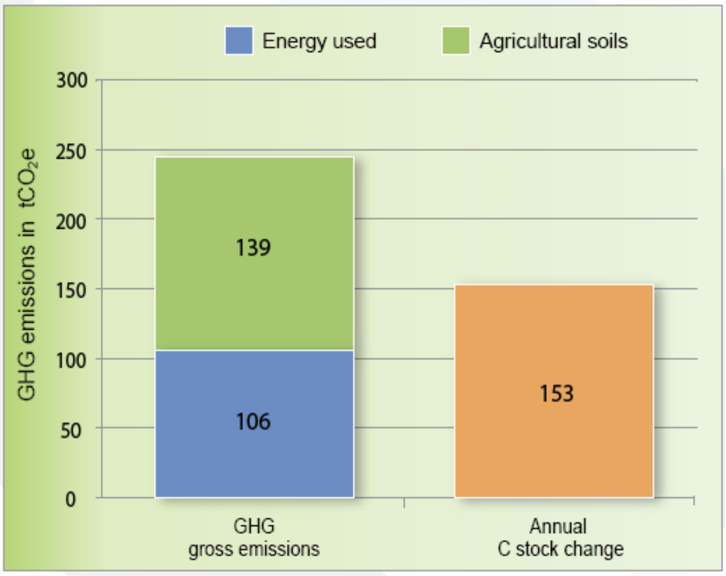
- Sorghum: rotation head of the cropping system, drought-resistant plant, strong root potential restructuring the soil.
- Peas: synthetic fixation of atmospheric nitrogen that enhances soil fertility, low root development and sensitivity to water excess compensated by the sorghum’s soil tillage.
- Buckwheat cover: rapid growth, resistant to drought, quick degradation of residues, offers melliferous potential for pollinators.
- Rapeseed: good efficiency of the residual nitrogen left by the peas, after harvesting rapeseed the regrowth can provide plant cover and food for potentially harmful slugs for the next crop.
- Winter wheat: sown directly in the rapeseed regrowth, wheat residues are left on the soil.
- Cover composed of peas and Brazilian oat: soil protection (long intercrop period of 9 months), atmospheric nitrogen fixation by peas, early destruction of the cover crop to meet the needs of soil temperature for sunflower.
- Durum wheat: sown in the sunflower residues, wheat residues left on the soil and sowing of a cover composed of peas and Brazilian oat before the sorghum.

Energy and GHG emissions assessment of the farm

The farm holding is characterised by a very low level of energy consumption per ha of UAA, with only 9.7 GJ/ha, given that the average consumption is 14.5 GJ/ha for a group of 155 French rainfed crop farms (-33 %). Also, the indicator of energy per tonne of dry matter (t dm) that indicates the energy efficiency for crop farms is 3.16 GJ/t dm, which is slightly below the average of reference group 1 (3.21 GJ/t dm). The established agricultural system therefore means that the energy consumption per ha is very low and the products are energy-efficient.



The farm emits 245.15 tCO_2e annually, which corresponds to an annual gross GHG emission of 1.43 tCO_2e/ha of UAA. These results are 30 % lower than the GHG emissions of the reference group, with an average of 2.03 tCO_2e/ha UAA. 57 % of the gross GHG emissions come from soils (mineral nitrogen applied, nitrogen in crop residues) and the rest of the emissions (43 %) come from energy used (processing of mineral fertilisers, fuel for tractors, etc.). Most of the GHGE (66 %) are generated directly on the farm, while 34 % are generated upstream of it. A set of favourable agricultural practices (no-tillage, cover crops, development of hedges) would allow the farm to increase its carbon stock to a compensation level of 61 % of the total annual gross GHG emissions. Thus, the net GHGE would only be 0.56 tCO_2e/ha.



Total GHG emissions of the farm and annual carbon stock change (tCO$_2$e)

The benefits of the actions implemented

The actions implemented on the farm helped reduce the energy consumption by 42 % and GHGE by 42 %, while significantly increasing the annual carbon sequestered on the farm: compensation of 61 % of the GHGE.

Measure	Energy reduction	GHG reduction	Contribution to the current annual C stock changes
Direct-seeding	24%	11%	74%
Cover crops	3%	5%	20%
Leguminous (16% of UAA)	9%	15%	0%
Nitrogen Balance	6%	12%	0%
Planting hedges	0%	0%	1%
Agroforestry (10 ha)	0%	0%	2%
TOTAL FARM	42%	42%	97%

Direct seeding extended to the entire surface of the farm resulted in a 65 % reduction in the initial fuel consumption, compared to the period when ploughing was practiced. With currently 45 litres of fuel per ha of UAA, this input has been optimised as far as is technically feasible. At farm level, direct seeding is a decisive measure to reduce energy and GHGE, and increase carbon sequestration in soils. In 10 years, the organic matter content has doubled in parallel with an increase in the biological soil activity and improved soil aeration. Farmers have established annual small-scale field trials to test and select the cover crops (mixed species) that satisfy their objectives. The choice of the type of cover crops is multifactorial: seed production and autonomy, complementarity of species, ease of germination, power of soil structuration, incorporation of biomass into the soil, etc. The choice of cover crops is not fixed; the climatic conditions of the year in question will guide the farmers' decisions. Cover crops annually represent 52 ha at farm level and ensure the soil is protected against risks of erosion and nitrogen leakage during winter periods. The biomass produced by cover crops enhances soil fertility, with recycling of around 20 kgN/ha of nutrients for the following crop, and means that less mineral nitrogen fertiliser needs to be purchased. Cover crops have a significant impact on increasing the carbon stock at farm level. Previously, the cropping pattern did not include any legume crops. The introduction of peas has reduced the overall dependency of the farm on mineral fertilisers, as the crops previously planted received 150 kgN/ha of fertiliser. Protein crops also have the advantage of leaving behind nitrogen that can be used for the next crop (rapeseed on this farm), thus reducing the mineral nitrogen purchased by around 30 kgN/ha. The share of 16 % of protein crops in the total UAA has a significant impact on the reduction of GHG emissions at farm level, and on its total energy consumption. The fertilisation plan based on an annual nitrogen balance at farm level is necessary to quantify the total nitrogen surplus. This way, the farm has progressively reduced the nitrogen applied to the crops by seeking a balance with the needs of plants. For this reason, the expected yield of the crops should not be overestimated, otherwise a high surplus of nitrogen could be observed. Progressively, the farm's nitrogen surplus decreased from 50 to 10 kgN/ha. Controlling the nitrogen surplus can significantly reduce the indirect GHGE from soils. In 10 years, more than 2 000 linear metres of hedges have been planted to reduce the size of the plots while fighting against soil erosion. Such ecological infrastructure is favourable to the development of auxiliary fauna; the pruning waste is used for the production of fragmented wood branches to improve soil fertility. At the beginning of 2013, a 10 ha plot was also converted to agroforestry, with 400 trees planted.

Other benefits noted

- The farm's soils are restored, with disappearance of erosion phenomena, better water infiltration in the case of heavy rain, increase of the productive potential of these plots.
- Better weed control, limited slug pressure on the main crop.
- Biodiversity enhanced through the planting of hedges.
- Reduction of working time and economic expenditure (reduction of inputs: fuel for tractors, mineral fertilisers, etc.).
- Free time used to educate, communicate and convey a different image of agriculture by welcoming many people to the farm.

Case study 2: Better practices for rice cultivation (Albufera Natural Park, Spain)

Rice emissions worldwide are known to be linked to water management and flooding practices (CH_4 emissions) and also to nitrogen fertilisation (N_2O emissions). This is due to a complex relationship between the methanogenesis process under anoxic conditions, the nitrification and denitrification of bacteria, the nitrogen added to the system and the agronomic practices. In order to successfully implement mitigation measures for rice, these major problems, at the least, have to be faced.

Nevertheless, the successful implementation of these measures relies on farmers' acceptance, and in most cases this is linked to money and time savings and to expected similar yields. For example, reducing nitrogen fertilisers is a very useful option to reduce GHGE when the nitrogen surplus on the farms is excessive, but in the Albufera area the cost reduction for farmers was not significant (EUR 20–30 /ha) and thus it was not implemented, even though it was demonstrated in several meetings that some of the farmers that had over-fertilised had smaller yields. In the Albufera case study, 4 farms out of 8 were affected by a surplus of nitrogen of between 30 and 78 kgN/ha, which represents between 17 and 37 % of the total amount of nitrogen inputs. As is frequently observed in crop systems, over-fertilization with nitrogen is traditionally linked to the idea of securing the crop yield, and this can be a significant constraint to address.

Measure	Energy reduction	GHG reduction
Nitrogen fertilizer reduction	8%	6%
Shared machinery and works	4%	1%
Lower sowing density	2%	0%
Implementation of ecological infrastructures	2%	0%
Better water and straw management	0%	23%
TOTAL FARM	**15%**	**31%**

Measures directly linked to energy saving but with a lower impact on GHG emissions, such as shared machinery and lower density sowing, are more widely accepted by farmers. In the case study area, a direct saving of 10 litres/ha of fuel (with added benefits such as machinery maintenance cost reduction and time saved on the farm) and a EUR 34-50/ha saving on seed purchase (with added benefits such as an expected reduction in fungicide treatments) was confirmed. The implementation of ecological infrastructure was also welcomed by some farmers in the Albufera area, as previous local studies (carried out by Fundació Assut in cooperation with the Universitat Politécnica de Valencia) have demonstrated that field edges planted with autochthonous vegetation (in this case, Spartina versicolor) are an important refuge for rice pest enemies, and thus can be helpful in reducing energy and GHG emissions related to pesticides. But again, the main interest for farmers was that these natural vegetated edges are less time-consuming and less expensive, compared to artificial edges that have to be restored and sprayed with herbicide on the ground every year and which represent significant fuel consumption and time-consuming work.

Water and straw management is, as demonstrated worldwide, the most effective measure for GHG reduction. Methane emissions depend on the cultivation period in days, the water regime before and during cultivation, and straw and organic matter management. Changes in the water management practices, whenever possible, are generally accepted by farmers as they do not involve investments, additional costs or significant changes in the crop management. Nevertheless, in the Albufera case study area these practices were found to be very complex to implement. The main constraint is that the historical irrigation system partially reduces the possibility of controlling water regimes and cultivation periods, as more than 20 000 ha are managed together as regards water, so the reduction of GHGE is limited to straw management. The traditional practice among farmers was to burn the rice straw, now deterred by the CAP and local regulations. Several attempts to use harvested straw have been put in place, such as bedding for animals. But the value of rice straw is not very high locally, the harvesting cost is increasing and the harvest can only be considered as one of the possible options. Straw chopping is another option but it also increases the harvesting cost and investment.

Finally, suitable management of water after harvesting was found to be one of the most effective measures: to wash the straw and/or to not flood for at least several weeks to avoid fresh organic matter flooding. But sometimes this management has an additional pumping cost, is not possible due to the rainy conditions, or other priorities are envisaged by farmers such as immediate flooding for hunting. So in the end, the implementation of these practices relies essentially on the individual farmer’s commitment.

Case study 3: GPS technology for precision agriculture (Perugia, Italy)

Description of the farm

- 110 ha UAA, mainly arable crops: durum and winter wheat, maize, barley, sunflower.
- Contractor for seeding on other farms.
- Annual production: 407 tonnes of wheat, 38 tonnes of maize, 17.5 tonnes of sunflower.

This farm is situated in the countryside on the outskirts of the municipality of Perugia, at an altitude of 250 metres, and the microclimate is influenced by the nearby Lake Trasimeno.

The high fuel costs, due to the 110 ha of own fields and more than 400 ha worked for other farms, pushed the family to renew their existing fleets with more efficient agricultural machinery.

