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AGRICULTURE GHG EMISSIONS: DETERMINING THE POTENTIAL CONTRIBUTION TO THE EFFORT SHARING REGULATION

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Disclaimer: The arguments expressed in this report are solely those of the authors, and do not reflect the opinion of any other party.

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Table of Contents

List of Tables

List of Figures

List of Boxes

Executive summary

KEY MESSAGES

- ***The agriculture sector can make a significant contribution to the EU's climate mitigation efforts***. While it is widely acknowledged that agriculture can contribute to mitigation by increasing carbon removals on agricultural land (reported under LULUCF), this study shows that there is also a significant untapped potential for the agriculture sector to contribute through reducing its non-CO_2 emissions.
- ***The extent of the sector's contribution will largely depend on the level of ambition of the sector, the costs of the mitigation action and the level of public support available***, but studies show that agriculture can achieve significant climate mitigation even in situations where the financial incentive for mitigation is low and where actions are not supported through policy. Mitigation actions that are available as well as their mitigation potential and costs will evolve over time, as new technology becomes available or more affordable.
- ***A wide range of mitigation actions are already available to the agriculture sector,*** but have yet to be adopted at the scale and intensity necessary to deliver lasting emission reductions.
- ***Care must be taken to balance climate mitigation with the potential impacts on production and to look for the environmental and economic co-benefits of mitigation efforts***. An important point to acknowledge is the evolving nature of all these factors, e.g. a mitigation action may only have short term production impacts.
- ***Focusing on non-CO_2 emissions, there is a great deal of variation in the mitigation potential of individual climate mitigation actions in the agriculture sector. This variation exists both in the potential of an action per unit of uptake as well as uncertainties regarding the overall potential applicability of that action,*** as a result of the differing emission effects of individual actions in different environmental, biogeographical and socioeconomic contexts as well as different baselines of current farming practice.
- ***Better information is needed to determine the precise level of mitigation potential in the agricultural sector.*** More effort should be devoted to monitoring climate action and its impact at the EU and Member State level.
- ***The cost of mitigation actions and the impact they have on production are important considerations in relation to their likely uptake and therefore overall potential.*** Some mitigation actions will be low cost and therefore could be adopted by farmers without significant investment or impact on production; some may have higher costs but result in greater efficiency or new revenue streams, whereas some will be high cost without being necessarily rewarded by gains in production or other cost savings or income generation – this is where financial support may be required. Where this is the case, different types of financial support may be required to compensate for the costs incurred. For instance, some actions may involve high costs in the form of one-off investments, some may have short-term only production impacts while other actions may lead to longer term costs or production effects.
- ***Supporting mitigation activities in the sector can have high costs in some cases, yet climate mitigation actions can achieve environmental co-benefits provided they are implemented in a way that is complementary to broader environmental goals and societal objectives.*** These co-benefits, particularly those for the environment, will only be provided under specific, often context-dependent, conditions.

- ***The existing studies reviewed in this report do not provide the information to support the widely held view that mitigation in agriculture is (or is not) more technically challenging or more cost-ineffective compared to other ESD sectors, particularly when environmental co-benefits are considered.*** The studies do show however that there are potentially significant impacts on production for some actions that should be balanced with mitigation effort and overall impact on GHG emissions.
- ***The influence of individual choices is significant. Unlike many other sectors, promoting climate mitigation actions in agriculture relies on the adoption of actions by millions of individuals and small businesses.*** Support and information awareness raising to farmers is therefore essential to engage farmers in climate mitigation actions and help deliver a range of environmental and economic co-benefits.
- ***Support for implementing mitigation activities is available through the CAP and can provide complementarity to other objectives and Union priorities.*** This includes advice and support frameworks, opportunities for testing innovative approaches, enhancing collaboration and financial support for the actions themselves.
- ***The right mix of supporting conditions is necessary to ensure that mitigation efforts are adopted and implemented correctly, to avoid any long-term production impacts which may lead to carbon leakage effects (production in third countries),*** reducing the overall mitigation effort at the global level, and ensure coherence with other environmental and economic objectives.
- ***Addressing climate mitigation from the agriculture sector requires consideration of both supply (i.e. production) and demand (i.e. consumption) side.*** The agriculture sector, like many others, responds to market demands and demographic changes. This study has not looked at the tools available to support mitigation action on the demand side, but these will need to be allied to measures on the production side, so as to reduce pressure on the sector as a whole.
- ***A clear decarbonisation agenda for the sector is necessary. Articulating this through a long-term low emission strategy for the agricultural sector should provide the necessary framework in which emission reductions and removals are to be achieved and by when.*** Setting a quantitative target for agriculture would give clarity to farmers and Member States about the necessary effort needed and set clear ambition. Any long-term strategy will need to consider the trade-offs between mitigation, production and the cost to society (and Member States). This will require a fresh look at the role of the sector both in terms of reducing emissions and increasing removals, as well as the role of society as a whole.
- ***Taking mitigation action in agriculture cannot be ignored and the sector must increase its contribution to emission reductions and removals***. There is only so long that agriculture emissions can be compensated by emission reductions in other ESD sectors or through sequestration and storage of carbon in other land-using sectors. Over time, there will be increasing competition to use removals from the land-using sectors to address increasingly challenging reductions in other sectors, beyond agriculture. A key question for research and policy is therefore what level of emission removals is possible within the land-using sectors and how (if at all) should this be shared out amongst other sectors as they reach the limits of mitigation (which the agricultural sector is far from having achieved to date).This study examines the potential contribution that the agriculture sector could make to climate mitigation efforts in the EU through the proposed Effort Sharing Regulation (ESR). It was commissioned by Transport and Environment in the context of developing understanding on the role of the non-ETS sectors could play in climate mitigation efforts in the EU.

The study considers only those emissions and mitigation actions in the agriculture sector that are covered by the current Effort Sharing Decision (ESD) and the proposed Effort Sharing Regulation (ESR). These include the non-CO_2 greenhouse gas (GHG) emissions comprising primarily of nitrous oxide (N_2O) and methane (CH_4). It explicitly does not aim to cover the mitigation actions associated with CO_2 emission reductions and removals from the LULUCF Decision sectors, other than where these are relevant to the discussion or included within mitigation activities and model estimates in the studies reviewed. Mitigation activities and mitigation potential are described primarily in the 2030 time horizon (where relevant) as related to the proposed ESR Regulation, and in 2050 in relation to the roadmap to a low carbon economy that sets the longer-term emission mitigation trajectory in the EU.

The research reviewed in this study shows that not only can agriculture contribute in a significant way to the EU's climate mitigation efforts under the ESR, but also that some of the actions with potential to be adopted could deliver much broader environmental (such as reduced diffuse pollution) and economic (such as reduced fertiliser consumption) benefits. To suggest that increasing mitigation effort in the sector is too costly or too difficult is therefore not entirely accurate. The question, however, is how much can it contribute and at what cost? In this regard, there are clear challenges to adopting mitigation activities in the sector at the scale which are likely to be required to meet longer-term emission reductions by mid-century.

Climate mitigation efforts in the agriculture sector have been relatively modest to date compared to those in other sectors and have largely been brought about through reductions in livestock numbers and increased efficiency in the use of fertiliser inputs. The challenges, both technical and political, of achieving cost effective reductions of GHG emissions in the agriculture sector have meant that little proactive large-scale action on climate mitigation in the agricultural sector has been taken to date. Those measures that have been adopted generally have reflected a mixture of national and international policy drivers as well as commercial pressures, rather than being set in the context of concerted action to achieve emissions reduction from the sector as a whole[1]. There is a clear challenge in the sector to balance the production of commodities with emission reductions, and to understand what the right balance should be in a low-carbon agriculture future. Yet limited political effort to address this challenge has only served to place it behind other sectors covered by the ESD and in the economy as a whole, and action therefore will become more pressing as the share of agriculture emissions in the economy increases.

The mitigation potential in the agriculture sector changes over time and will evolve as new technology becomes available or more affordable. The greatest challenges are therefore both how agriculture can contribute to emissions reductions while continuing to produce food, as well as the level of ambition there is to support mitigation in the sector, how agriculture is perceived in the climate change debate and the way in which it is incorporated into the policy frameworks.

At the UNFCCC level, agriculture is accounted for alongside forest and other land uses (AFOLU), which are some of the only sectors that have the potential to both reduce emissions but also increase removals from the atmosphere in above and below ground biomass. The longer there is a delay to action on non-CO_2 gases from agriculture the greater the effort that will have to come from carbon removals from the atmosphere via land management (both from agricultural and forestry land use). This is because if net zero emissions are to be achieved by 2050 (as would be required to meet the Paris Agreement target), aggressive cuts in emissions will have to take place in the coming decades, also from the agricultural sector. If these do not occur, emissions will have to be heavily compensated through carbon removals, sequestration and storage. Carbon sequestration and storage will, in turn, face a number of challenges including increasing competition for land where removals can take place and increasing competition for resources (e.g. water) needed to maintain or increase storage stock, as well as the saturation of existing carbon sinks. A key question is therefore what a sustainable and realistic level of removals in the land using sectors is likely to be and, from an accounting perspective, what share should be made available to agriculture to aid its mitigation efforts. The alternative route would be to compensate agricultural emissions through requiring more ambitious reductions elsewhere in the ESR sectors, which would put a disproportionate burden on other economic sectors.

[1] Hart K, Allen B, Keenleyside C, Nanni S, Maréchal A, Paquel K, Nesbit M and Ziemann J (2017) *The consequences of climate change for EU agriculture. Follow-up to the COP21 - UN Paris climate change conference*. European Parliament, Brussels.

At least some mitigation effort will be very likely to have to come from the agriculture sector in the short term, at least in some Member States more than others, particularly where agriculture represents a significant share of total greenhouse gas emissions. The degree of effort required will also be influenced by the level of achievement of overall mitigation efforts in other sectors[2]. The question arising is therefore what can the EU do in order to promote mitigation effort in the sector through policy.

Agriculture and climate change in the EU

The EU's agriculture sector is diverse reflecting the environmental (climate and geographical) and cultural diversity of Member States. The sector comprises around 10.8 million farms and is responsible for the management of over 40% of the EU's land area, including both farmed land as well as the management of semi-natural habitats. In this way it is responsible for the production of a range of ecosystem services that benefit society beyond food and fibre production, such as the provision of clean water, biodiversity, cultural landscapes, prevention of soil degradation and air quality. Agriculture delivers a total economic output of €411 billion, with a gross value added (GVA) to the EU of €164.7 billion. Agriculture, forestry and fishing represent approximately 1.5% of the total EU GVA in 2015, the lowest of all sectors.