They bought a brand new tractor with a GPS driving system: a GPS receiver installed on the tractor connected to a display screen for assisted driving, and coupled to the sowing and fertilising system.

Using this technology has permitted the farmers to obtain significant repayment immediately, with a relatively low investment. The cost of equipping a tractor (almost every tractor because it is a very adaptable system) with a GPS system is about EUR 8 000: considering that during the 2011/2012 season they saved around 5 % of fuel, around 10 % of mineral fertilisers, around 5 % of seeds and around 5 % of working hours, the immediate cost savings were more than EUR 2 500 for the fields owned.

With GPS technology, farmers can accurately guide their vehicles and have the benefit of less operator work, less fuel and also significant savings for all the different operations performed in the field: planting, fertilising, spraying of pesticides, cropping, harvesting and so on.

A significant added value factor is that farmers can record and collect geo-referenced data that can be used for field analyses: they can analyse crop performance and investigate variations within their field that contributed to a higher or lower crop yield such as differences in soil types, seed variety, nutrient availability, water run-off or pooling, and other important factors.

They can then adjust their farming practices for the next year to maximise productivity and profitability while reducing the environmental impacts of the farm.

Case study 4: Dairy farm with biogas plant (Constance, Germany)

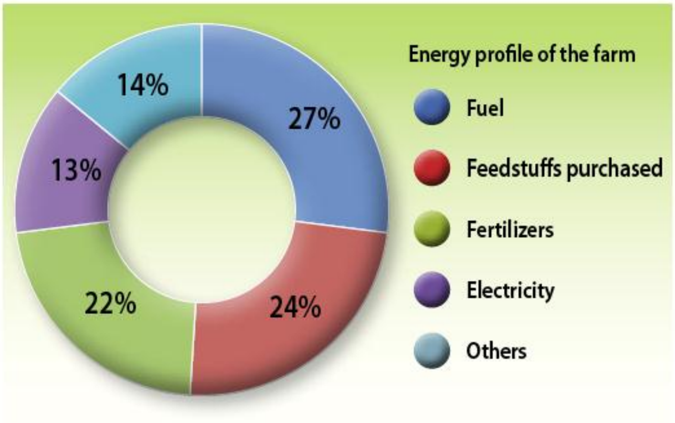
The Renewable Energy Law in Germany has encouraged the production of electric power in biogas plants over the past few years. A special financial bonus for the use of manure makes biogas plants attractive for dairy farms. Most of the existing biogas plants are using manure, as well as energetic crops specially grown for the biogas plants. The first biogas plant in the District of Constance started power production in 1997. Nowadays, about 30 biogas plants are connected to the public energy grid in the district.

Description of the farm

- Average annual rainfall: 650 mm (Elevation: 650 m).
- 86.1 ha of UAA
  - 44 ha of permanent grassland
  - 8 ha of perennial ryegrass
  - 30 ha of maize silage (including 9 ha after rye)
  - 9 ha of rye and 8 ha of sold wheat.
- Dairy milk
  - 51 dairy cows with offspring
  - Annual milk production of 370 tonnes
  - Around 7 250 litres of milk/cow/year.
- Biogas plant since 2003 with 150 kW electric output, fed with manure as well as energetic crops (maize silage, grass silage, rye silage).
- Conventional farming.

Energy and GHGE of the farm

The energy consumption of the farm consists of fuel (27 %), feedstuffs purchased (24 %), fertilisers (22 %), electricity (13 %) and other inputs corresponding to farm buildings, machinery and farm plastics (14 %). Thus, the 4 main sources represent 86 % of the overall energy consumption.



Use of each energy source

Fuel is consumed as follows: 40 % for the dairy milk and another 40 % for the crops for the biogas plant, while the remaining 20 % is shared between cereals and employee transportation. About 55 % of the energy from purchased feedstuffs is used for the biogas plant (energetic crops) and 45 % for dairy production. Fertilisers are linked mainly to dairy milk (65 %), another 25 % to biogas and 10 % to cereals. Also, 80 % of the electricity consumed from the grid is needed for dairy production. The remaining 20 % is mainly used in a small seasonal restaurant (open only for 4 months in summer) that mainly serves products from the farm.

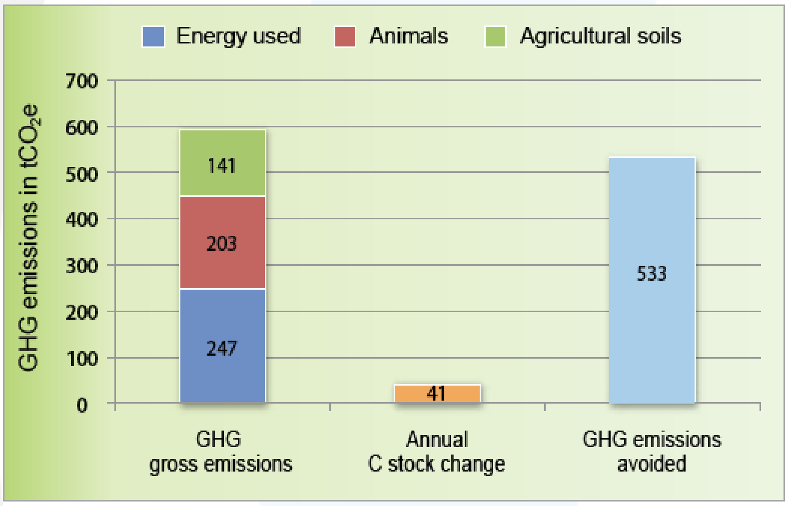
Energy consumption for each type of production

The energy input in 2011 was 3 338 GJ, which equals 38.8 GJ per hectare. The energy consumption for the different branches on the farm can be described as follows:

- Milk production uses approximately 50 % of the overall energy consumption, mainly through fuel, electricity, fertiliser and purchased feedstuffs.
- The biogas plant uses around 37 % of the overall energy consumption, mainly through fuel, purchased energetic crops and fertiliser. Taking into account the energy produced by the biogas plant (electricity and heat), the installation is quite effective, with 2.8 times more energy produced than consumed.
- The remaining 13 % of the overall energy consumption is related to cereals, the seasonal restaurant and employees' transportation.

GHGE

The farm emits about 591 tCO_2e annually, which equals 6.86 tCO_2e per hectare of UAA. About half of the emissions (42 %) originate from the used direct energy, 34 % are linked to animal production, and 24 % are emissions from the agricultural soils. Due to intermediary crops, conservation of permanent grassland and hedges that function as carbon storage, a total of 41 tCO_2e can be stored annually. That represents 7 % of the farm's annual emissions. The biogas plant produces about 900 MWh of electricity per year. This electric power replaces the German electricity mix (coal, nuclear power, gas and renewable energy), which leads to significant CO_2 emissions of about 485 tCO_2e being avoided. By using part of the wasted heat that results from electric power production, another 45 tCO_2e can be saved. This heat is used to heat the farmer's house, the restaurant, and for hot water production for the milking parlour. Thus, the GHGE avoided by substituting renewable energies for fossil fuels are comparable to the gross GHGE of the farm.



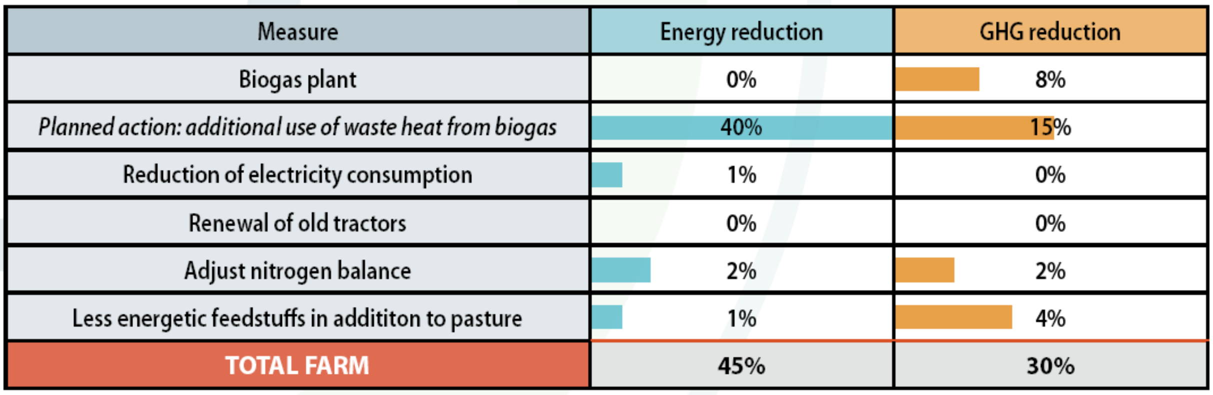
- **Annual GHG gross emissions, carbon stock change and GHG emissions avoided by the production of renewable energies (in replacement of fossil energies) on the farm in tCO_2e**

The main steps of change

Over the past three years, several types of measures have been implemented on the farm, dealing with investments or best agricultural practices. Most of these measures are related to the issues of the farm (electricity, fuel, feedstuffs purchased and mineral fertilisers) and have so far proved to be quite efficient. A significant measure was the construction in 2012 of an additional fermenter for the biogas plant. This central and complex measure has led to significant changes on the farm. The fermentation time can be prolonged and thus the efficiency of the methane production can be increased. More methane leads to more electric power with the same amount of substrate. The higher capacity also enables the farmer to be more flexible in applying the digestate as manure and to be more efficient while reducing emissions due to fertilisation. Further mitigation measures applied consist of the reduction of concentrated feedstuffs and the adjustment of the nitrogen balance of the farm.

Benefits of applied and planned measures

The described measures decrease energy consumption, or respectively allow a credit for the use of renewable energy of about 45 % and decrease GHGE by about 30 %.



Measure	Energy reduction	GHG reduction
Biogas plant	0%	8%
Planned action: additional use of waste heat from biogas	40%	15%
Reduction of electricity consumption	1%	0%
Renewal of old tractors	0%	0%
Adjust nitrogen balance	2%	2%
Less energetic feedstuffs in addititon to pasture	1%	4%
TOTAL FARM	**45%**	**30%**

The farm's biogas plant has existed since 2003. The plant is fed with liquid manure from dairy cattle and energetic crops (own production and purchased). The installation is useful for decreasing GHGE from manure management, mainly methane (-54 tCO_2e). At the end of 2010, two small block heat and power plants (63 kW and 35 kW) were replaced by a bigger one (150 kW). This resulted in a 10 % increase in the use of power (mainly because of the purchased fodder), but at the same time increased energy output (power) by about 30 %.

In 2012, the existing biogas plant was extended with an additional fermenter that allows the increase of methane as well as the produced power. Optimised use of the waste heat during the process can replace heating fuels, evaluated on this farm at about 40 000 litres. External uses must be found, as all the farm’s heating needs are already covered by the waste heat: heating the workers' apartments and also energy for the industrial production of ice. This measure leads to a theoretic energy yield of 1 407 GJ and a reduction of greenhouse gases by about 107 tCO_2e. The farmer would like to implement this measure, but a complex plan is necessary.

On the farm, several measures to reduce energy consumption were implemented successively: for instance, new efficient heat pumps were installed in the heating system to save on electric energy, the dunging of the livestock building was adjusted to a lower interval in consideration of animal health and the temperature management in the milk storage room has been optimised through a simple roof hatch to release the warm air, which reduces the operation time of the milk tank. These measures reduced the annual electricity consumption by 10 % (4 000 kWh); 41.6 GJ and 2.1 tCO_2e respectively.

The replacement of two old machines (a 21-year-old tractor and a 40-year-old wheel loader) by two new machines reduces fuel consumption (reduction of 12 GJ and 3 tCO_2e). The use of legumes as green manure replaces a part (8 %) of the mineral fertiliser purchased. Thus, the reduction of 1 tonne of mineral nitrogen fertiliser is accompanied by an energy reduction of 55 GJ and a GHG reduction of 17 tCO_2e.