Agricultural emissions are associated with a range of anthropogenic activities[3] but also with biological processes that naturally emit GHGs and which are influenced by weather, climate, and other natural processes. Uncertainty about the magnitude of emissions is therefore more pronounced in agriculture than in industrial sectors and for the same management activity, net emissions may vary in diverse agronomic, biophysical, environmental and climatic situations[4]. In addition, the land using sectors (including agriculture) have a more complex relationship with GHG emissions in that they can lead to removals of GHG emissions from the atmosphere through the sequestration of CO_2 in soils and biomass.

GHG emissions arising from agriculture and agricultural land are covered under both the ESD (primarily non-CO_2 emissions) and the LULUCF Decision (primarily CO_2) emissions. This study focuses on those emissions reported under the ESD and proposed ESR and are referred to in this report as 'agricultural emissions'. In the EU, the latest available data (2014) show that agricultural emissions are the fifth largest contributor to GHG emissions (11.3%; 514.1MtCO_{2e}), after the energy, transport, industry, residential and commercial sectors. Agricultural GHG emissions arise largely from non-CO_2 GHGs, primarily nitrous oxide (N_2O) which accounts for 58% of non-CO_2 emissions from agriculture (largely from nitrification and de-nitrification processes taking place as a result of fertiliser application, manure from grazing animals as well as other biological processes from exposed soils); and methane (CH_4) 42% (largely from livestock digestion and rice cultivation). There is considerable variation in emissions between Member States, with Ireland having the highest share of agriculture in national GHG emissions (32.2%; 18.7MtCO_{2e}) and Malta the lowest (3%; 0.088 MtCO_{2e}). In absolute terms, the greatest contribution of GHG emissions from the agriculture sector to the EU total comes from France (18%; 79 MtCO_{2e}), Germany (15%; 66.1 MtCO_{2e}) and the United Kingdom (10%; 44.6 MtCO_{2e}). Together these three Member States account for just under 44% of total EU-28 agriculture emissions.

In the EU, the overall level of non-CO_2 emissions in agriculture has declined by 113 MtCO_{2e} from 1990 to 2014, a 21% reduction. The decline has been a result of a decrease in livestock numbers, in fertiliser application and improved manure management[5]. These changes have come about largely as a result of productivity increases per unit area as well as developments in and implementation of agricultural and environmental policies (e.g. the Nitrates directive). The pace of reduction has slowed in the last decade, with EU-28 agriculture GHG emissions decreasing by 16% in the period 1990 to 2000 and by 9.3% between 2000 and 2014[6]. During the period since 2005, the share of agriculture in overall EU GHG emissions has increased, reflecting the emission

[2] Matthews A (2016) *Mitigation potential in EU agriculture*. Blog article. http://capreform.eu/mitigation-potential-in-eu-agriculture/ Accessed 3 October, 2016

[3] see Table 2 in Hart K, Allen B, Keenleyside C, Nanni S, Maréchal A, Paquel K, Nesbit M and Ziemann J (2017) *The consequences of climate change for EU agriculture. Follow-up to the COP21 - UN Paris climate change conference*. European Parliament, Brussels.

[4] Underwood E and Tucker G M (2016) Ecological Focus Area choices and their potential impacts on biodiversity. Institute for European Environmental Policy, London

[5] http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_-_greenhouse_gas_emission_statistics

[6] EEA (2016), Annual European Union greenhouse gas inventory 1990–2014 and inventory report. 2016 Submission to the UNFCCC Secretariat. EEA Report No 15/2016. European Environment Agency; and CAP Context indicator 45 https://ec.europa.eu/agriculture/sites/agriculture/files/cap-indicators/context/2016/c45_en.pdf

reductions in other sectors and, since 2012, an increase in overall agriculture emissions (as reported by European Environment Agency (EEA).

Mitigation projections for the agriculture sector

Almost all of the EU-wide research on agriculture GHG emission reductions reviewed in this study involves projections or impact analyses, rather than pure mitigation potentials. These include the impact assessments accompanying the proposal for new EU climate policies (such as the proposed ESR and LULUCF Regulations) as well as exploratory studies looking at the different actions and their mitigation potential on the ground. Only one (Martineau et al, 2016) assesses the mitigation potential of different mitigation actions, but still does not go as far as assessing the aggregated potential of these actions at the EU level. As consequence, there is a lack of evidence on the true mitigation potential of the agriculture sector as a whole.

There remain many uncertainties in the potential for mitigation within the agriculture sector. The studies reviewed show mitigation projections (not potentials) of between 2.4% and 25% depending on the supporting conditions and the level of impacts accepted on production, third country imports and cost to consumers etc. These projections show clearly the agriculture sector can contribute significantly towards the EU's climate mitigation efforts, but that support for implementing mitigation activities is necessary when trying to influence the choices of millions of EU farmers.

Mitigation projections and impacts for agriculture non-CO_2 GHGs vary considerably and are highly influenced by economic drivers and the way in which model estimates are generated. The influence of economic growth and fossil fuel prices shows the fragility of the assessments made in the reference scenarios. The revisions to the 2013 baseline to bring it up to date for 2016 included reductions in the projected economic growth in the EU and increases in oil and gas prices[7]. This resulted in a 4% decrease in total projected emissions without any additional mitigation effort from any sector.

The cost of mitigation actions in projection models in the sector is heavily influenced by the carbon price calculated by or inputted to the modelling framework and how this interacts with other targets. For example a carbon price of €0.05/tCO_2eq and an energy efficiency target of 27% is projected in EUCO27 to lead to a reduction in agriculture non-CO_2 emissions of 8.1%[8]. However in practice, the expected choices made by farmers and land managers vary in response to whether or not they are supported in their climate mitigation efforts. In addition to the level of support, the choices of farmers and land managers across the EU are influenced heavily by other factors, such as the investment capacity of farms, farmers' knowledge and information, simplicity and flexibility of the technology, etc.[9]. All these are either difficult to or cannot be modelled and therefore are challenging to assess, and explains why model projections should be treated with care.

Mitigation actions and potential for the EU agricultural sector

The projections for agriculture non-CO_2 emission reductions vary in part as a result of the assumed applicability and uptake of different mitigation actions. Mitigation activities are wide ranging but generally aim to reduce the anthropogenic causes of GHG emissions in the sector, such as the loss of N_2O from soils as a result of leaving them bare between rotations, or reducing emissions from enteric fermentation in ruminant livestock. Other mitigation actions available to the land using sectors not assessed by this study include those that actively remove carbon from the atmosphere and sequester it in soils and biomass (primarily CO_2). Mitigation potential is expected to evolve over time, as new technology is made available, or becomes more affordable.

[7] This latter point having primarily an impact on CO_2 emissions from the ESD sectors.

[8] own calculation based on Appendix II.a (EU28 table) of E3MLab and IIASA (2016)

[9] e.g. farm size, applicability or appropriateness to the farm's conditions/production system, farmer's planning horizon, unwillingness to adopt technology, lack of information, etc.

Considering only those actions that address non-CO_2 gases[10], the largest abatement potentials for each % point of additional uptake in the EU have been estimated to relate to the following actions[11]:

- Crop production:
  - Use of cover/catch crops (1,100 – 1,900 kt CO_2eq/yr/%uptake);
- Nutrient and soil management:
  - Biological nitrogen (N) fixation in rotations and in grass mixes (1,400 – 2,900 kt CO_2 eq/yr/%uptake);
  - Use of nitrification inhibitors (470 – 1,400 kt CO_2 eq/yr/%uptake);
- Livestock production:
  - Livestock disease management (23-230 ktCO_2 eq/yr/%uptake)
  - Feed additives for ruminant diets (37-55 ktCO_2 eq/yr/%uptake)
- Other:
  - Carbon auditing tools (for both CO_2 & non-CO_2 emissions) (470 – 940 kt CO_2 eq/yr/%uptake)

Uncertainties relating to uptake and use of individual actions makes the bottom-up aggregation of overall potentials within the sector subject to high levels of uncertainty. This is also linked to the effectiveness of the mitigation action, which depends upon factors such as current farm practice, the bio geographical context and how the measure is implemented.

The cost of mitigation actions and the impact they have on production are also important considerations in relation to their likely uptake and therefore overall potential. Some mitigation actions will be low cost and therefore could be adopted by farmers without significant investment or impact on production (e.g. biological N fixation in rotation and grass mixes). Some will have a cost but result in either production gains, reduction in input costs or generate new revenue streams (e.g. livestock disease management or anaerobic digestion). Others will have high upfront costs that are not necessarily rewarded by gains in production or other cost savings or income generation (e.g. conversion of arable land into grassland).

Climate mitigation actions can achieve environmental co-benefits provided they are implemented in a way that is complementary to broader environmental goals. Many of the mitigation actions reviewed have important co-benefits, both in relation to gross margins and environmental gains. The increased efficiency in the use of fertilisers through introducing nitrogen fixing crops into a rotation can deliver cost gains and benefit the environment (under specific conditions), as well as delivering significant mitigation benefits. However, these win-win-win approaches can require changes in production methods on the part of an individual farmer, which can often be perceived as an unnecessary risk where the benefits of the change for the farm business will only become visible over the long term, and profits are already considered reasonable.

The influence of individual choices is significant. Unlike many other sectors, promoting climate mitigation actions in agriculture relies on the adoption of actions by millions of individuals and small businesses. This is akin to reducing transport emissions by trying to influence individual car drivers as opposed to a more limited set of fuel suppliers or car manufacturers. Support and information awareness raising to farmers is therefore essential to engage farmers in climate mitigation actions and help deliver a range of environmental and economic co-benefits.

Policy instruments

The main policy that directly influences management decisions made in the agriculture sector is the CAP. Climate action now forms one of the three core objectives of the CAP across both Pillars: viable food production; ***sustainable management of natural resources and climate action***; and balanced territorial development. The mainstreaming of climate priorities within the CAP has been helped by the commitment

[10] We excluded "Preventing deforestation and removal of farmland trees", "Conversion of arable land to grassland to sequester carbon in the soil" and "Woodland planting" because even though they have a positive impact on non-CO2 emissions, this is only due to a change in land use – from arable land to forestry or to grassland. They are a special case in that emission reductions are obtained through not having arable land anymore.

[11] The potentials indicated provide a means of comparison between mitigation actions, but include caveats.

under the Multiannual Financial Framework (MFF) for the period 2014-2020 to devote at least 20 % of the Union budget to support for climate change objectives. However the CAP's contribution to this target has been criticized as overestimating the likely scale of climate expenditure in practice.

Most of the mitigation actions described in this report can already be supported via the CAP. However, relatively few are compulsory, with discretion given to Member States on what and how they choose to implement these activities, how they design the detailed rules, definitions and support measures. As such CAP measures can help support the adoption of climate mitigation actions by farmers but they are not always deployed in a way that promotes a widespread uptake[12].