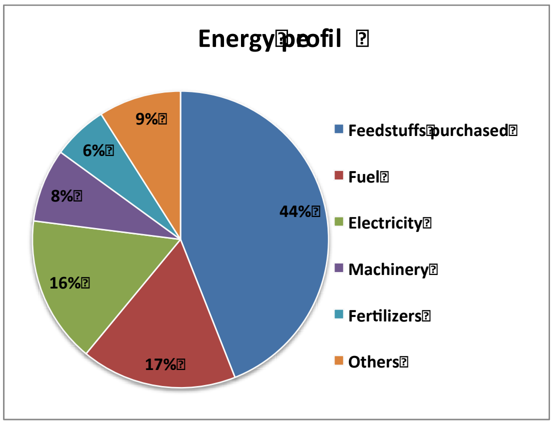
A potential reduction in the dairy sector is to decrease the energy input for fodder production. About 72 tonnes of concentrated feedstuff with a crude protein content of 40 % could theoretically be replaced by the same amount of concentrated feedstuff with 20 % crude protein and additional pasture. This allows an energy reduction of 41 GJ, i.e. 12 %, and a reduction in GHGE of 28 tCO_2e, i.e. 28 %.

Case study 5: Solar dryer for fodder (Tarn, France)

Description of the farm

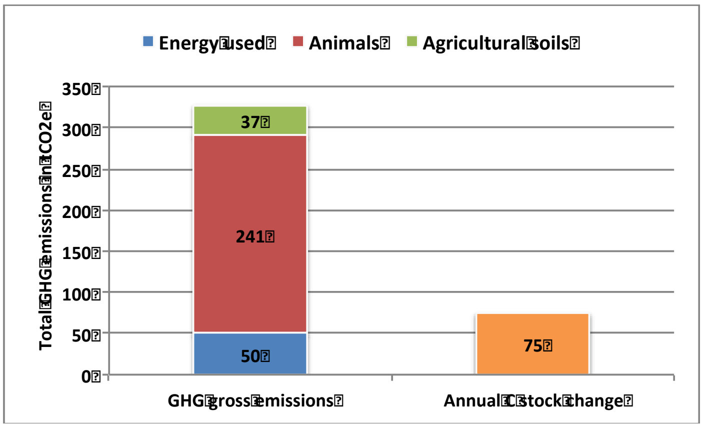
- 42 ha UAA, only fodder surfaces.
- 300 ewes (Lacaune breed) and 80 ewe lambs.
- Annual production of 67 200 litres of milk and 276 lambs.
- Clay-limestone soils, good agronomic potential
- Input reduction strategy for crop management
- Only fodder surfaces (lucerne as a base and mixed temporary grasslands)

The farm's total energy consumption is 673 GJ/year, which corresponds to 16 GJ/ha and 10 GJ/1 000 litres of milk. The energy profile is mainly represented by feedstuffs purchased for animals (50 tonnes of concentrated feedstuffs, 35 tonnes of hay and 30 tonnes of straw litter)(44 %), agricultural fuel (2 500 litres) and electricity (16 %) (mainly the milking parlour).



In comparison with similar farms producing sheep's milk, the pilot farm consumes more energy per ha (+69 %) and less per unit produced (-26 %). This result is explained by a higher milk production per ha compared to the reference group, the milk production per sheep being similar.

The estimated total GHGE of the farm reach 328 tCO_2e, of which 50 tCO_2e are related to the energy consumed directly and indirectly, 241 tCO_2e are related to the animals (enteric fermentation and manure management) and 37 tCO_2e are related to the agricultural soils (fugitive emissions of N2O). The annual carbon stock change from grassland is estimated at a total sink of 75 tCO_2e/year, which compensates for around 23 % of the total gross GHG emissions of the farm.



GHGE from animals are mainly due to enteric fermentation (73 %) in the sheep in relation to their metabolism, and are difficult to reduce. However, changes in food intake can help reduce these emissions (a more digestible diet). The net GHGE are estimated at 6.0 tCO_2e/ha and 3.75 tCO_2e/1 000 litres of milk.

Actions implemented: solar dryer for fodder

Faced with regular drought problems limiting the farm's autonomy in terms of fodder and milk production, the farmers decided to build a solar dryer for fodder in order to improve its quality (nitrogen content), while reducing the dependence of the farm on external concentrates. The solar dryer system is based on the recovery of hot air under the roof (presence of an insulating material) that enables recovery of the calories accumulated during sunny periods. The particularity of this roof is that, in addition to having a solar sensor function, it is used for electricity production thanks to 1 300 m^2 of photovoltaic panels.
The hot air recovered under the roof is then pulsed by a fan through two cells (total capacity of 150 tonnes) where the loose hay is stored. A hydraulic forage claw on rails places the forage in the hay barn at harvest time, and then it is distributed to the animals during the winter. This solar dryer system ensures the quality of the harvested fodder, particularly by reducing the drying rate by half compared to the use of ambient air.

Once the fodder from the solar dryer has been consumed, the amount of purchased feedstuffs required, which represented 44 % of the total energy consumption of the farm, is reduced by half,. External purchases of fodder have also been stopped and fuel consumption for tractors has decreased by around 30 %. In addition to these benefits, the fodder is more appetizing, which resulted in a 15 % increase in the farm's milk production.

However, consumption of electricity from the grid has increased (from 10 000 kWh/year to 25 000 kWh/year) due to the operation of both the fan and the claw, but this is largely compensated by the annual production of 200 000 kWh of renewable electricity by the photovoltaic panels. Finally, the farm makes an energy saving of about 46 % and has reduced its GHGE by 6 %.

Case study 6: Solar panels for heating water in a cheese factory (Aveyron, France)

Description of the farm:

- organic certification.
- 55 ha of UAA, only permanent grassland.
- 27 cows (Simmental breed).
- Annual production of 120 000 litres of milk.
- Energy profile of the farm: electricity (47 %), feedstuffs purchased (20 %), fuel (18 %).
- Main sources of GHGE: enteric fermentation and manure storage (71 %), direct soil emissions (9 %), feedstuffs purchased (8 %).

This dairy farm is situated on the plateau of Aubrac (France) at an altitude of 1 000 metres, and belongs to the production area of the Laguiole cheese 'AOC' (protected designation of origin), which comprises 80 producers. When the son took up farming on the family farm, a project to construct a cheese factory equipped with a maturing room was drawn up, in order to progressively transform the entire milk production process. The energy assessment performed prior to the cheese factory project had already shown the heavy burden of grid electricity consumption, which accounts for 47 % of the farm's total energy consumption. The main consumption source is the operation of the milking system (production of hot water, milk tank and vacuum pump).

Cheese processing will double the hot water requirements of the farm, which will increase from 200 to 400 litres per day. To cope with this new expenditure, the farmers have decided to invest in solar thermal panels to ensure savings of 50 to 60 % on their electricity bill. Milk processing will take place throughout the year, with a peak in milk production in late spring, also corresponding to a significant solar coverage rate. The investment payback period will be about 10 years for this farm, taking into account that it has received a grant covering 50 % of the total cost.

Case study 7: Cover crops and nitrogen balance in permanent crops (Valencia, Spain)

20 orange farms located in the east of Spain (Valencia and Castellón), in an agricultural landscape mainly dominated by orange farms, were assessed. Under the influence of regional plans, the gravity irrigation systems on some of the traditional farms have been converted into drip irrigation systems, usually depending on a central pumping station that can irrigate very large surfaces. Orange crops need high inputs of nitrogen fertilisers, and over the past few years the benefits for farmers have been greatly reduced due to rising prices and dependency on inputs.

Description of the farms

- 20 farms with different varieties of oranges and tangerines.
- Average size: 0.8 ha of UAA per farm.
- 12 farms with surface irrigation by gravity and 8 farms with drip irrigation.
- Average yield: 22.5 tonnes per ha.
- Average amount of mineral fertiliser used on conventional farms: 213 kgN/ha.

Oranges, tangerines and other Citrus species have been cultivated in subtropical areas of south-east Asia and other parts of the world since ancient times, but were traditionally used for ornamental and medicinal purposes. Modern citriculture, that is, the production of oranges and tangerines for food purposes, began in the Valencia region at the end of the 18th century. One century later, and especially during the first half of the 20th century, the whole agricultural landscape was transformed and an economic revolution took place. Nowadays, more than 180 000 ha are used for citriculture (35 % of the agricultural soils). The orange trade currently represents a EUR 622 000 000 business, which corresponds to 16 % of the total exports from the Valencia region.

The main changes and current situation

Traditional orange farms changed dramatically in the 1950s. Until then, the high nitrogen needs were met by using local manure, no herbicides were sprayed and cover crops contributed to the conservation of soils. Pesticides were unknown and the use of machinery was not widespread. Orange farms used the traditional irrigation infrastructure developed between the 13th and 19th centuries, using water from rivers that was distributed by gravity to large cropland areas. Consequently, the energy used on the farms and the agricultural inputs were reduced to a minimum. International exports and low-cost farming inputs contributed to a well-established and powerful farming society. Up until the 1950s farmers could make their living by farming a surface of 1.5 ha.

From the 1960s onwards, important changes were implemented to increase yields and, consequently, benefits for farmers that were directly related to production. The "Green Revolution" introduced mineral fertilisers, herbicides, pesticides, new and more productive varieties (but which were more dependent on inputs), and machinery that made farmers' work easier, but all these changes also led to a high dependence on external inputs. During the last decade of the 20th century, another important change was promoted by regional institutions and farmer communities in order to reduce water consumption, make farmers' work easier and increase the effectiveness of fertilisation: a significant number of farms replaced their traditional irrigation systems with drip irrigation systems, where water is pumped through electricity to a vast surface of the farm using pipes.

Fertilisation and irrigation periods are controlled by the irrigation community (landowners in the irrigated area) and farmers bear the cost of the pumping and fertilisation service, as well as the local equipment needed on the farm. This continuous modernisation process has certainly improved farmers' benefits and has made their way of life easier, but on the other hand has led to a difficult situation where high dependence on external inputs and the continuous decrease in fruit prices is nowadays threatening the survival of a lot of farms.

Energy and GHGE assessment of the farm

In order to have a good overview of the citriculture sector as regards energy and GHG aspects, 20 farms representing the current situation were selected, i.e. including surface and drip irrigation, whether in conventional agriculture (13 farms) or organic farming (7 farms). As regards the irrigation system, surface-irrigated farms (12 farms) have, on average, proven to be more efficient in the use of energy, both per surface (22.4 GJ/ha) and for production (0.95 GJ/tonne), than farms using drip irrigation systems (29.98 GJ/ha and 1.35 GJ/tonne), although significant variations are noted between farms.