Multi-annual commitments are important when addressing emission reductions that can take multiple years to realise in practice. Support provided under the CAP's Rural Development Programmes (RDPs) is therefore important in this regard, and climate mitigation actions can be supported through commitments under the agri-environment-climate measure (e.g. the appropriate management of soils), the organic farming measure (e.g. by reducing the use of mineral fertilisers), as well as through up-front capital investments, where required for climate action. The cooperation, capacity building and information and advice measures are also relevant.

Beyond policy incentives or regulatory targets, farmers respond to the market, which in turn is influenced by consumer trends. Labelling can be an important tool to help consumers understand better the climate impact (positive and negative) of the products they purchase which can help stimulate demand for climate friendly and more environmentally sustainable produce. This could also enable farmers to access new markets with potential price premiums, providing additional stimulus for climate action in the sector.

Other policies and strategies that influence climate mitigation in agriculture in a more indirect way include globally binding agreements, such as the Kyoto Protocol (to 2020) and the Paris Agreement (to 2030) – which in the EU led to the introduction of the Emission Trading System, the Effort Sharing Decision (and the proposed Regulation) and the LULUCF proposal; long term strategies, such as the EU's low carbon roadmap; climate and energy policy, such as the Renewable Energy Directive (RED); and sector strategies, such as the Circular Economy Action Plan and Bioeconomy strategy. These policies and strategies help support or provide regulatory incentives to undertake climate mitigation activities in the agriculture sector in the short term.

In 2016 the European Commission introduced the winter package of proposals for a clean energy transition in Europe. This includes a variety of proposed updates to existing legislation, such as revisions to the Renewable Energy Directive, as well as setting out a new proposed Governance Regulation (COM(2016) 759 final/2). Article 14 of the proposed Regulation requires Member States to prepare and report to the Commission their long-term emission strategies with a 50-year perspective to contribute to emission reduction and removals within the Union. Specifically for ESD sectors this includes the requirement for a long-term low emission strategy to cover: emissions reductions and enhancement of removals in individual sectors including electricity, industry, transport, the buildings sector (residential and tertiary), agriculture as well as land use, land-use change and forestry. Having a long-term plan for emission reductions in the ESD sectors will be useful to help frame the contribution necessary from agriculture and what level of removals are expected in the wider land-using sectors. However, without specific targets for the sector, there is a risk that ambition will remain limited given the reticence by many Member States, farmer and landowner organisations for a more targeted approach to mitigation in the agriculture sector.

[12] Martineau et al (2016)

Introduction

This study examines the potential contribution that the agriculture sector could make to climate mitigation efforts in the EU through the proposed Effort Sharing Regulation (ESR). It was commissioned by Transport and Environment in the context of developing understanding on the role the non-Emission Trading System (non-ETS) sectors[13] could play in climate mitigation efforts in the EU.

The study begins with a brief description of the EU's agriculture sector and its contribution to economy wide emissions. The specific focus of this work is those emissions and mitigation actions in the agriculture sector that are covered by the current Effort Sharing Decision (ESD[14]) and the proposed ESR[15]. These include the non-CO_2 greenhouse gas (GHG) emissions comprising primarily of nitrous oxide (N_2O) and methane (CH_4). It explicitly does not aim to cover the mitigation actions associated with CO_2 emission reductions and removals from the Land Use, Land Use Change and Forestry (LULUCF) sectors[16], other than where these are relevant to the discussion or included within mitigation activities and model estimates in the studies reviewed. Mitigation activities and mitigation potential are described primarily in the 2030 time horizon (where relevant) with respect to the proposed ESR, and in 2050 in relation to the roadmap to a low carbon economy that sets the longer-term emission mitigation trajectory in the EU.

The report is structured as follows:

- Chapter 1 of the report provides the context to the report, describing the general agricultural context in the EU, agricultural non-CO_2 GHG emissions and their sources and the EU policies that have an influence on mitigation efforts within the agricultural sector.
- Chapter 2 describes the various mitigation projections and potentials that have been estimated at the EU level, including the different approaches taken and a summary of agricultural mitigation projections from three key studies.
- Chapter 3 considers a range of specific mitigation actions relevant to the EU agriculture sector and their potential to reduce GHG emissions. It reviews the literature assessing the emission abatement potential of different actions and the challenges and opportunities for implementation.
- The report concludes (Chapter 4) with a discussion on the projections and mitigation actions, highlighting the potential role of the agriculture sector in the EU in reducing non-CO_2 emissions via the ESR. It discusses the key policy instruments available to promote and enable mitigation activity in the sector.

[13] Sectors not covered by the EU Emissions Trading System (ETS), i.e. sectors falling in the scope of the Effort Sharing Decision (ESD) and the proposed Effort Sharing Regulation (ESR).

[14] Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020

[15] COM/2016/482 - Proposal for a Regulation on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 for a resilient Energy Union and to meet commitments under the Paris Agreement and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change.

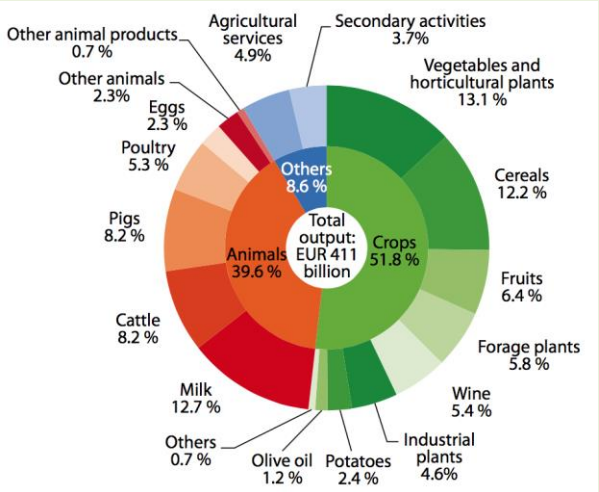
[16] Decision No 529/2013/EU of the European Parliament and of the Council on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land use, land-use change and forestry and on information concerning actions relating to those activities

1 Agriculture and climate mitigation in the EU

1.1 The agriculture sector in the EU

The EU's agriculture sector is diverse reflecting the environmental (climate and geographical) and cultural diversity of Member States. Agriculture is composed of various sub-sectors including the production and use of animals, such as the livestock (e.g. cattle, pigs and poultry) and dairy sectors; the production and use of crops (e.g. cereals and vegetables); as well as permanent and tree crops, such as olives, fruit and vines. The agriculture sector as a whole is responsible for the management of over 40% of the EU's land area, including both farmed land as well as the management of semi-natural habitats. In this way it is responsible for the production of a range of ecosystem services that benefit society beyond food and fibre production, such as the provision of clean water, biodiversity, cultural landscapes, prevention of soil erosion and degradation and air quality.

Figure 1: % total output of the agriculture industry in the EU-28 (2015)



Source: Eurostat, 2017

Agriculture delivers a total economic output of €411bn, with a gross value added (GVA) to the EU of €164.7bn[17], with France, Italy, Germany and Spain being the largest producers (Eurostat, 2017). The production of crops represents the largest contribution to GVA at 51.8% (Figure 1). Agriculture, alongside forestry and fishing, represent ~1.5% of total EU GVA in 2015, the lowest of all sectors[18].

Intermediate consumption[19] accounts for the difference between total output and GVA. Intermediates account for ~20.7% of the production value of crops (seeds and plantings, fertilisers, and plant protection products), whereas intermediates for livestock (feed and vet expenses) account for 59.5 %.

Within the EU-28 there are approximately 10.8 million farms[20] (2013 figures), with approximately 46% of all farms located in Romania and Poland (3.6 million and 1.4 million respectively) where farm sizes are typically smaller than in other regions.

Woodland and trees are a common feature of the EU's agricultural landscape and range from the traditional agro-forestry systems of the dehesas and montados of Spain and Portugal, to the network of hedgerows and trees seen in parts of central and northern Europe. Agriculture (including agro-forestry and individual or small groups of trees in the agricultural landscape) accounts for 41% of the EU's land area, whereas forests and other wooded land account for a slightly higher 43% (Eurostat, 2017). The relationship between agriculture and forestry is complex, and often farms include areas of woodland or forest within their management. This is reflected in the Common Agricultural Policy (CAP), which provides support to manage forests as well as agricultural land types, such as cropland (including permanent crops) and grassland.

[17] Once intermediate consumption and input costs have been accounted for.

[18] **Source:** Eurostat nama_10_a10

[19] Purchases made by farmers for raw and auxiliary materials that are used as inputs for crop and animal production; including expenditure on veterinary services, repairs and maintenance, and other services.

[20] Source – Eurostat ef_kvaareg

1.2 Accounting for agriculture's GHG emissions in the EU

Agriculture, alongside other land use sectors, produce both carbon dioxide (CO_2) and non-CO_2 emissions, as well as having the potential to remove GHG emissions from the atmosphere in the form of CO_2 sequestration. Emissions arise both from anthropogenic and biological processes and this increases the degree of uncertainty of agricultural emissions estimates. Those non-CO_2 emissions (primarily methane and nitrous oxide) are accounted under the ESD or proposed ESR, whereas CO_2 emissions and removals from land use are covered by the LULUCF Decision which accounts for cropland and grazing land management (from 2021), as well as activities that result in land use change, such as afforestation. From a land use perspective, 'non-CO_2' and 'CO_2' emissions are very much interlinked and where necessary, this report makes reference to LULUCF emissions/removals on agricultural land. Additional (primarily CO_2) emissions arising from energy use in agriculture (e.g. fuels used in grain drying, horticultural greenhouses or in traction vehicles) are also reported under the ESD. Table 1 shows the difference gases and sectors covered by the three EU climate reporting frameworks, including the EU ETS, which does not cover agriculture directly.

Table 1: Coverage of GHGs and sectors by the three EU climate reporting frameworks

MECHANISM	GHGS COVERED	RELEVANCE TO AGRICULTURE	SECTORS
Effort Sharing Decision (ESD)	All GHGs covered by Kyoto (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) with targets based on CO_2 equivalence. NF_3 not included in ESD despite introduction under Kyoto second commitment period.	Non-CO_2 emissions from agriculture and CO_2 emissions from energy use in agriculture • Explicitly excludes emissions from land use, land use change and forestry (LULUCF)	• Energy supply (not generation) • Industrial processes • Transport energy use (excluding international maritime shipping and aviation), **including agricultural transport and other energy uses** • Buildings (household energy use) • Services and small industrial installations • **Agriculture** • Waste
Land Use, Land Use Change and Forestry (LULUCF) Decision	Reporting and accounting on selected GHG emissions relevant to Kyoto reporting requirements - CO_2, CH_4, and N_2O.	Primarily CO_2 emissions from cropland and grazing land management.	• **For each accounting period:** emissions from afforestation, reforestation, deforestation and forest management (since 1990). Member States may also prepare and maintain accounts to reflect emissions and removals resulting from re-vegetation and wetland drainage and rewetting. Reporting only on cropland & grazing land management and preparation for accounting from 2021. • **From 2021:** Cropland & grazing land management accounting
Emissions Trading System (ETS)	• Carbon dioxide (CO_2) • Methane (CH_4) • Nitrous Oxide (N_2O) • Hydrofluorocarbons (HFCs) • Perfluorocarbons (PFCs) • Sulphur Hexafluoride (SF_6)	CO_2 and N_2O emissions from the production of nitric acids and ammonia used in the manufacture of fertilisers. • Bioenergy facilities with potential to use agriculturally produced biomass. • Zero carbon rating of biomass at point of collection	• Power and heat generation • Energy-intensive industry sectors including oil refineries, steel works and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, **acids, ammonia** and bulk organic chemicals • Civil aviation

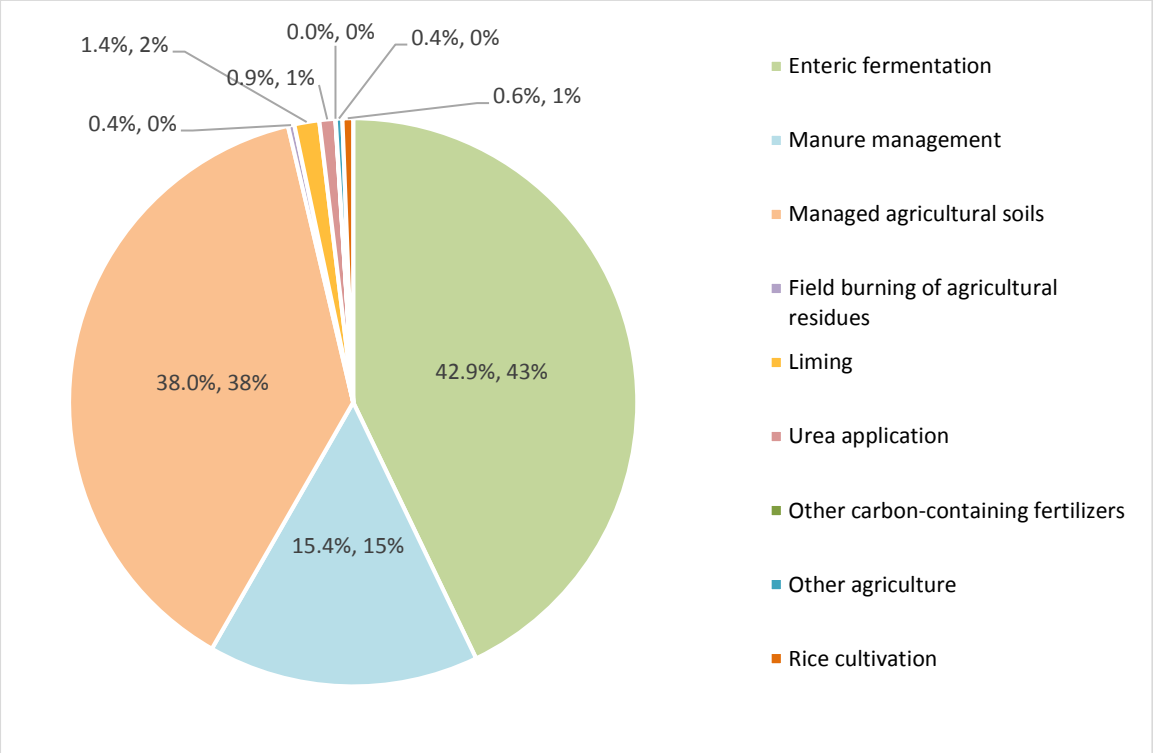
Source: own compilation based on Hart et al, 2017

The current EU accounting framework focuses on emissions arising within the Community and therefore does not take into account indirect emissions, such as those arising from agricultural production associated with imported animal feed.

1.3 Agriculture GHG emissions in the EU

This study focuses on those emissions reported under the ESD and proposed ESR and are referred to in this report as 'agricultural emissions'. In the EU, the latest available data (2014) show that agricultural emissions are the fifth largest contributor to GHG emissions (11.3%; 514.1MtCO_{2e}), after the energy, transport, industry, residential and commercial sectors[21]. As shown in Figure 2, emission contributions from agriculture arise primarily from three sources: enteric fermentation[22] (42.9%; 186.8 MtCO_{2e}); management of agricultural soils [23] (38.0%; 165.7 MtCO_{2e}); and manure management[24] (15.4%; 67.1 MtCO_{2e}).

Figure 2: Agricultural GHG emissions by IPCC source in 2014



Source: EEA (aei_pr_ghg)

Agricultural GHG emissions arise largely from non-CO_2 GHGs, primarily nitrous oxide (N_2O) which accounts for 58% of non-CO_2 emissions from agriculture (largely from nitrification and de-nitrification processes taking place as a result of fertiliser application, manure management as well as other biological processes from exposed soils,); and methane (CH_4) 42% (largely from livestock digestion, manure management and rice cultivation). Only a minor share of agricultural emissions

[21] **Source:** National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism provided by Directorate-General for Climate Action (DG-CLIMA). http://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment. This figure includes fuel used in agriculture. Emissions from agriculture excluding fuel use accounted for 435.74 MtCO2e in 2014 (or 9.9% of all GHG emissions in the EU).

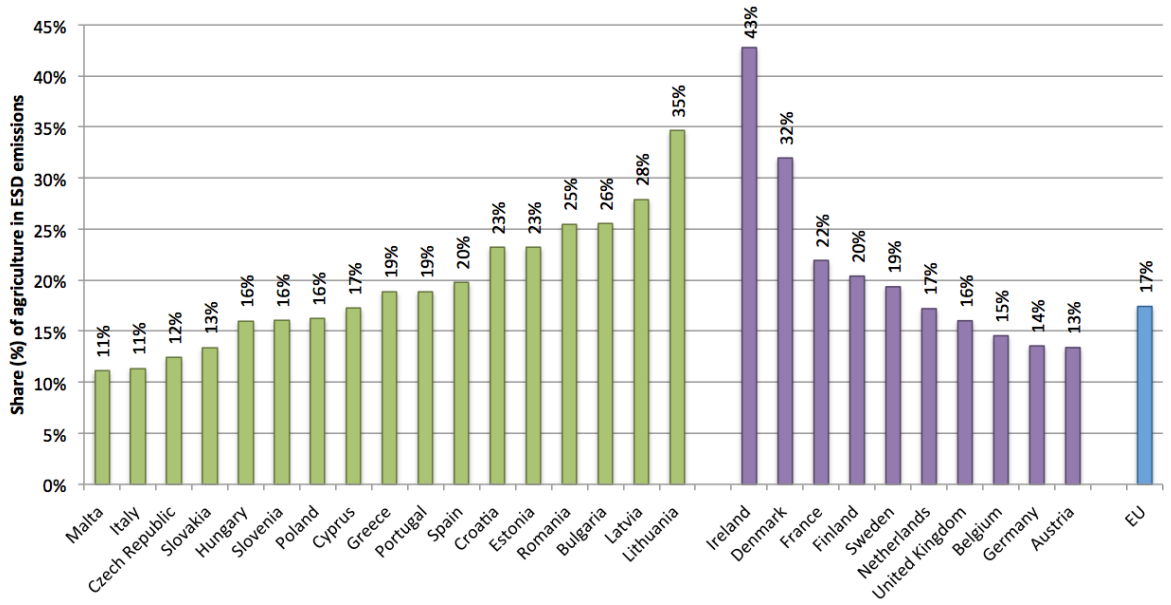
[22] The process of digestion of carbohydrates by ruminant animals, such as cattle, sheep, goats or deer.

[23] Agricultural soil emissions are mainly due to nitrification and de-nitrification processes, which produce nitrous oxide (N_2O) emissions.

[24] The process of manure decomposition, which produces methane and nitrous oxide emissions.

reported under the ESR are CO_2 emissions compared to non-CO_2 gases and arise as part of field burning of agricultural residues, liming and urea application. The proportion of non-CO_2 GHG emissions from agriculture at the EU level masks considerable differences between Member States. As a proportion of national GHG emissions the contribution is highest in Ireland (32.2%; 18.7MtCO_{2e}) and lowest in Malta (3%; 0.088 MtCO_{2e}). In absolute terms, the greatest contribution of GHG emissions from the agriculture sector to the EU total comes from France (18%; 79 MtCO_{2e}), Germany (15%; 66.1 MtCO_{2e}) and the United Kingdom (10%; 44.6 MtCO_{2e}). Together these three Member States account for just less than 44% of total EU-28 agriculture emissions. Figure 3 shows the share of agricultural non-CO_2 GHG emissions covered by the ESD for EU Member States.

Figure 3: Share (%) of projected agriculture in ESD emissions in 2015



Source: Hart et al, 2017, based on EEA, 2015. **Note:** Green bars represent Member States with GDP lower than the EU Average. Purple bars represent Member States with GDP higher than the EU average.

Agricultural emissions are associated with a range of anthropogenic activities[25] but also with biological processes that naturally emit GHGs and which are influenced by weather, climate, and other natural processes. Uncertainty about the magnitude of emissions is therefore more pronounced in agriculture than in industrial sectors and for the same management activity, net emissions may vary in diverse agronomic, biophysical, environmental and climatic situations (Underwood et al, 2013). In addition, the land using sectors (including agriculture) have a more complex relationship with GHG emissions in that they can lead to removals of GHG emissions from the atmosphere through the sequestration of CO_2 in soils and biomass.

In the EU, the overall level of non-CO_2 agriculture emissions has fallen by 113 MtCO_{2e} from 1990 to 2014, a 21% reduction. This decline is attributable to a decrease in livestock numbers over the same period as well as decreases in fertiliser application and through improved manure management[26]. This is a result of productivity increases per unit area as well as improvements in farm management practices, particularly with respect to fertiliser use and the developments in and implementation of agricultural and environmental policies (e.g. the Nitrates directive). The pace of reduction has slowed in the last decade, with EU-28 agriculture GHG emissions decreasing by 16% in the period 1990 to 2000 and by 9.3% between 2000 and 2014 (EEA, 2016 and CAP Context indicator 45[27]).

[25] see Table 2 in Hart et al, 2017

[26] http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_-_greenhouse_gas_emission_statistics

[27] https://ec.europa.eu/agriculture/sites/agriculture/files/cap-indicators/context/2016/c45_en.pdf

During the period since 2005, the share of agriculture in overall EU GHG emissions has increased, reflecting the emission reductions in other sectors and since 2012 an increase in overall agriculture emissions (as reported by European Environment Agency (EEA[28]).