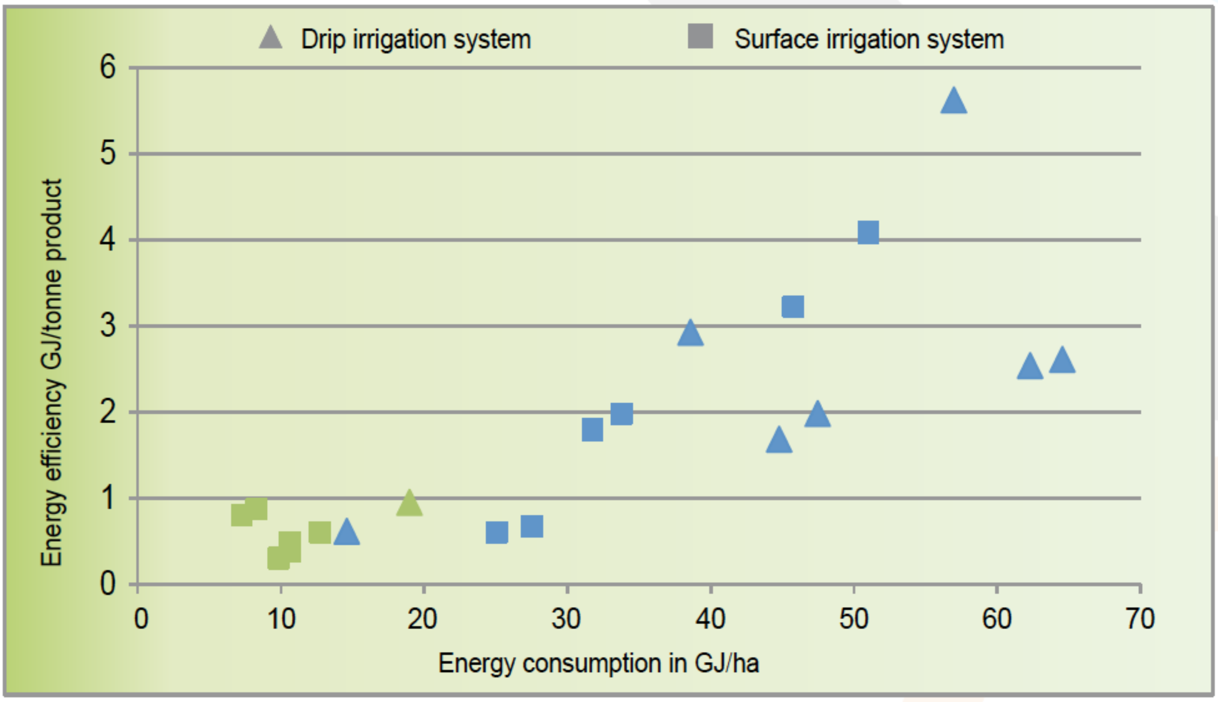


Figure 1: Energy consumption per ha and per tonne of product for drip and surface irrigation system. Blue colour corresponds to conventional farms and green colour to organic farms

In surface-irrigation farms (8 farms), fertilisers (52 %) and fuel consumption (32 %) represent the main source of energy consumption, with minor consumption sources being machinery (9 %) and others such as pesticides (5 %), plastic bags, etc. (2%). On drip-irrigated farms, 55 % of the energy consumed is related to the pumping irrigation system and fertilisers represent 14 %. Nevertheless, as fertilising is managed for the whole irrigation community through the drip system, this energy cost is not directly controlled by the farmers, who cannot change the fertilising dose themselves. This means that at least 70 % of the energy costs in this system do not depend on the farmers' individual decisions. The rest of the energy costs related to the farm are fuel consumption (19 %), plastics and irrigation equipment (7 %), machinery (4 %) and pesticides (1 %). As regards the comparison between organic and conventional farms, organic farms are clearly more efficient in the use of energy, both per surface and production. The results show that organic farms have a lower energy consumption, both per ha and per tonne. This is mainly explained by the replacement of mineral fertilisers with local manure. In some cases, organic farmers who have used cover crops for long periods have even reduced the amount of fertiliser they apply. Herbicides are not used and insecticide treatments are limited to mineral oil spraying in the summer. Fuel consumption (87 %), plastic bags (8 %) and fertilisers (5 %) are the largest sources of energy consumption on these farms. Electric power was used for irrigation on only one of the organic farms assessed, representing 59 % of the total energy consumption of this farm.

GHGE related to energy consumption are quite similar for both irrigating systems (1.85 tCO_2e/ha for surface and 2.03 tCO_2e/ha for drip), with greater differences in emissions related to agricultural soils (2.17 tCO_2e/ha for surface and 1.36 tCO_2e/ha for drip). But again, very significant differences exist between organic and conventional farms, with an average total of gross GHG emissions of 1.31 tCO_2e/ha for organic farms and 3.7 tCO_2e/ha for conventional farms. Similar observations concern carbon sequestration, with an additional carbon storage per ha twice as high on organic farms as on conventional farms, which is explained by the systematic use of cover crops.

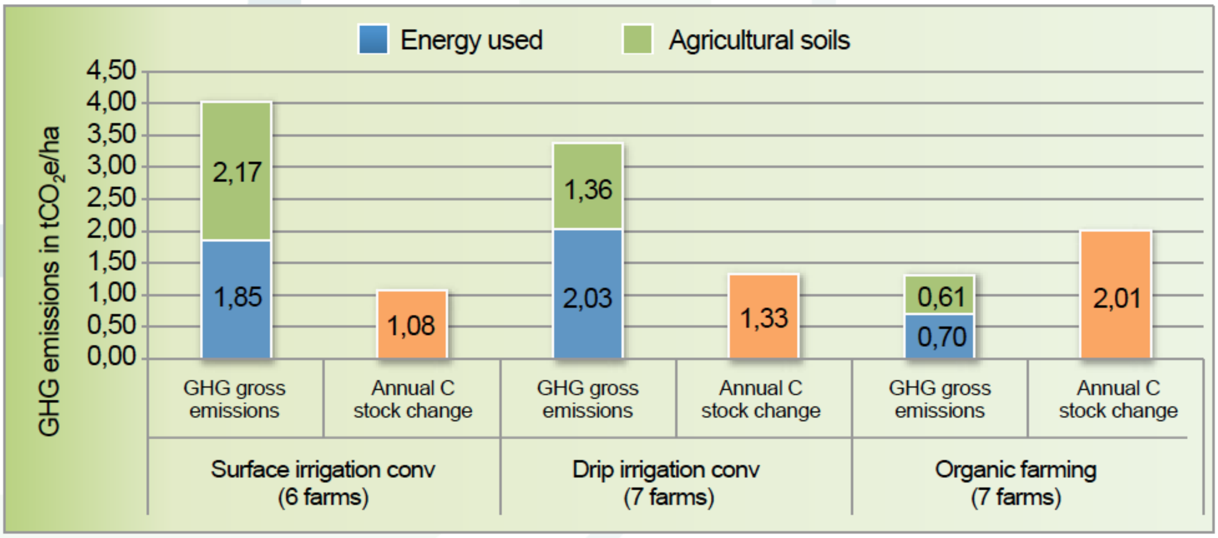
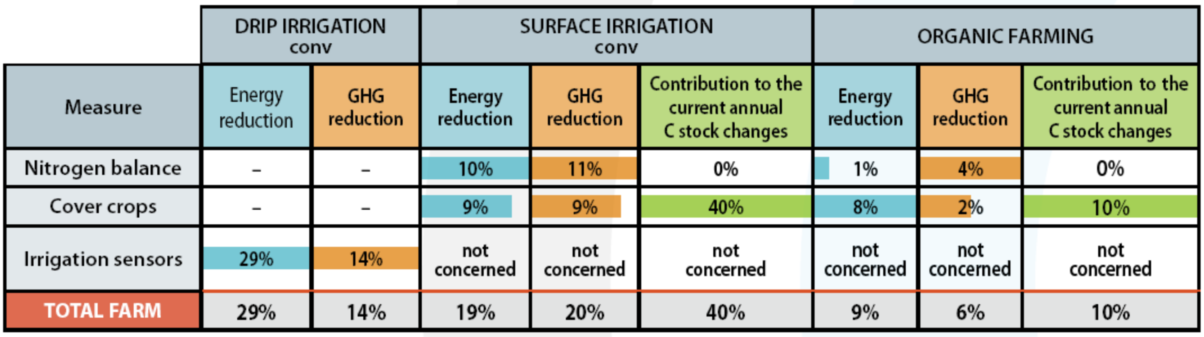


Figure 2: Annual GHG emissions and C stock change for conventional farms under surface irrigation, conventional farms under drip irrigation system and organic farms

The benefits of the actions implemented

Due to the existence of differences in management systems, mitigation measures were different for the different types of orange farms. For drip irrigation systems, for which energy for fertigation could not be controlled directly by farmers, the establishment of irrigation sensors was the only feasible and effective measure, with an average decrease of 29 % in overall energy consumption and a 14 % decrease in GHGE.



	DRIP IRRIGATION conv		SURFACE IRRIGATION conv			ORGANIC FARMING		
Measure	Energy reduction	GHG reduction	Energy reduction	GHG reduction	Contribution to the current annual C stock changes	Energy reduction	GHG reduction	Contribution to the current annual C stock changes
Nitrogen balance	–	–	10%	11%	0%	1%	4%	0%
Cover crops	–	–	9%	9%	40%	8%	2%	10%
Irrigation sensors	29%	14%	not concerned	not concerned	not concerned	not concerned	not concerned	not concerned
TOTAL FARM	29%	14%	19%	20%	40%	9%	6%	10%

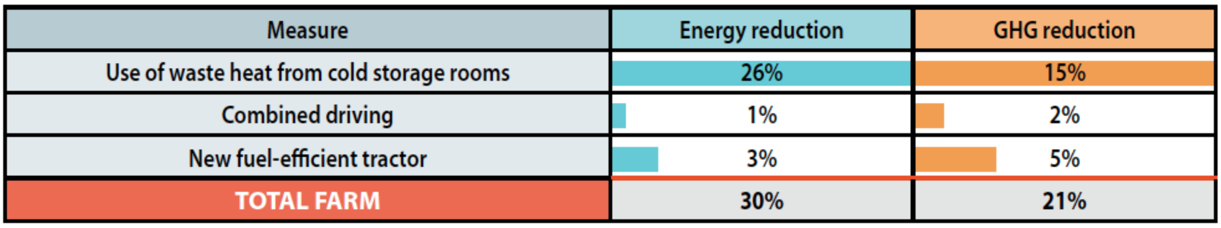
For surface-irrigation farms, action plans are focused on nitrogen fertiliser reduction, use of cover crops (thus reducing to a minimum the use of herbicides and fuel consumption), and implementation of ecological infrastructure. For conventional farms, the overall energy consumption has decreased by 19 % and the GHGE have decreased by 20 %, while additional carbon sequestration is observed. For organic farms the gains are lower, with average reductions of 9 % for energy and 6 % for GHGE, which is explained by their current lower levels of energy consumption and GHGE compared to conventional farms. Nitrogen balance was poorly implemented as most of the farmers want to secure their yield, even if it has been demonstrated that higher nitrogen inputs are not necessarily related to a higher yield and can sometimes cause additional problems with pests or weeds. Most of the farms could reduce nitrogen fertilisation by 5 to 15 %. However, the price of nitrogen fertilisers is still so low compared to the expected savings from fertilisers for such small plots (0.8 ha UAA) that farmers do not see the advantage in reducing their use of fertilisers. On the other hand, the introduction of cover crops has been successful, mainly because it has transversal benefits, such as reducing or eliminating herbicide treatments and tillage, which have a direct impact on direct energy saving, thus lowering costs. Spraying uncovered soils with herbicides is a relatively new agricultural practice. Most of the farmers still remember that they were able to manage their farms without using herbicides, which makes it easier to convince them to go back to this former management method.

The implementation of ecological infrastructure through the planting of young hedges has not led to a significant increase in carbon storage at farm level for the moment. Nevertheless, this measure will demonstrate its benefits as regards the carbon sink in the medium term. Finally, the irrigation sensor measure implemented on drip irrigation farms is very efficient in terms of energy and GHG reduction, and provides good value for money with a return on investment (due to electricity savings) in a few years. Irrigation sensors are connected to a central computer that controls water needs and conductivity. Another benefit, which as yet has not been tested, would be to improve nitrogen management by reducing nitrogen leaching.

Case study 8: Pomaceous and stone fruit cultivation (Constance, Germany)

Description of the farm

- 18.4 ha of UAA, full-time farm with pomaceous and stone fruit cultivation (15.2 ha apples, 2.9 ha redcurrants + blackcurrants, 0.3 ha plums).
- Annual fruit production: 555 tonnes.
- Own Controlled Atmosphere (CA) - cold storage rooms for apples.
- Energy profile of the farm: electricity 60 %, fuel 16 %, plastics and packaging 8 %, farm buildings 6 %.
- Main GHGE sources: electricity 34 %, fuel 23 %, farm buildings 10 %.