[28] Greenhouse gas emissions from agriculture – EEA - aei_pr_ghg

2 Mitigation projections for the EU agricultural sector

KEY FINDINGS

- ***The agriculture sector can contribute significantly towards the EU's climate mitigation efforts, yet there remain many uncertainties in the precise level of this mitigation potential.*** The studies reviewed show mitigation projections (*not potentials*) of between 2.4% and 25% depending on the supporting conditions and the level of impacts projected as being acceptable within the models on production, third country imports and cost to consumers, etc.
- ***The overall level of mitigation projected in the sector is highly influenced by the inputs to the models.*** These include broad economic drivers such as economic growth projections or fossil fuel prices that can change mitigation projections without any action in the sector; as well as the level of pre-set mitigation targets, associated energy efficiency targets, etc. For example some limited policy support (as modelled through a carbon price of €0.05/tCO_{2e}) and an energy efficiency target of 27% (as projected in EUCO27) leads to a reduction in agriculture non-CO_2 emissions by 8.1%* (or 5.7% above business as usual). Where energy efficiency requirements are increased to 30% (EUCO30) and public support is absent (in this scenario the carbon price is €0tCO_{2e}), the contribution from agriculture is not projected to go above business as usual (2.4% as in Ref2016). [*own calculation based on Appendix II.a (EU28 table) of E3MLab and IIASA (2016)]
- ***The existing studies reviewed in this report do not provide the information to support the widely held view that mitigation in agriculture is (or is not) more technically challenging or more cost-ineffective compared to other ESD sectors, particularly when environmental co-benefits are considered.*** The studies do show however that there are potentially significant impacts on production for some actions that should be balanced with mitigation effort and overall impact on GHG emissions.
- ***The high degree of influence of economic drivers in the modelling studies suggests that financial support to farmers is necessary to trigger mitigation action.*** In general terms, the greater the level of support and greater freedom offered to farmers to choose the mitigation activity most suited to their specific situation, the greater the mitigation impact is seen in the model assessments. For example, in the EcAMPA studies the total cost of subsidy per unit of CO_{2e} mitigated is the highest in the scenario with no specific mitigation target imposed. This results in a projected mitigation impact of 11% reduction in GHG emissions with only 1% coming from reduction in production. This impact on production is the lowest of any scenario and as such, has the lowest leakage effects to third countries, giving what could be considered a more realistic picture of the cost of mitigation activities within the EU, with the caveat that these are modelled rather than actual mitigation costs.
- ***The implication for public support for mitigation impact in the agriculture sector appears to be high, particularly if production impacts are to be avoided.***
- ***In practice, the choices of farmers and land managers across the EU are influenced heavily by other factors,*** such as the investment capacity of farms, farmers' knowledge and information, simplicity and flexibility of the technology, willingness to invest, etc. All these are either difficult or not possible to model are therefore challenging to assess and explains why model projections should be treated with care.
- ***Models do provide a useful tool to assess the influence of different drivers on a given objective but often lack the sophistication and underlying data on which to assess mitigation potentials.*** As such these approaches do not allow for a greater understanding of what the sector could potentially deliver under different conditions of support or via implementation of a given set of mitigation actions for a given price. Neither do they assess what is cost effective when including the potential benefits to the sector that could come from climate action, such as efficiency gains or mitigation actions that can deliver co-benefits such as improvements in water quality, biodiversity or soil quality (and therefore increased compliance, in particular with environmental legislation).
-

This chapter considers the different mitigation projections carried out for the agriculture sector to 2030 and reviews the assumptions made in those assessments and what this means for understanding the potential climate mitigation contribution of agriculture in the ESR.

2.1 Introduction

The potential role of the agriculture sector in contributing towards the EU's climate mitigation efforts has been examined in a number of different studies and modelling exercises. These include the Impact Assessments accompanying the proposals for an Effort Sharing Regulation (SWD(2016) 247 final) and for a Regulation on LULUCF (SWD(2016) 249 final) as well as exploratory studies looking at the different actions and their mitigation potential on the ground. While the focus of this report is on agriculture emissions reported under the ESR, the LULUCF Impact Assessment (focused primarily on CO_2 emissions) is included in our analysis as it considers in detail the potential flexibility needed between LULUCF and ESR accounting and thus includes some indications of the potential for non-CO_2 emission reductions in the sector.

Almost all of the EU-wide research on agriculture GHG emission reductions reviewed in this study involves either *projections* or *impact* analyses (Box 1), rather than pure mitigation potentials. Only one (Martineau et al, 2016 – discussed in section 3) assesses the mitigation potential of different mitigation actions, but still does not go as far as assessing the aggregated potential of these actions at the EU level. As consequence, there is a lack of evidence on the true mitigation potential of the agriculture sector as a whole.

Box 1: Understanding mitigation studies

In understanding mitigation studies, it is important to distinguish what each study or scenario aims to do. Some studies consider emission reduction potentials, some focus on projections, and others look at impacts of mitigation targets.

- An emission reduction ***potential*** is one where the possible contribution of a sector(s) to GHG emission reductions is determined on the basis of the approaches available to the sector[29] and the likelihood that they will be adopted under certain conditions. These approaches are then combined to produce aggregate estimates of mitigation potential. Here it is common to see technical, economic or market potentials[30] cited in relation to whether they are technologically possible, cost efficient, or likely to be adopted in reality.

- An emission reduction ***projection*** takes a similar approach, but rather than look at the *potential* of the different activities within a sector to deliver emission reductions, these studies set a series of parameters (such as expected technology development, future production levels, and likely uptake by policy or individuals) and project the mitigation level with an assumed set of mitigation activities allowed to develop in a known policy context[31]. Projections are what form the baseline or business as usual scenarios in most impact assessments.

- The final set of studies consider the ***impacts*** of a policy or policy target on a given sector or objective. In this case, the emissions reduction level is usually determined in advance (in the form of a target) in order to see what *impact* it will have on a sector.

Put more simply *potential* and *projection* studies look to the future and identify what could happen in a possible future (*potential*) and what is expected to happen (*projection*) in a defined future. Whereas *impact* studies look at the effect of realising a given level of mitigation ambition on the economy and sectors involved.

[29] Which could include behavioral change, technology development or adoption, etc.

[30] Technical potential + without economic or socio-cultural constraints; Economic potential = technically feasible and within reasonable economic constraints, such as a carbon price; Market potential = taking into account both technical and economic limits and combining these with policy incentives, cultural, institutional, and other factors.

[31] For example with the existing climate, energy and agriculture policies continuing to operate to 2030 linked to expected changes in technology, population changes, efficiency increases etc.

Source: own compilation

In the following sections we explore the different approaches taken in some of the key studies to calculate emission reductions in the agriculture sector and explain how the different mitigation projections for the agriculture sector have been determined. These include: the EU 2016 reference scenario (section 2.2); the projections based on the EUCO27 and EUCO30 European Council scenarios (section 2.3); and, the EcAMPA 2 study by the JRC (section 2.4). Table 2 below provides a summary of the mitigation projections reviewed from these studies.

Table 2: Summary of mitigation projections and enabling conditions identified

Study	Agricultural GHG non-CO_2 emissions reduction (in 2030, compared to 2005 levels)	Enabling conditions specific to agriculture	Impacts for the agricultural sector
Reference scenario 2016 (Ref2016)	2.4% (-10.66 $MtCO_{2e}$)	No policy support other than policies existing in 2014 (projections under 'business-as-usual' scenario).	Emissions reduction is low - Only win-win solutions are adopted as a result of projected trends.
European Council scenario EUCO27 Using Ref2016	8.1% (-35.95 $MtCO_{2e}$)	Very limited policy support other than policies existing in 2014 (equivalent to a €0.05/tCO_{2e}. carbon price).	Emissions reduction level is low/moderate – Win-win solutions are accompanied by some policy incentive to mainstream their adoption.
European Council scenario EUCO30 Using Ref2016	2.4% (-10.66 $MtCO_{2e}$)	No policy support other than policies existing in 2014.	Emissions reduction level is low - Only win-win solutions are adopted as a result of projected trends. The ESR emission target is met through increased energy efficiency and no contribution from the agricultural sector.
EcAMPA 2 (JRC)	-11.4% to -25%	**Various:** Voluntary / Mandatory choice of mitigation actions; Support for implementation up to 80% of mitigation costs.	**Various:** Production impacts where mitigation is not supported by subsidies; Cost impacts to EU budget as a result of subsidised support.

Source: Own compilation **Note:** the first three studies presented here represent projections of what could be achieved in the sector given specific constraints. The last study (EcAMPA2) provides both projected emission reduction figures (based again on a given set of constraints) and shows the impact of a fixed set of target reduction potentials (15, 20, 25%).

2.2 EU Reference Scenario 2016

The **EU Reference Scenario 2016 (Ref2016)** provides the baseline projection[32] from which impacts on the agriculture (and other) sector(s) are determined in relation to informing the proposals for the future Effort Sharing and LULUCF Regulations.

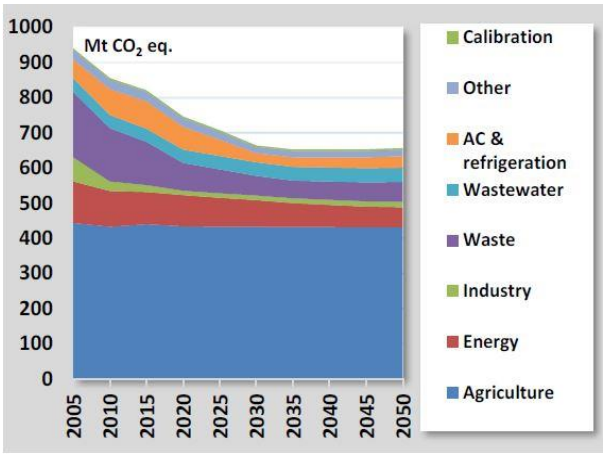
Ref2016[33] includes the effect of all EU and Member State policies adopted to implement the ESD with a cut-off date of December 2014, but assumes no new policies are adopted for the period 2021-2030. For agriculture, Ref2016 projects that the EU will achieve its ESD target by 2020. However, in doing so, non-CO_2 agricultural emissions are expected to decline by only 2.1% (9.27 $MtCO_{2e}$) by 2020 and by 2.4% (10.66 $MtCO_{2e}$) by 2030 compared to 2005. This is significantly more limited than the

[32] Based on a model-derived simulation of the GHG emissions in different sectors, with a focus on energy and transport.

[33] Ref2016 is an update from the Ref2013 scenario used in the Impact Assessment of the 2030 climate and energy package in 2014 (*SWD(2014) 15 final*).The revisions to the 2013 baseline to bring it up to date (becoming Ref2016) and included reductions in the projected economic growth in the EU and increases in oil and gas prices[33]. It is worth noting that this resulted in a 4% decrease in total projected emissions without any additional mitigation effort from any sector. This is significant compared to the 2.1% reduction foreseen in Ref2016 for agricultural non-CO_2 emissions. The influence of economic growth and fossil fuel prices shows the fragility of the assessments made in the reference scenarios.

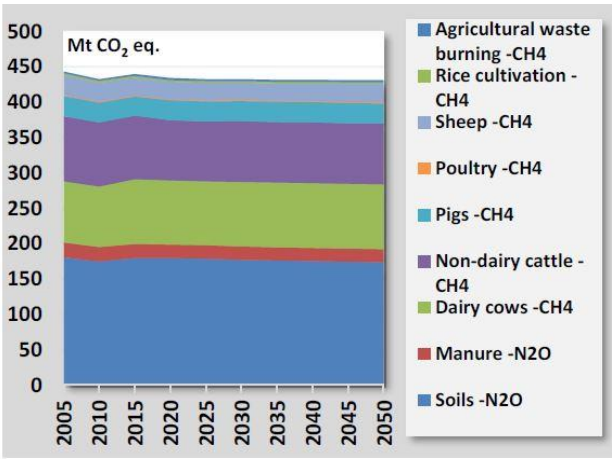
expected reductions of other ESD (and non ESD) sectors, with existing measures (Figure 4). The rough stabilisation of agriculture emissions to 2030 is projected to be as a result of compensatory trends in the sector such as greater production output mitigated by increased efficiency per unit of production (*SWD(2016) 247 final*). Figure 4 and Figure 5 also shows that, despite significant reductions between 1990 and 2005, since 2005, there appears to have been limited further action taken in the agricultural sector to reduce emissions contributing to the ESD target.

Figure 4: 2016 EU Reference scenario projections for non-CO_2 emissions to 2030, by sector.



Source: (*SWD(2016) 247 final*), Annex 8.4

Figure 5: 2016 EU-28 Reference scenario projections for non-CO_2 emissions, Agriculture



Source: European Commission, 2016

2.3 Scenarios EUCO27 and EUCO30 based on European Council targets

The primary purpose of these two scenarios was to determine the EU level energy efficiency targets that had been proposed by the European Council in its October 2014 conclusions for the 2030 climate and energy framework as a whole (EUCO 169/14). These included a 27% target in the EUCO27 scenario and a 30% target in the EUCO30 scenario. Both build on Ref2016, and add the 2030 emission reduction, energy efficiency, and renewable energy targets set out in the EU's Climate and Energy package, as well as a range of other targets that will influence overall mitigation efforts within the ESR sectors in the 2030 timeframe, such as increased energy efficiency in buildings or more stringent eco-design standards for motors[34].

It appears that the two scenarios seek to explore the potential to deliver the ESR target with as little impact on the agriculture sector as possible. The reason for this is that fact that the Council concluded in 2014 (EUCO 169/14) that "*the multiple objectives of the agriculture and land use sector, with their lower mitigation potential, should be acknowledged, as well as the need to ensure coherence between the EU's food security and climate change objectives*", inviting the Commission to "examine the best means of encouraging the sustainable intensification of food production, while optimising the sector's contribution to greenhouse gas mitigation and sequestration, including through afforestation". The Impact Assessment scenarios (EUCO27 and EUCO30) therefore interpret the Council's conclusions and seek to model different options to achieve GHG emission reductions that minimise impacts on agricultural production.

[34] The two scenarios have the same targets for GHG reduction and renewables (at least -40% GHG reduction target (with the split ETS/non-ETS reducing by -43%/-30% in 2030 compared to 2005); and a 27% share of renewables), but test two different levels of energy efficiency, 27% and 30% respectively. As set out on pages 136-139 of the Impact Assessment accompanying the proposal for an Effort Sharing Regulation (SWD(2016)248 Final).

Box 2: The EUCO27 and EUCO30 mitigation scenario projections

For ***EUCO27*** an assumed carbon price* of €0.05/tCO_{2e} is applied (up to 2030) to non-CO_2 emissions across non-ETS sectors in order to trigger "cost-effective emission reductions" until 2030 in the model[35]. After 2030, the carbon price increases to that of the EU ETS. With a low carbon price to 2030, the EUCO27 projection only captures the highly cost effective actions, i.e. those actions that enable emissions reduction for a price of almost zero. These are most likely to be win-win mitigation actions, such as more efficient application of fertilisers, which provide economic and climate co-benefits alongside compliance with the EU Nitrates Directive. Despite the low carbon price the EUCO27 results show a significant agriculture non-CO_2 emission reduction projection of 8.1% (35.95 $MtCO_{2e}$) [35] in 2030 compared to 2005[36], i.e. a 5.7% reduction above the reference scenario of 2.4% reduction by 2030. This suggests that cost effective mitigation action not only is possible in the agricultural sector to 2030 but could bring about significant emission reductions, even with a low carbon price.

For ***EUCO30*** the energy efficiency target is increased to 30% but with an assumption of no policy incentives for mitigation in the agriculture sector until 2030. As such a €0/tCO_{2e} carbon price is used in the modelling framework, and thus no additional cost-effective actions are triggered in agriculture. After 2030 the projection includes the same assumptions as EUCO27 with a carbon price rising to that of the EU ETS. The increase in the energy efficiency target (and assumed sectoral response in the modelling framework) indicates that the ESR target at the EU level can be met with no further reduction in non-CO_2 emissions in the agriculture sector beyond that which would be achieved through the cost effective options that would be applied anyway under a business as usual scenario to 2030 (2.4% reduction or 10.66 $MtCO_{2e}$ (Ref2016).

Source: Own compilation **Note: *** The carbon price referred to here is a means of setting the point at which mitigation action becomes cost effective in the economy and within a given sector. This can be pre-set in a model, as is the case here, or determined as the result of a modelling process.

These model assessments suggest that cost effective mitigation action not only is possible in the agricultural sector to 2030 but could bring about significant emission reductions of around 8.1% (35.95 $MtCO_{2e}$), i.e. a 5.7% reduction above the reference scenario of 2.4% reduction by 2030. However the ambition of farmers to deliver these emission reductions will depend on the extent to which they are encouraged to, or can afford to do so in practice. This is seen through the different model scenarios in relation to the assumed 'carbon price' which affects the point at which mitigation actions become feasible in relation to the economics of agricultural production (Box 3). In practice, the greater the incentive (i.e. the higher the carbon price in the model) the greater the projected emission reductions from the sector.

Box 3: The impact of carbon price in climate mitigation models

The impact of the assumed carbon price is important in determining the mitigation potential in the agriculture sector. We have seen that EUCO27 and EUCO30 assumed carbon prices set at a very low level and zero, respectively. This is much lower than carbon prices assumptions in other sectors and it seems that one of the reasons for this is that the European Council anticipated that Member States would try to minimise the contribution of the agricultural sector to the ESD/ESR. In the Impact Assessment accompanying the 2014 Commission communication on the 2030 climate and energy package (COM(2014)15 final), a carbon price range of €11 - €40/tCO_{2e} were used to project non-CO_2 emission reductions and resulted in a range of possible reductions of non-CO_2 GHGs in the agriculture sector between 19% and 28%[37]. This is as a result of more mitigation actions becoming 'cost-effective' in theory and thus adopted in the modelling framework. Unfortunately the two impact assessments (2014 and 2016) cannot be compared directly, due to different assumptions and data used in the model runs and reference levels. However, it is useful to note that in the

[35] The carbon price is used here only as a means to stimulate a response by the model. In practice, there is no carbon price applied to ESD/ESR sectors. The carbon price of €0.05/tCO_{2e} reflects what in reality would be any policy measure/incentive encouraging the implementation of "cost-effective" mitigation actions.

[36] The 8.1% figure is the authors' own calculation based on Appendix II.a (EU28 table) of E3MLab and IIASA (2016)

[37] Based on own calculations, this is equivalent to emission reductions of 91.39 $MtCO_{2e}$ and 134.96 $MtCO_{2e}$ respectively (2005 reference level of 482 $MtCO_{2e}$).

2014 assessment, even with the inclusion of Renewable Energy targets at 35% (higher than the 27% in the 2016 scenario), and energy efficiency targets, agriculture non-CO_2 emissions are projected to reduce by a minimum of 19% (for a relatively modest carbon price of €11/tCO_{2e}.).

Source: own compilation

2.4 Projections from the EcAMPA 1 and 2 studies

The ESR and LULUCF[38] impact assessments use a limited number of scenarios in order to test the impact of different policy options across a wide range of sectors. Whilst this is useful for economy wide emission reduction targets, they lack the detail to assess the mitigation potential from the agriculture (and land using sectors) under more nuanced scenarios. Here the EcAMPA studies 1 and 2 by the JRC (Domínguez et al, 2016; Doorslaer et al, 2015) bridge this gap, providing a more detailed look at the quantitative impact of GHG mitigation policy options on agricultural emissions and their production and economic implications (EcAMPA 1).

The more recent EcAMPA 2 study looks at the impact on the agriculture sector under eight different policy scenarios where the model forces pre-set emission reduction targets (15%, 20% and 25%) for the sector. Of most interest in this report is the assessment of production and price impacts on the sector and the way in which these differ in response to whether or not the targets are incentivised through some form of financial support (i.e. allowing farmers to access new technology or adopt new approaches), whether the use of specific mitigation actions is mandatory or voluntary, or whether emission reductions are a function of a decrease in production within the EU (Figure 6).

The mitigation target is achieved in all scenarios (as a result of model optimisation) but the impacts on the sector (e.g. production changes, commodity prices) vary considerably. In all scenarios, there is generally a disproportionate impact on the livestock sector with larger decreases in production, partly as a result of higher initial emission levels and fewer available mitigation options within the timeframe of the model. Without supported or subsidised mitigation actions, a significant proportion of the target is met with a reduction in production (particularly livestock) as an assumed cost effective response from the agriculture sector. Negative impacts on production could result in carbon leakage from increased production outside the EU unless consumption patterns were to change. The greatest impacts on production are seen for those scenarios with no subsidies provided to mitigation actions and limited choice for farmers in the actions themselves) (see Figure 6).

Where mitigation action is subsidised, negative production effects can be significantly reduced. This is evident from the subsidised voluntary no-target scenario (SUB80V_noT in Figure 6 below), where mitigation actions are supported, the choice of actions is voluntary and there is no prescribed mitigation target. In this scenario it is assumed that farmers adopt the actions most suited to their farming and economic situation. It shows that production impacts can be reduced significantly[39] by subsidising (e.g. through the CAP) up to 80% of the cost of mitigation actions and allowing farmers the choice of options applied on their farm, yet still projecting a reduction in non-CO_2 GHGs from agriculture in the order of 11.4% compared to the reference scenario in the study or ~13.7% compared to 2005 figures[40].