Measure	Energy reduction	GHG reduction
Use of waste heat from cold storage rooms	26%	15%
Combined driving	1%	2%
New fuel-efficient tractor	3%	5%
TOTAL FARM	**30%**	**21%**

Use of waste heat from cold storage rooms

60 % of the farm's overall energy consumption results from the need for electricity for the CA cold storage. It is therefore worth devising measures to use electricity more efficiently. Thanks to the special CA cooling technology, local apples can be stored fresh from harvest in autumn until late spring without any loss of quality. In addition to high air humidity, a high CO2 level and a low oxygen level in the cold storage room, a constantly low temperature of 2–3°C is necessary. The farm needs a lot of electricity for this cooling process, which covers several months, especially because the cold storage rooms are so large that the harvests of neighbouring farms can also be stored. The farm's electricity consumption over the last three years was about 70 000 kWh per year. The waste heat from the cooling system had to be evacuated from the storage building by ventilators.

To use the waste heat, the farmer has installed heat exchangers to absorb the heat from the outgoing air. Water preheated in this way is used for hot water generation, with a supplement provided by woodchip heating. Finally, the hot water is used to heat two houses which have been converted into flats. Some accommodation for seasonal workers is also planned. In this way, the large amount of heat generated in autumn, at the start of the apple storage period, can also be used (heating and hot water for showers). The complete construction was put on stream in March 2013. The capital cost was about EUR 65 000 (planning, heat exchangers, hot water buffer storage, woodchip heating, local heating pipes). The estimated annual energy benefit is 30 000 kWh, which means that 7.05 tCO_2e of GHGE could be avoided by not using electricity from the grid.

This measure will help the farm reduce its total energy consumption by 26 % and its total GHGE by 15 %.

Combined driving: Mulch machine and pesticide sprayer

Diesel is the second biggest source of energy consumption on the farm (16 %). Frequent use of the tractor in the fruit orchards leads to an annual consumption of about 200 litres of diesel per hectare. Combining two work processes (mulching and spraying) could reduce the number of rides by a range of 5 to 7 rides per year. Combined driving uses about 20 % more fuel per ride, but as the number of rides per ha is reduced, this results in reduced fuel consumption at farm level. The farmer tested this technique on 12 ha during June and September 2013 with his new tractor.

The expected reduction in fuel consumption is around 290 litres of diesel per year, which represents 7 % of the farm's current fuel consumption. The price of the technique is in the range of EUR 20 000.

Acquisition of a new fuel-efficient tractor

The previous tractor was about 30 years old. Approximately 800 litres of diesel per year could be saved by using a new fuel-efficient tractor, i.e. 20 % of the farmer´s total fuel consumption. The new tractor was purchased in 2012 and cost approximately EUR 60 000.

These two measures (combined driving and the replacement of a tractor) explain a 27 % decrease in the total fuel consumption, which corresponds to a 4 % decrease in the farm's total energy consumption and a 7 % decrease in its total GHGE.

Case study 9: Production of renewable energy in a wine cellar (Umbria, Italy)

Description of the farm

- 8 ha UAA of vineyards, different types of grape variety.
- Annual production: 50 tonnes of grapes, 300 hectolitres of wine.
- Energy profile of the farm: packaging/bottles 43 %, electricity 23 %, fuel 20 %.
- Main GHG emission sources of the farm: packaging/bottles 53 %, fuel 17 %, electricity from the grid 13 %.
- Annual electricity consumption (before installation of the photovoltaic panels): 12 500 kWh/year.

This small wine farm is located in the gentle hills on the south side of Trasimeno Lake, at an altitude of 260 metres. Thanks to the quality of the grapes, the farm is part of the “Trasimeno Hills Wine Road”, a non-profit association committed to the development of the local area. In 2005, the farmers decided to purchase new barrels for the winery in order to obtain high quality wine. To preserve the taste and the typical flavour of each grape, every barrel is dedicated to specific qualities of wine. Later, a cooling system for fermentation was also installed, leading to increased electricity costs. Thus, electricity represented 23 % of the farm's total energy consumption. For this reason, in addition to the opportunity to benefit from government incentives on the production of electricity from renewable sources in Italy, photovoltaic panels were installed on the roof of the winery in 2011.

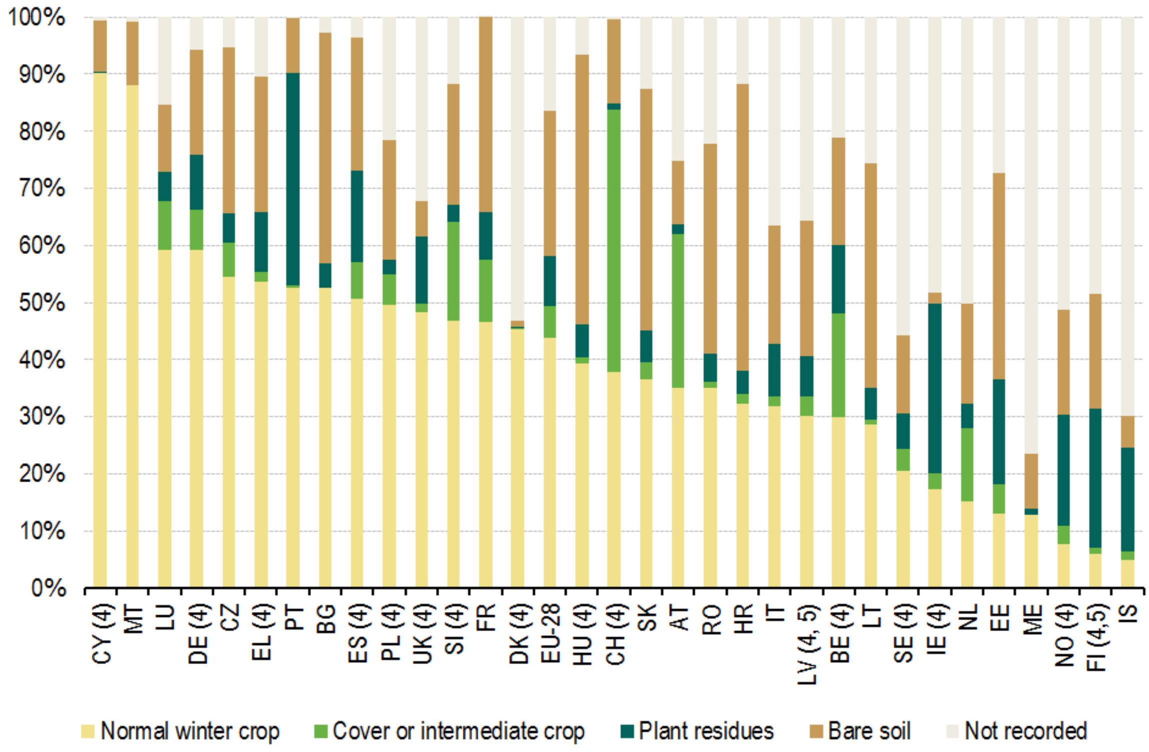
The power of the plant installed is about 46.20 kW for a total surface area of 350 m^2, and it is made of polycrystalline silicon solar panels. The electricity produced by the photovoltaic system, 52 000 kWh per year, manages to cover 70 % of the requirements of the winery, and the rest is channelled into the electricity grid and resold, generating a significant additional income. The return on investment for this farm is around 12 years (total investment of EUR 154 000). In this way, the holding has decreased its total energy consumption by 16 % and its total GHGE by 9 %.

ANNEX 3: SOIL COVER

During the winter of 2010 in the EU, 44 % of the arable area was covered with normal winter crops, 5 % with cover or intermediate crops, 9 % with plant residues and 25 % was left as bare soil. For 16 % of the arable area, soil cover was not recorded. Areas for which no soil cover was recorded include areas under glass and areas not sown or cultivated during the reference year (e.g. temporary grassland, hops; see the section on data sources and availability for further information).

Soil cover during winter varies from country to country. In Cyprus and Malta the climate is less harsh during the winter, and the majority of the arable area is covered by normal winter crops. In Iceland, Norway and Finland on the other hand, the winters are cold and hardly any of the arable area is covered by normal winter crops. Austria and Switzerland have the highest proportion of arable land covered with cover or intermediate crops, and Portugal and Ireland have the highest proportion left under plant residues. In Croatia, Bulgaria, Hungary, Slovakia, France, Romania, Lithuania and Estonia more than a third of the arable area was left as bare soil.

Figure 6: Soil cover on arable land



Notes are explained in the section 'data sources and availability'.

Source: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agri-environmental_indicator_-_soil_cover

NOTE 2

This document was requested by the European Parliament's Committee on Agriculture and Rural Development.

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POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES

AGRICULTURE AND RURAL DEVELOPMENT

MEASURES AT FARM LEVEL TO REDUCE GREENHOUSE GAS EMISSIONS FROM EU AGRICULTURE

NOTE 2

Abstract

Ten measures, broken down into 26 sub-measures, related to agricultural practices, are proposed to reduce GHG emissions in France. They are related to nitrogen fertilisation, carbon storage in soils and biomass, animal diets, biogas production and energy savings. At EU level, the "green payment" of the new CAP can support the implementation of three sub-measures (leguminous plants, buffer strips, hedges). The "greening equivalency" principle may promote agroforestry, reduced tillage, cover crops and cover cropping. In the case of France, the abatement calculated for these 7 sub-measures represents 23 % of the total abatement calculated for all measures.

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CONTENTS

LIST OF ABBREVIATIONS

ADEME	French Environment and Energy Management Agency
CAP	Common Agricultural Policy
CH_4	Methane
CITEPA	French Interprofessional Technical Centre for Studies on Air Pollution
CO_2	Carbon dioxide
CO_2e	Equivalent carbon dioxide
EFA	Ecological Focus Area
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
INRA	French National Institute for Agricultural Research
LULUCF	Land Use, Land-Use Change and Forestry
MAAF	French Ministry of Agriculture, Food and Forestry
MEDDE	French Ministry of Ecology, Sustainable Development and Energy
Mt	Million (10^6) tons
N_2O	Nitrous oxide

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Background

Greenhouse gas (GHG) emissions from the agricultural sector represent 9.8 % of the total EU emissions (excluding LULUCF). A specific feature of these emissions is that they are mostly non energy-related and controlled by biological processes. Nitrous oxide (N_2O) is produced by agricultural soils during biochemical nitrification and denitrification reactions. N_2O emissions are therefore strongly related to the use of nitrogen fertilisers. Methane (CH_4) is produced by ruminants, as a result of enteric fermentation, and by animal manure stored in anaerobic conditions.

Agriculture can help improve the net GHG emissions balance via three levers: a reduction in N_2O and CH_4 emissions, carbon storage in soils and biomass, and renewable energy production.

In France, agriculture accounts for 17.8 % of emissions. Like other European countries, France has launched an ambitious policy aimed at reducing its emissions. The French National Institute for Agricultural Research was commissioned to conduct a study on the abatement of greenhouse gas (GHG) emissions in the agricultural sector in mainland France.

Aim

The objective of this briefing note is to present ten measures that were proposed to reduce GHG emissions from the agricultural sector, and to analyse to what extent the new Common Agricultural Policy (CAP) is likely to support their implementation. The briefing note is based on a French study whose aim was to select abatement measures concerning agricultural practices and to estimate their abatement potential and associated costs.

Results

The 10 proposed measures, broken down into 26 sub-measures, are related to **nitrogen fertilisation management** (reducing the use of synthetic mineral fertilisers, increasing the proportion of leguminous crops on arable land and temporary grassland), **carbon storage in soils and biomass** (developing no-till cropping systems, introducing more cover crops, vineyard/orchard cover cropping and grass buffer strips in cropping systems, developing agroforestry and hedges, optimising grassland management), **animal diets** (replacing carbohydrates with unsaturated fats and using additives to reduce enteric CH_4 emissions, reducing the amount of proteins in the diet of livestock to limit the quantity of nitrogen excreted in manure) and **energy production and consumption on farms** (methanisation and flares, energy savings). Although the study was carried out in the French context, most of the identified measures are adapted to the EU agricultural context.

The calculated overall abatement potential can be broken down into three approximately equal parts:

The first part corresponds to sub-measures with a **negative cost**, i.e. leading to a financial gain for the farmer. These are mainly sub-measures involving **technical adjustments with input savings,** with no loss of production. This category includes sub-measures relative to grassland management, sub-measures designed to generate fossil fuel savings, adjustment of nitrogen fertiliser application, adjustment of the amount of protein in the diet of cattle and pigs. Most of this abatement potential with a negative cost is related to nitrogen management (fertiliser application to crops and grassland, legumes, nitrogen content in the diet of livestock). Then come grassland management and fossil fuel savings.

The second part corresponds to sub-measures with a **moderate cost (less than EUR 25 per metric ton of CO_2e avoided)**. This category includes sub-measures requiring specific investments (for example, for methanisation) or modifying the cropping system slightly (reducing tillage, agroforestry, development of grain legumes), that may potentially lead to moderate reductions in production outputs, partially compensated for by a reduction in costs (fuels) or additional marketable products (electricity, wood).

The third part corresponds to sub-measures with a **high cost (greater than EUR 25 per metric ton of CO_2e avoided)**. This category includes sub-measures requiring an investment with no direct financial return (flares, for example), the purchase of specific inputs (nitrification inhibitor, unsaturated fats or additives incorporated into the diet of ruminants, etc.), dedicated labour time (cover crops, hedges, etc.) and/or involving greater production losses (grass buffer strips reducing the cultivated surface area, for example), with no reduction in costs and with no or few additional marketable products generated. Some of these measures nonetheless have a positive impact on other agricultural and environmental objectives. These measures contribute to multiple objectives and their value and cost cannot be assessed solely in terms of their beneficial effects on GHG emissions abatement.

Which CAP policy tool can support the implementation of the identified measures?

The first pillar of the new CAP has introduced the principle of a payment associated with "greening measures". A principle of "greening equivalency" has also been proposed. The objectives are

(i) to protect permanent grassland (ban on ploughing in designated areas)
(ii) to promote crop diversification
(iii) to maintain an "ecological focus area"

Assuming specific support for protein crops, the greening measures of the new CAP are likely to support the implementation of 3 (out of 26) of the proposed sub-measures identified by the French study: increasing the surface area of grain legumes, buffer strips and hedges.

The principle of "greening equivalency" may be used to promote 4 additional sub-measures: reduced tillage, cover crops, vineyard/orchard cover cropping and agroforestry.

For France, the calculated annual abatement of a scenario combining these 7 sub-measures is 7.5 $MtCO_2$e per year. This represents 23 % of the overall abatement calculated for all proposed measures.

The impact of the green payment principle on GHG abatement is limited by the fact that key agricultural practices such as mineral nitrogen fertilisation, animal diets, manure management and energy production and consumption on farms are not targeted by the greening measures.

These additional levers would need to be supported through the second pillar in order for more ambitious reduction targets to be met.

1. CONTEXT

KEY FINDINGS

- Greenhouse gas emissions from the agricultural sector represent 9.8 % of the total EU emissions (excluding LULUCF).
- A specific feature of these emissions is that they are mostly non energy-related. 4.9 % are due to agricultural soils (nitrous oxide), 3.1 % to enteric fermentation (methane) and 1.6 % to manure management.
- In France, agriculture accounts for 17.8 % of emissions.
- The French National Institute for Agricultural Research (INRA) was commissioned to conduct a study on the abatement of greenhouse gas (GHG) emissions in the agricultural sector in mainland France (published July 2013).
- The objective of the study was to select ten abatement measures concerning agricultural practices and to estimate their abatement potential and associated costs.

Greenhouse gas emissions in the agriculture sector represent around 9.8 % of total EU emissions. A specific feature of agricultural emissions is that they are mostly non energy-related and controlled by biological processes. Nitrous oxide (N_2O) is produced by agricultural soils during biochemical transformations of nitrogen (nitrification and denitrification reactions). The amount of N_2O emitted is closely linked to the use of nitrogen fertilisers. Methane (CH_4) is produced by ruminants (by eructation) and manure during anaerobic fermentation. The weight of N_2O and CH_4 emissions in the GHG agricultural balance is related to their 100-year global warming potentials (GWP), which are much higher than that of CO_2 ($GWP_{CO2} = 1$, $GWP_{CH4} = 25$, $GWP_{N2O} = 298$) (GIEC, 2006).

Agriculture can help improve the net GHG emissions balance via three levers: a reduction in N_2O and CH_4 emissions, carbon storage in soil and biomass, and energy production from biomass (biofuels, biogas), reducing emissions by replacing fossil energies. The majority of authors agree that there is considerable scope for progress but, given the predominantly diffuse nature of the emissions and the complexity of the underlying processes, estimating emissions is riddled with uncertainty and the abatement potentials are currently less accurately quantified than in other sectors.

In France, agriculture accounts for 2 % of the gross domestic product but 17.8 % of emissions (excluding energy consumption and land-use change), as estimated by the national inventory, with 94 Mt of CO_2 equivalent (CO_2e) out of a total of 528 MtCO_2e (2010 Inventory of emissions, CITEPA 2012). The 17.8 % of emissions attributed to agriculture do not include emissions related to its energy consumption, which are included in the "Energy" sector of the national inventory. If these emissions are incorporated, the share of agriculture rises to around 20 % of total French GHG emissions, with N_2O, CH_4 and CO_2 respectively accounting for 50 %, 40 % and 10 % of the sector's emissions, expressed in CO_2e.

Like other European countries, France has launched an ambitious policy aimed at reducing its emissions. The objective is to achieve a 75 % reduction by 2050 compared to levels in 1990, the reference year. This drive needs to be reflected in the country's various economic sectors, including the agricultural sector.

The ADEME (French Environment and Energy Management Agency), the MAAF (Ministry of Agriculture, Food and Forestry) and the MEDDE (Ministry of Ecology, Sustainable Development and Energy) commissioned INRA (French National Institute for Agricultural Research) to conduct a study on the abatement of greenhouse gas (GHG) emissions in the agricultural sector in mainland France. The objective of the study was to select ten abatement measures concerning agricultural practices and to estimate their abatement potential and associated costs or benefits in economic terms.

2. SELECTION OF TEN TECHNICAL MEASURES

KEY FINDINGS

- The measures were selected according to five criteria: eligibility with respect to study specification, GHG abatement potential, availability of required technology and scientific knowledge, applicability, synergies or antagonisms with other agri-environmental objectives.
- The proposed measures must be related to an agricultural practice, as decided by the farmer. They should not involve major change to the production system or a reduction in production output in excess of 10 %.
- Four main levers and 10 measures, broken down into 26 sub-measures, were identified.
- They are related to nitrogen fertilisation management, carbon storage in soils and biomass, animal diets and energy production and consumption on farms.

2.1. Measure selection criteria

The measures to be examined were selected according to the following criteria:

- ✓ **Measure eligibility with respect to the study specifications**. The measure must relate to an agricultural practice - as decided by the farmer - with an expected abatement at least partially located on the farm, involving no major change to the production system and no reduction in production output in excess of 10 %.

- ✓ **Greenhouse gas emissions abatement potential**. Measures with an abatement potential deemed to be low or uncertain were eliminated. The potential may be judged to be low either due to a modest unitary abatement and/or because the potential applicability of the measure is limited in the agricultural context of France (e.g. measure concerning paddy fields).

- ✓ **Current availability of the technology required to implement the measure and of validated scientific knowledge establishing its efficacy**. For example, measures still in the research phase, involving technology that is not yet fully mastered (incorporation of biochar into soil to serve as a carbon store), or for which applications are not currently available (genetic improvement of crops or livestock on the basis of new criteria), were not selected.

- ✓ **Applicability of the measure**. This can be problematic due to a low technical feasibility on a large scale (modification of the physicochemical conditions of the soil), risks (known or suspected) to health or to the environment, incompatibility with current regulations (concerning the use of antibiotics in farm animals, for example) or a low level of social acceptability (transgenesis).

- ✓ **Potential synergies or antagonisms with other major agricultural objectives**. This secondary criterion primarily served to support the choice of measures already meeting the other criteria (also helping to reduce pollution, for example) or, conversely, to eliminate other measures (involving "intensification" of production systems, for example).

2.2. The ten measures examined

These measures (numbered from ❶ to ❿) concern four technical levers. Each one includes several sub-measures for which the abatement potential is cumulative (apart from the no-till measure, split into three alternative, non-cumulative technical options). The measures presented below are not given in order of priority or importance.

2.2.1. Reduce the application of mineral nitrogen fertiliser, the source of the majority of N_2O emissions.

❶ **Reduce the use of synthetic mineral fertilisers** in order to reduce the associated N_2O emissions. This reduction in fertiliser application can be obtained: by more effectively adjusting the application to crop requirements, with realistic yield targets; by making better use of organic fertilisers; by improving the efficiency of the nitrogen supplied to the crop by means of application conditions (delaying the first application in the spring, adding a nitrification inhibitor, localised incorporation of fertiliser).

❷ **Increase the proportion of leguminous crops**, which, thanks to their symbiotic fixation of atmospheric nitrogen, do not require external nitrogen fertiliser and leave nitrogen-rich residues in the soil, reducing the amount of mineral fertiliser application required for the next crop. Two sub-measures were examined: increasing the proportion of grain legumes in arable crop rotations; introducing and maintaining a higher proportion of legumes in temporary grassland.

2.2.2. Store carbon in soil and biomass by accumulating organic matter, either by increasing the production of perennial biomass or the amount of organic matter returned to the soil, or by slowing down its mineralisation.

❸ **Develop no-till cropping practices** to help store carbon in soils. No-till cultivation prevents the disruption of soil aggregates that protect organic matter, slows down its decomposition and mineralisation and hence increases carbon storage. The elimination of tillage practices that consume large quantities of fossil fuel also helps reduce CO_2 emissions. Three technical options are studied: a switch to continuous direct seeding, direct seeding with occasional tillage, 1 year in 5, or continuous surface tillage.

❹ **Plant more cover crops** in cropping systems in order to store carbon in soil (and limit N_2O emissions). The aim is to extend or generalise the use of cover crops (sown between two cash crops) on arable farms, cover crops in orchards and vineyards (permanent or temporary green cover) and grass buffer strips around the edges of fields.

❺ **Develop agroforestry** (lines of trees planted in cultivated fields or on grassland) **and hedges** (around the edge of fields) to promote carbon storage in soil and plant biomass.

❻ **Optimise grassland management** to promote carbon storage and also reduce N_2O and CH_4 emissions related to the application of mineral fertilisers and to livestock manure. The options considered include: extending the grazing season to reduce the proportion of manure produced indoors and hence the associated N_2O and CH_4 emissions; increasing the lifespan of temporary grazing in order to delay ploughing up of the grass, which accelerates the release of carbon due to decomposition of organic matter in the soil; reducing fertiliser application on the most intensive grassland; making the most extensive grassland (for example, moorland) moderately more intensive by increasing livestock density in order to increase plant production and hence carbon storage.