In all other scenarios however, it should be noted that the production impacts and mitigation actions cannot be separated easily in the results, i.e. farmers may choose to adopt mitigation actions, as well as reducing activity in some areas, such as avoiding cultivation on particularly difficult fields[41]. In

[38] Mentioned here as it includes examination of the role of agriculture in climate mitigation objectives in order to determine potential flexibilities between the two accounting mechanisms.

[39] Accounting for only 1% of emission reductions in the scenario.

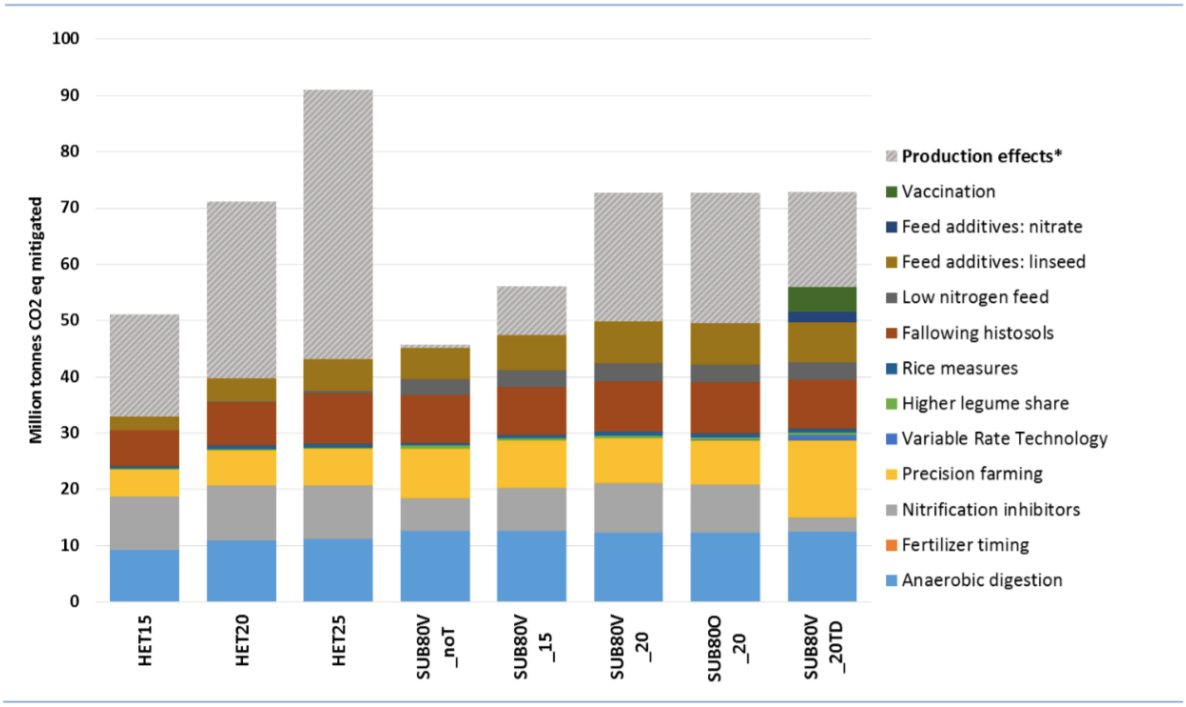
[40] See Table 20 in Domínguez et al, 2016

[41] As is observed in agriculture systems in general in response to market prices, fuel and input costs (Allen et al, 2014; Allen et al, 2015).

the EcAMPA 2 scenarios the setting of GHG emission reduction obligations for the EU agriculture sector without financial support shows important production effects. Where demand is constant, the model shows decreases in EU production to be partially offset through increases in emissions from agricultural production in third countries, due to increased EU imports, with corresponding GHG impacts at the global level. The EcAMPA 2 study predicts that this would be the case particularly for the livestock sector (mainly beef production). The carbon leakage effect has the potential to significantly diminish the net effect of EU mitigation efforts on global GHG emissions, although as noted above, will not affect the EU's achievement against its ESR target.

These impacts however are predicted to be significantly reduced with supported mitigation actions in the sector. While the estimated share of the mitigation leaked to third countries is 29% when no subsidies are provided (and a 20% target is imposed), this drops to between 19% to 14% in scenarios where mitigation actions are subsidised (Domínguez et al, 2016). Providing subsidies can lead to over achievement in some scenarios, i.e. emission reductions greater than the target emission reduction level used in the model.

Figure 6: Share of mitigation potential under different scenarios modelled in EcAMPA 2



Source: Domínguez et al, 2016 **Note:** EcAMPA 2 Scenario targets and main assumptions: **HET15**: Non-subsidised Voluntary Adoption of Technologies, with a compulsory 15% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness; **HET20**: Non-subsidised Voluntary Adoption of Technologies, with a compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness; **HET25**: Non-subsidised Voluntary Adoption of Technologies, with a compulsory 25% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness; **SUB80V_noT**: 80% Subsidised Voluntary Adoption of Technologies, No Mitigation Target; **SUB80V_15**: 80% Subsidised Voluntary Adoption of Technologies, with a Compulsory 15% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness; **SUB80V_20**: 80% Subsidised Voluntary Adoption of Technologies, with a Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness; **SUB80O_20**: 80% Subsidised Mandatory/Voluntary Adoption of Technologies, with a Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness; **SUB80V_20TD**: Subsidised Voluntary Adoption of Technologies (with more rapid technological development), with a Compulsory 20% mitigation target for EU-28 agriculture, allocated to MS according to cost-effectiveness

The EcAMPA scenarios show that mitigation in the agriculture sector is possible, as high as 11% without production or leakage impacts and up to 25% EU emission reductions (just under 15% once

leakage effects are considered), providing that supporting conditions are available, such as incentivised uptake of mitigation actions, or the freedom of farmers to choose which actions are most economically efficient given their specific circumstances. The authors do however note that the impact on public finances to provide financial support to farmers of these actions could be very high[42] although do not provide comparisons to those costs in other sectors.

[42] Ranging between €12.7 and €15.6 billion, depending on the scenarios.

3 Mitigation actions and potential in the agricultural sector

KEY FINDINGS

- ***There is a great deal of variation in the non-CO_2 mitigation potential of individual climate mitigation actions in the agriculture sector. This variation exists both in the potential of an action per unit of uptake as well as uncertainties regarding the overall potential applicability of that action*** as a result of the differing emission effects of the implementation of individual actions in the different environmental, biogeographical and socioeconomic contexts of the EU as well as different baselines of current farming practice. Combined with the lack of detailed baseline information on the current application of these types of actions on the ground, this uncertainty makes attempts to estimate the likely uptake and implementation of mitigation actions very difficult, resulting in estimates with a low degree of confidence. This uncertainty is compounded when attempting to aggregate individual mitigation potentials to provide a bottom-up assessment of mitigation potential at the EU level and as a result the studies reviewed here have not sought to do this.
- ***The cost of mitigation actions and the impact they have on production are important considerations in relation to their likely uptake and therefore overall potential.*** Some mitigation actions will be low cost and therefore could be adopted by farmers without significant investment or impact on production (e.g. biological N fixation in rotation and grass mixes). Some will have a cost but result in either production gains, reduction in input costs or generate new revenue streams (e.g. livestock disease management or anaerobic digestion). Others will have high upfront costs that are not necessarily rewarded by gains in production or other cost savings or income generation (e.g. conversion of arable land into grassland).
- ***Climate mitigation actions can achieve environmental co-benefits provided they are implemented in a way that is complementary to broader environmental goals.*** Despite some cost implications for farmers, many of the mitigation actions reviewed have important co-benefits, both in relation to gross margins and environmental gains. The increased efficiency in the use of fertilisers through introducing nitrogen fixing crops into a rotation can deliver cost gains and benefit the environment (under specific conditions), as well as delivering significant mitigation benefits. However, these win-win-win approaches can require changes in production methods on the part of an individual farmer, which can often be perceived as an unnecessary risk where the benefits of the change for the farm business will only become visible over the long term, and profits are already considered reasonable. Furthermore, environmental co-benefits will only be provided under specific, often context-dependent, conditions.
- ***The influence of individual choices is significant. Unlike many other sectors, promoting climate mitigation actions in agriculture relies on the adoption of actions by millions of individuals and small businesses.*** This is akin to reducing transport emissions by trying to influence individual car drivers as opposed to a more limited set of fuel suppliers or car manufacturers. Support and information awareness raising to farmers is therefore essential to engage farmers in climate mitigation actions and help deliver a range of environmental and economic co-benefits.

This chapter considers the different mitigation actions available to the agriculture sector, their potential for climate mitigation and the conditions necessary for their implementation.

3.1 Introduction

The projections for agriculture non-CO_2 emission reductions vary in part as a result of the assumed applicability and uptake of different mitigation actions. Mitigation activities are wide ranging but generally aim to reduce the anthropogenic causes of GHG emissions in the sector, such as the loss of N_2O from soils as a result of leaving them bare between rotations, reducing emissions from enteric fermentation in ruminants, as well as to introduce activities that actively sequester carbon in soils and biomass.

It should be noted that mitigation potential will evolve as new technology is made available, or more affordable, over time, and therefore is not a static concept. This section uses information on mitigation actions and potentials as available in literature at the time of writing, which means that existing but not well documented technologies were not considered.

Mitigation potentials can be estimated for individual types of mitigation action per unit of uptake by EU farmers in different biogeographical situations. However the uncertainties relating to uptake of individual actions in different parts of the EU and the limited baseline information on current farming practices, makes the bottom-up aggregation of the overall likely mitigation potential particularly challenging. Uncertainty around mitigation potential values partly arises also from continued high uncertainty levels associated with GHG emission estimates[43].

3.2 Review of mitigation actions that could be taken by the agricultural sector

Two key studies in this area examine the mitigation potential of actions in the agriculture sector, using a bottom up approach[44]. One evaluates the cost effectiveness of mitigation actions in agriculture (OECD, 2014) and the other focuses on the actions available to the sector within the EU (Martineau et al, 2016[45]).

The OECD study identifies 182 mitigation actions (impacting on both CO_2 and non-CO_2 agricultural emissions) and gives some perspective as to the types of mitigation actions usually considered for agriculture. However, the report acknowledges that while many type of actions could be possible, the impact of only a few is currently documented and that data on cost-effectiveness and mitigation abatement potential are limited. Table 3 shows a summary of these 182 mitigation actions grouped according to the IPCC categories they most directly relate to.