2.2.3. Modify livestock diet, to reduce direct CH_4 emissions (by eructation) or the amount of nitrogen-containing substances (urea in particular) excreted, these being a source of N_2O emissions.

❼ **Reduce methane production by cattle,** by guiding rumen function towards metabolic pathways that produce less CH_4, via limited changes to the composition of the animals' diet. Two methods are envisaged: increasing the amount of unsaturated fat (in the form of oilseed) in the diet in place of carbohydrates; incorporating an additive (nitrate) into diets with a low fermentable nitrogen content (based on silage maize).

❽ **Reduce the amount of protein in the diet** to limit the quantity of nitrogen excreted in manure, corresponding to the fraction of protein ingested that the animals do not retain since it is surplus to their requirements. This involves reducing the protein content of concentrated feed given to dairy cows and better tailoring the diet of fattening pigs and sows to their development stage, adapting the compound feed to each particular stage and adjusting its composition through the use of synthetic amino acids.

2.2.4. Recycle manure to produce energy and reduce fossil fuel consumption on the farm to reduce methane emissions produced by fermentation of livestock manure and CO_2 emissions.

❾ **Trap the CH_4 produced by fermentation of livestock manure** during its storage and eliminate it by combustion, i.e. convert it into CO_2. The CH_4 is burned, with the production of electricity or heat, or simply flared. Since the global warming potential (GWP) of CO_2 is 25 times lower than that of CH_4, the combustion of CH_4 into CO_2 can be beneficial, even in the absence of any conversion to energy (case of flares). This measure involves increasing the volume of livestock manure methanised or, if this is not possible, covering slurry storage tanks and installing flares.

❿ **Reduce fossil fuel consumption (gas, fuel oil, diesel) on the farm** by improving the insulation and heating systems of livestock buildings and greenhouses and optimising the diesel consumption of tractors (by engine adjustment and application of eco-driving rules) to limit direct CO_2 emissions.

3. GREENHOUSE GAS EMISSIONS ABATEMENT POTENTIALS AND COMPARATIVE COSTS OF THE MEASURES

KEY FINDINGS

- The 26 selected sub-measures were ranked according to the cost of the metric ton of CO_2e avoided.
- The overall abatement potential can be broken down into three approximately equal parts: (i) sub-measures with a negative cost, involving technical adjustments and input savings (nitrogen, energy), (ii) sub-measures with a moderate cost (less than EUR 25 per metric ton of CO_2e avoided), involving investments or modifications to cropping systems, with additional marketable products, and (iii) sub-measures with a higher cost (greater than EUR 25 per metric ton of CO_2e avoided), involving investments, the purchase of specific inputs, dedicated labour time or greater production losses, with no additional marketable products.
- The overall annual GHG emissions abatement potential calculated for all measures and sub-measures would be 32.3 Mt CO_2e in 2030. The calculated value is slightly lower if interactions between measures are considered (between 26.6 and 29.6 Mt CO_2e).
- Current inventory rules are likely to account for only one third of this potential.
- Considering emissions induced upstream or downstream of the farm has little effect on the calculated abatement potential for most of the sub-measures. It markedly increases the abatement potential of measures related to nitrogen management and legumes because of the GHG emissions due to nitrogen fertiliser production.
- The hypotheses adopted for the economic calculations have a significant impact on the results obtained. For example, excluding the state subsidy reinforces the interest of reduced tillage but reduces the interest of methanisation.

3.1. Measure assessment variables

The annual greenhouse gas emissions abatement potential and annual cost of each of the measures were quantified on the basis of unitary estimates of the abatement potential and cost, the potential applicability (surface area, animal population, etc.) and hypotheses regarding the adoption of the measures over the period 2010-2030.

3.1.1. Greenhouse gas emissions unitary abatement potential

The "unitary" abatement potential (depending on the measure: per hectare, per head of cattle, etc.) was calculated up to 2030, reviewing all the GHG emission sources potentially affected by the measure.

A distinction was made between direct (produced within the farm) and indirect (occurring in nearby areas) emissions on the one hand, and induced emissions on the other, occurring upstream or downstream of the farm, related to modification of the purchase or sale of goods resulting from the measure.

Two calculations were made: one using the method employed by the organisation producing the inventory of French GHG emissions (CITEPA), and the other employing a method proposed by the experts, in order to take into account effects that the first method is inherently incapable of quantifying.

3.1.2. Determination of the unitary cost of the measure for the farmer

This unitary cost includes overhead variations (purchase of inputs, labour costs, etc.), investments, revenue changes associated with production changes (any yield losses, sale of wood or electricity, etc.). The costs of sub-measures were calculated incorporating state subsidies where these cannot be separated from the prices implemented (subsidised purchase of electricity produced by methanisation, tax exemptions for agricultural fuels), excluding "optional" subsidies (coupled aid schemes, Single Payment Entitlements, regional subsidies, for example).

3.1.3. Determination of the potential applicability of the measure

The potential applicability (surface areas or livestock numbers) was estimated taking into account any potential technical obstacles. It may be limited, for instance, by technical constraints, meaning that some surface areas (crops or soil types, etc.) or some herds (due to their feeding method, etc.) are not appropriate or do not enable implementation of the measure under conditions that are technically acceptable to the farmer.

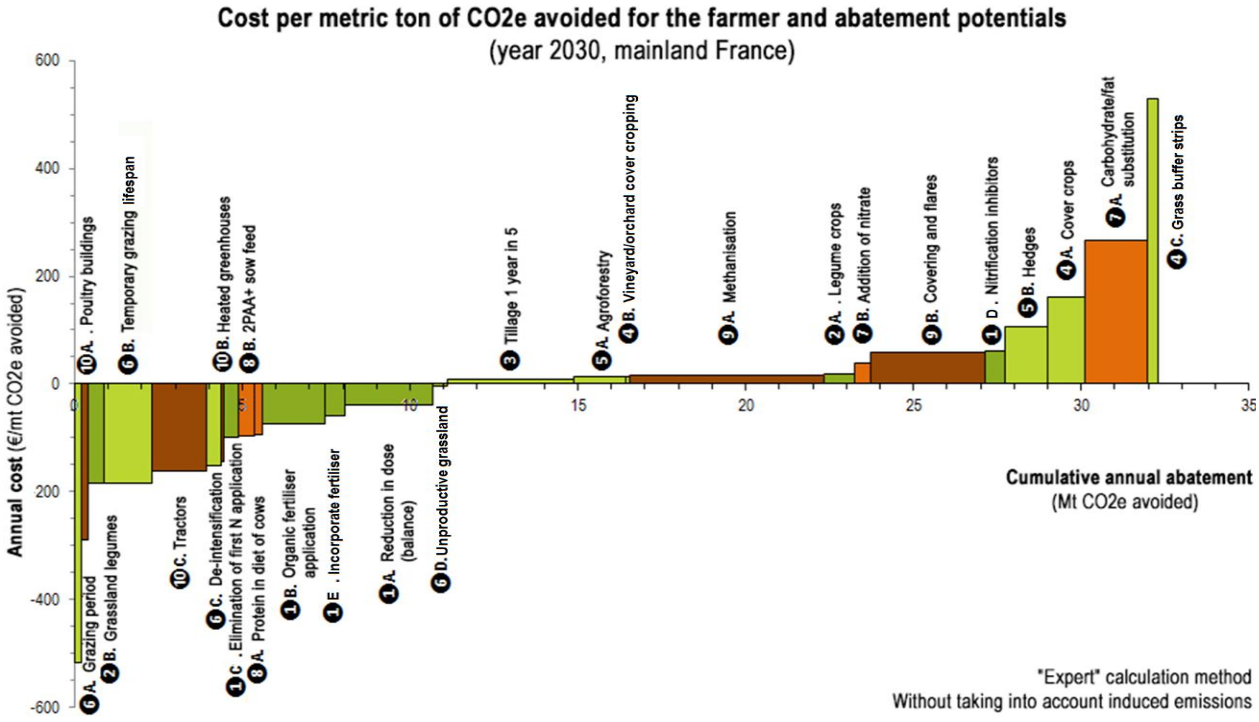
3.1.4. Choice of a measure adoption scenario

An adoption scenario was estimated describing the measure uptake rate, starting from the reference situation in 2010, taking into account various obstacles (investment, equipment availability, limited social acceptability, etc.) that may hamper or delay adoption of the measure.

By determining these variables, the annual abatement potential and the annual cost of the measure (obtained by multiplying the annual unitary values by the national potential applicability) can be calculated, as can the cost per metric ton of CO_2e avoided by implementation of the measure (obtained by dividing the annual unitary cost of the measure by the annual unitary abatement it generates).

The two variables conventionally used to compare the measures are the annual abatement potential and the cost per metric ton of CO_2e avoided. The graph showing the technical abatement potential (on the x-axis) and the cost per metric ton of CO_2e avoided (on the y-axis) for each measure can be used to compare the measures on the basis of these two criteria. Figure 1 presents these two variables (estimated for 2030 using the calculation method proposed by the experts) for all the sub-measures. When several alternative technical options have been explored for one measure, only one of these is reported (ploughing one year in five for the no-till measure).

Figure 1: Cost per metric ton of CO_2e avoided for the farmer and abatement potentials



Source: Author

HOW TO INTERPRET FIGURE 1

This "MACC" (Marginal abatement cost curve), represents:
- **horizontally: the annual GHG emissions abatement potential** up until 2030 on a national scale; abatement is calculated excluding induced emissions, using the "expert" calculation method, without taking into account interactions between measures;
- **vertically, the cost for the farmer of the metric ton of CO_2 equivalent avoided**; this technical cost is calculated including state subsidies that cannot be separated from the price paid by or to the farmer. A "negative" cost corresponds to a gain for the farmer, while a "positive" cost represents a shortfall.

For each sub-measure (see list in table 1), **the height of the rectangle thus indicates the cost per metric ton of CO_2e avoided** (in EUR per t CO_2e) and **the width of the rectangle the emissions abatement** (in Mt of CO_2e avoided per year) calculated on the potential applicability achieved in 2030.
The sub-measures are arranged in order of increasing cost. On the left, on the horizontal axis, are the sub-measures generating a gain for the farmer; in the centre, those for which the cost (negative or positive) is low; on the right, those which have a higher cost.
This graph makes it easier to compare measures and can be used to directly read off the cumulative emissions reductions that can be achieved for a unitary cost lower than a given sum.

Table 1: List of measures

MEASURES	Sub-measures	GHG
❶ Reduce the use of synthetic mineral fertilisers	A. Reduce the dose of mineral fertiliser by more effectively adjusting yield targets B. More effectively replace synthetic mineral nitrogen with nitrogen from organic products C1. Delay the date of the first fertiliser application in the spring C2. Use nitrification inhibitors C3. Incorporate into the soil and localise fertilisers	**↓ N2O**
❷ Increase the proportion of leguminous crops on arable land and temporary grassland	A. Increase surface areas of grain legumes on arable farms B. Increase and maintain legumes on temporary grassland	**↓ N2O**
❸ Develop no-till cropping systems	3 technical options: switch to continuous direct seeding, switch to occasional tillage, switch to surface tillage	**↓ CO2**
❹ Introduce more cover crops, vineyard/orchard cover cropping and grass buffer strips	A. Develop cover crops sown between two cash crops in arable farming systems B. Introduce cover cropping in vineyards and orchards C. Introduce grass buffer strips alongside water courses or around the edges of fields	
❺ Develop agroforestry and hedges	A. Develop agroforestry with a low tree density B. Develop hedges around the edges of fields	**↓ CO2**
❻ Optimise grassland management	A. Extend the grazing period B. Increase the lifespan of temporary grazing C. Reduce nitrogen fertiliser application on the most intensive permanent and temporary grassland D. Make permanent grassland that is not very productive moderately more intensive by increasing livestock density	**↓ CO2** **↓ N2O**
❼ Replace carbohydrates with unsaturated fats and use an additive in the diet of ruminants	A. Replace carbohydrates with unsaturated fats in feed rations B. Incorporate an additive (nitrate) into feed rations	**↓ CH4**
❽ Reduce the amount of protein in the diet of livestock	A. Reduce the protein content in the feed rations of dairy cows B. Reduce the protein content in the feed rations of pigs and sows	**↓ N2O**
❾ Develop methanisation and install flares	A. Develop methanisation B. Cover storage pits and install flares	**↓ CH4**
❿ Reduce the fossil fuel consumption of agricultural buildings and machinery on the farm	A. Reduce fossil fuel consumption for heating livestock buildings A. Reduce fossil fuel consumption for heating greenhouses C. Reduce the fossil fuel consumption of agricultural machinery	**↓ CO2**

3.2. Comparative cost and GHG abatement potential of sub-measures

The expected overall abatement potential can be broken down into three parts:

- ✓ The first part corresponds to sub-measures with a **negative technical cost**, i.e. leading to a financial gain for the farmer. These are mainly sub-measures **involving technical adjustments with input savings,** with no loss of production. This category includes sub-measures relative to **grassland management** (extension of grazing period, increase in proportion of legumes on grassland, extension of lifespan of temporary grazing, making most intensive grassland less intensive), sub-measures designed to generate **fossil fuel savings** (adjustment of tractors and eco-driving, insulation and improvement of greenhouse and livestock building heating systems), **adjustment of nitrogen fertiliser application** to more realistic yield targets, adaptation of application dates and locations, more effectively taking into account nitrogen supplied by organic products, **adjustment of the amount of protein in the diet of cattle and pigs**. ***Most of this abatement potential with a negative cost is related to nitrogen management*** (fertiliser application to crops and grassland, legumes, nitrogen content in the diet of livestock). Then come ***grassland management*** and ***fossil fuel savings***.

- ✓ The second part corresponds to sub-measures with a **moderate cost (less than EUR 25 per metric ton of CO_2e avoided)**. This category includes sub-measures requiring specific investments (for example, for methanisation) or modifying the cropping system slightly (reducing tillage, agroforestry, development of grain legumes), that may potentially lead to moderate reductions in production outputs, partially compensated for by a reduction in costs (fuels) or additional marketable products (electricity, wood). In this second group, estimation of the abatement potential is highly sensitive to the hypotheses relative to the potential applicability of the measures (surface area or manure volume concerned) and the cost depends greatly on the prices used for the calculations. An assessment excluding state subsidies increases the value of no-till systems and reduces that of methanisation. These measures contribute to agricultural and environmental objectives beyond that of solely reducing GHG emissions: production of renewable energy (methanisation), reduction in erosion risk (no-till), landscape quality and biodiversity (agroforestry). Reduced tillage may lead to an increase in the use of herbicides, but the option favoured (tillage one year in five) limits this risk.

- ✓ The third part corresponds to sub-measures with a **high cost (greater than EUR 25 per metric ton of CO_2e avoided)**. This category includes sub-measures requiring an investment with no direct financial return (flares, for example), the purchase of specific inputs (nitrification inhibitor, unsaturated fats or additives incorporated into the diet of ruminants, etc.), dedicated labour time (cover crops, hedges, etc.) and/or involving greater production losses (grass buffer strips reducing the cultivated surface area, for example), with no reduction in costs and with no or few additional marketable products generated. Some of these measures nonetheless have a positive impact on other agricultural and environmental objectives (for example, effects of cover crops, grass buffer strips and hedges on biodiversity, landscapes, erosion control, reduction of pollutant transfer to water). These measures contribute to multiple objectives and their value and cost cannot be assessed solely in terms of their beneficial effects on GHG emissions abatement.

3.3. Overall abatement potential of the ten measures

Assuming that the sub-measures are additive, the overall annual GHG emissions abatement potential related to the implementation of all ten measures (broken down into 26 sub-measures) would be 32.3 Mt CO_2e in 2030, excluding induced emissions. This estimation cannot be directly compared with the French agricultural emissions in the national inventory, which are calculated using different rules. There is also an impact on the results depending on whether or not interactions between measures or induced emissions are taken into account.

3.3.1. The impact of the calculation method

By their very nature, the calculation equations used by CITEPA for the inventory of national emissions are not capable of reporting the expected abatement of some of the measures or sub-measures proposed in the context of this study. This is the case for measures promoting carbon storage in soil via the cultivation methods used without any change in land use, such as no-till or agroforestry.

By applying the calculation methods used by CITEPA for the national inventory in 2010, the cumulative annual abatement excluding induced emissions for all the measures (still assuming that they are additive) is 10.0 Mt CO_2e per year in 2030, i.e. less than a third of the value obtained with the calculation methods proposed by the experts.

3.3.2. Incorporation of interactions between measures

The implementation of a (sub-)measure may modify the abatement potential of another one, due to interactions. When interactions are taken into account, the cumulative abatement potential for all the measures falls from 32.3 to 29.6 or 26.6 MtCO_2e per year, depending on the calculation method.

3.3.3. Incorporation of induced emissions

When emissions induced upstream or downstream of the farm, relating to modification in the purchase or sale of products as a result of the measure, are taken into account, this has little effect on the calculated abatement for the majority of the sub-measures, although there are a few exceptions. This markedly increases the potential calculated for measures relating to fertiliser application and legumes (due to GHG emissions related to the production of nitrogen fertilisers) and to the nitrogen content in the diet of livestock (due to emissions related to the production of soybean meal). Conversely, when induced emissions are taken into account, this reduces the value of adding fats to the diet of cattle, which leads to an increase in upstream emissions for the production of raw materials.

3.4. Uncertainties and sensitivity of results

3.4.1. Uncertainties relative to the calculations

The level of uncertainty concerning the unitary abatement potential is generally high given the marked variability in the processes involved in GHG emissions and carbon storage and the difficulties encountered when measuring gas emissions (and N_2O in particular). For some measures, there is also a high level of uncertainty regarding the potential applicability and adoption kinetics (agroforestry, methanisation, for example). Overall, the abatement potentials of the fertiliser application, no-till, agroforestry and grassland management measures are the ones presenting the greatest amount of uncertainty.

3.4.2. Sensitivity of the results to the economic hypotheses adopted

The hypotheses adopted for the economic calculations have a significant impact on the results obtained. Hence, the relatively modest cost of the methanisation sub-measure is linked to the fact that the state subsidy is taken into account in the purchase price for the electricity produced; excluding the subsidy, this cost rises from EUR 17 to EUR 55 per metric ton of CO_2e avoided. Conversely, a calculation without the subsidy represented by the tax exemption status of agricultural fuels increases the value of occasional tillage: the cost per metric ton of CO_2e avoided actually becomes negative, falling from + EUR 8 to - EUR 13.

Demonstration of an abatement potential with a negative technical cost, also observed in the context of similar studies conducted in other countries, suggests the existence of adoption obstacles of a different type (risk aversion, etc.). Private transaction costs, linked to the technical nature and complexity of implementation of the measures and the administrative procedures sometimes required may partially explain why they are not spontaneously adopted.

4. WHICH CAP POLICY TOOL CAN SUPPORT THE IMPLEMENTATION OF THE IDENTIFIED MEASURES?

KEY FINDINGS

- Assuming specific support for protein crops, the greening measures of the new CAP are likely to support the implementation of 3 (out of 26) of the proposed sub-measures: increasing surface area of grain legumes (2A), buffer strips (4C) and hedges (5B).
- The principle of "greening equivalency" may be used to promote reduced tillage (3), cover crops (4A), vineyard/orchard cover cropping (4B) and agroforestry (5A).
- For France, the calculated annual abatement of a scenario combining these 7 sub-measures is 7.5 $MtCO_2e$ per year. This represents 23 % of the overall abatement calculated for all proposed measures.
- The impact of the green payment principle on GHG abatement is limited by the fact that key agricultural practices such as mineral nitrogen fertilisation, animal diets or manure management are not targeted by the greening measures.
- These additional levers would have to be supported through the second pillar in order to reach more ambitious reduction targets.

The first pillar of the new CAP has introduced the principle of a "green" payment. In addition to the basic payment scheme, each holding will receive a payment per hectare for respecting certain agricultural practices. The three measures foreseen are:

(i) **maintaining permanent grassland** (ban on ploughing in designated areas);

(ii) **crop diversification** (at least 2 crops when the arable land of a holding exceeds 10 ha; at least 3 crops when the arable land of a holding exceeds 30 ha; the main crop may cover at most 75 % of arable land, and the two main crops a maximum of 95 % of the arable area; not applicable if more than 75 % of the eligible area is grassland/herbaceous forage crops);

(iii) **maintaining an "ecological focus area"** (EFA) of at least 5 % of the arable area of the holding; only applicable for farms with more than 15 ha of arable land. EFA may include field margins, hedges, trees, fallow land, landscape features, biotopes, buffer trips, afforested areas. The objective will rise to 7 % after a Commission report in 2017 and a legislative proposal.

The principle of a "greening equivalency" has also been introduced, so that the application of environmentally beneficial practices already in place are considered to replace the three aforementioned basic requirements.

Table 2 shows the correspondences between the "green" payment measures of the new CAP and the proposed measures to mitigate GHG emissions in the French study.

The ban on ploughing of permanent grassland is a prerequisite for sub-measures related to permanent grassland management, but the calculated abatement was based on specific management options (6A extend the grazing period, 6C reduce nitrogen application on most intensive grassland and 6D make less productive permanent grassland slightly more intensive to increase C storage) which are not targeted by the green payment.

The current greening measure on crop diversification is probably not stringent enough to significantly increase the area of protein crops (sub-measure 2A in Table 1). However, Member States can choose to use up to 2% of their national envelope to support the cultivation of these crops. The implementation of this measure will therefore depend on Member States' decisions.

The greening measure dedicated to the ecological focus area is likely to favour the development of buffer strips (sub-measure 4C) and hedges (sub-measure 5B). These sub-measures belong to the third group (high cost per metric ton of CO_2e avoided), but it must be considered that these measures also have positive effects on biodiversity, erosion control and reduction of pollutant transfer to water (i.e. not only on GHG emission abatement).

Additional measures or sub-measures may be supported through the principle of "greening equivalency": reduced tillage (3), cover crops (4A), vineyard/orchard cover cropping (4B), agroforestry (5A).

For France, the calculated annual abatement of a scenario combining the 7 sub-measures which are likely to be promoted by the green payment (assuming additional specific support for protein crops) (2A, 4C, 5B) and by the green equivalency principle (3, 4A, 4B, 5A) is 7.5 MtCO2e per year. **This represents 23 % of the overall abatement calculated for all proposed measures.**

The impact of the green payment principle on GHG abatement is limited by the fact that major agricultural management techniques which are responsible for the main part of the emissions, such as mineral nitrogen fertilisation, animal diets, manure management, energy production and consumption on farms, are not targeted by the greening measures.

Reaching more ambitious GHG emission abatement targets will only be possible if these additional levers are targeted by the second pillar.

Table 2: Correspondence between the green payment measures and the selected measures to mitigate GHG emissions in the French study

MEASURES	Permanent grassland	Crop diversif.	Ecological focus area
Reduce the use of synthetic mineral fertilisers			
Increase the proportion of leguminous crops on arable land and temporary grassland		X	
Develop no-till cropping systems			
Introduce more cover crops, vineyard/orchard cover cropping and grass buffer strips in cropping systems			X
Develop agroforestry and hedges			X
Optimise grassland management	X		
Replace carbohydrates with unsaturated fats and use an additive in the diet of ruminants			
Reduce the amount of protein in the diet of livestock			
Develop methanisation and install flares			
Reduce the fossil fuel consumption of agricultural buildings and machinery			

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