Table 3: Agriculture mitigation activities cited in OECD

IPCC categories	Categories of mitigation actions*
Enteric fermentation (73)	livestock management (49) livestock housing (7)
Manure management (17)	livestock manure (17)
Managed agricultural soils (85)	cropland management (64) management of organic soils (1) grazing land management (16) restoration of degraded lands (4)
Field burning of agricultural residues (1)	cropland management (1)
Not counted as agriculture under UNFCCC (7)	land use change (7)
Not counted as agriculture under UNFCCC (16)	energy efficiency (16)

Source: own compilation based on OECD, 2014 **Notes:** * The number of measures within each category is given in brackets.

Like the OECD study, Martineau et al (2016) acknowledge that documented mitigation impacts are relatively limited and therefore identify 22 mitigation actions related to land management activities, covering both CO_2 and non-CO_2 GHGs and reviews the potential abatement rates found in literature. The emission abatement potentials for which quantitative data is available in this report are therefore limited to actions presented in Martineau et al (2016). Some mitigation actions were

[43] The key uncertainties lie with sourcing activity data and factors used to estimate emission levels.

[44] i.e. aimed at evaluating what contribution the sector could provide, as opposed to estimating the impact of a fixed objective.

[45] The key studies used to support the analysis included in Martineau et al (2016) are: Frelih-Larsen et al., 2014 [Mainstreaming climate change into rural development policy post 2013]; Buckingham et al., 2014 [Review of land management actions]; Lugato et al., 2014 [Preserving Organic Carbon Stocks in Europe Through an Optimal Exploitation of Agricultural Crop Residues]; Moran et al., 2008 [UK MACC]; Schils et al., 2008 [The EU CLIMSOIL project reviewing the interrelations between soils and climate change]; Moorby et al., 2007 [A UK review of a large number of MAs].

excluded from the Martineau et al (2016) review[46], notably anaerobic digestion (which links to manure management) which the EcAMPA 2 study (Domínguez et al, 2016) suggests could have a significant abatement potential.

3.3 Emission abatement potentials by mitigation action

Table 4 sets out the annual abatement potential values of different mitigation activities based on a meta-review of available studies and literature in this area (Martineau et al, 2016). Ranges of low, medium and high abatement estimates are presented for each mitigation action identified and represent the quantity (in $ktCO_{2e}$) of GHG emissions that would be avoided (i.e. not emitted) every year for each 1% of additional uptake of the mitigation action in the EU. These estimates are taken entirely from Martineau et al (2016), providing a means of comparison between actions (albeit with caveats[47]) as well as insights into the relevance of these actions across the EU. The OECD study only provided patchy estimates of abatement potential – with the focus being on mitigation cost effectiveness estimates.

The values in Table 4 do not reflect any additional emissions reductions coming from losses of production. Martineau et al (2016) recognises that some mitigation actions have a negative impact on production but in the absence of an economic equilibrium model, the additional abatement resulting from lower production levels cannot be captured.

The authors also note that many mitigation potential values, especially those for cropland/grassland management activities, are not reductions in emissions as such but often are CO_2 sequestration of carbon in soil and/or biomass. While the focus of this report is on non-CO_2 GHGs, Table 4 also includes CO_2 relevant types of actions to show that i) one mitigation action may affect "primarily" one type of GHG, e.g. N_2O, but often this has in turn an impact on the level of other GHG emissions, e.g. CO_2. This illustrates how in practice the reporting mechanisms covering most of agricultural emissions (ESD and LULUCF) are highly interlinked.

The mitigation potentials identified are only for individual actions and are considered independently of others. In practice, the implementation of certain actions may be complementary or in some instances mutually exclusive. For example, it would be impossible to implement both the conversion of arable land into grassland and using catch/cover crops on the same plot of land. Even where actions can be combined, e.g. breeding lower methane emissions in ruminants and feed additives for ruminant diets, the actions may be complementary and lead to different abatement rates. The choice of actions by farmers will rely to some extent on the applicability of the actions to a given area, to the farm, whether support and guidance is provided to implement the action, etc.

[46] Anaerobic digestion was considered only as an option to reduce GHG emissions during manure storage but not in relation to its potential to produce renewable energy and thus substitute fossil fuels. Data reviewed did not indicate this to be a cost effective action under this approach.

[47] As estimates were harmonised but originally based on different units as found in literature.

Table 4: Abatement rate potentials for selected mitigation actions in agriculture

	Abatement rate potential (kt CO_2eq/year per additional % point of uptake*)			GHGs		IPCC Relevant sectors		
Mitigation actions	*Low*	*Median*	*High*	*Non-CO_2*	*CO_2*	*Enteric fermentation*	*Manure management*	*Managed agri soils*
Reduced tillage	23	45	68	++				x
Zero tillage	100	210	310	++	+			x
Leaving crop residues on the soil surface	140	1,400	2,800	+	+			x
Ceasing to burn crop residues and vegetation	N/A	880	N/A	+	+			x
Use cover/catch crops	**1,100**	**1,500**	**1,900**	++	+			x
Livestock disease management	23	120	230	+		x		
Use of sexed semen for breeding dairy replacements	14	32	50	+		x		
Breeding lower methane emissions in ruminants	7	11	14	+		x		
Feed additives for ruminant diets	**37**	**55**	**74**	+		x		
Optimised feeding strategies for livestock	8	15	23	+		x		
Soil and nutrient management plans	48	84	120	+	+		x	
Use of nitrification inhibitors	**470**	**950**	**1,400**	+				x
Improved nitrogen efficiency	24	130	240	+		x	x	
Biological N fixation in rotations and in grass mixes	**1,400**	**2,200**	**2,900**	+		x	x	
Carbon auditing tools	470	710	940	+	+	x	x	x
Improved on-farm energy efficiency	74	110	150	+	+	x	x	x
Selected LULUCF actions primarily impacting on CO_2 emission reductions, but with some relevance to non-CO_2 GHG mitigation								
Conversion of arable land to grassland to sequester carbon in the soil	2,800	5,900	9,300	+	++			x
New agroforestry	280	950	1,700	+	++			x
Wetland/Peatland conservation/restoration	2	7	12	+/-	++			x
Woodland planting	2,800	3,100	3,500	+	++			x

Source: based on Martineau et al (2016) and own assessment regarding the non-CO_2 and CO_2 relevance and IPCC sectors.
Notes: + = reductions in emissions; - = increase in emissions; x = relevance to IPCC category; * The abatement rates should be read as follows: if the mitigation action potentials found in literature were applied on one additional per cent of relevant land or livestock, it would result in additional removals or abated emissions of […] kilotonnes of CO_2 equivalent per year. Martineau et al (2016) tried to estimate the likely applicability, or uptake, of those mitigation actions in the EU to provide estimates of total emission reductions for each action. However, although an interesting method, the level of confidence from the resulting figures is low and is not considered further in this study.

Some actions like carbon auditing tools are designed to plan the use of other mitigation actions – focusing on both non-CO_2 and CO_2 emissions. Carbon auditing tools involve data collection to find out where the largest GHG emissions arise and allow the identification of hotspots to target or where there may be cost efficiency savings for the farmer. The mode of action therefore does not directly affect GHG emissions, but rather encourages changes to practices that decrease GHG emissions. In the table, the values represent the abatement potential assuming the mitigation actions recommended by the results of the carbon audit are implemented.

The range of abatement potentials is considerable for all mitigation actions. This shows the impact that local conditions such as the types of soils, current farming practices, implementation, etc., can have on emission reductions.

Considering only those actions that address non-CO_2 gases[48], the largest abatement potentials for each % point of additional uptake in the EU have been estimated to relate to the following actions:

- Crop production:
    - Use of cover/catch crops (1,100 – 1,900 kt CO_2eq/yr/%uptake);
- Nutrient and soil management:
    - Biological nitrogen (N) fixation in rotations and in grass mixes (1,400 – 2,900 kt CO_2 eq/yr/%uptake);
    - Use of nitrification inhibitors (470 – 1,400 kt CO_2 eq/yr/%uptake);
- Livestock production:
    - Livestock disease management (23-230 ktCO_2 eq/yr/%uptake)
    - Feed additives for ruminant diets (37-55 ktCO_2 eq/yr/%uptake)
- Other:
    - Carbon auditing tools (for both CO_2 & non-CO_2 emissions) (470 – 940 kt CO_2 eq/yr/%uptake)

These actions apply primarily to the management of cropland (i.e. crop production and nutrient and soil management). The first three of these high mitigation potential options help to improve the efficiency in which nitrogen is used on farms, and thus reduce the potential loss of N_2O from soils by increasing the retention or preventing the loss of nitrogen (N) from soils. This is achieved by using catch or cover crops between rotations to absorb excess fertilisers left in the soil, increasing nitrogen fixation (binding of nitrogen in plant roots) in plants, or using nitrification inhibitors to allow a slower release of nitrogen to crops and increasing efficiency. Livestock disease management and feed additives for ruminant diets was estimated in Martineau et al (2016) as having the highest potentials amongst livestock mitigation actions that were reviewed[49], through an improved ratio of GHG emissions per output produced and by reducing CH_4 formation in the rumen, respectively. Finally, carbon auditing helps to reduce emissions by identifying areas where GHG emission improvements could be made on farms, the types of activities that could be adopted and potential synergies for farmers.

One important point is that mitigation actions have varying applicability, and relevance, across the agricultural landscape, which in turn impacts on their overall mitigation potential in the EU. For

[48] We excluded "Preventing deforestation and removal of farmland trees", "Conversion of arable land to grassland to sequester carbon in the soil" and "Woodland planting" because even though they have a positive impact on non-CO2 emissions, this is only due to a change in land use – from arable land to forestry or to grassland. They are a special case in that emission reductions are obtained through not having arable land anymore.

[49] Abatement rates reported in Martineau et al (2016) are generally lower for livestock mitigation actions compared to actions reviewed in other categories.

example, some mitigation actions might have low individual mitigation potentials, but are applicable across a significant area of the EU making their overall potential contribution to climate mitigation considerable. For example biological N fixation in rotations and in grass mixes, nitrification inhibitors in soils, or nitrogen efficiency measures could be applied on most EU arable land. Conversely, some mitigation actions can have relatively high mitigation potentials, per unit of uptake, but the areas to which this would apply may be relatively small within the EU. In addition, the relevance of given mitigation actions to the specific land or livestock considered must be taken into account, e.g. while zero tillage may be in theory be applicable to any arable land, it is more relevant in certain regions, such as semi-arid areas.

Cost considerations are likely to be an important factor impacting the uptake of the mitigation actions in practice. It should be noted that while, for instance, livestock disease management, using feed additives or improving nitrogen efficiency may relatively easily be taken up by farmers, actions like using sexed semen for breeding dairy cattle or breeding low emissions cattle would have high upfront costs and appear less likely to be widely implemented in the short to medium term.

This being said, many of the mitigation actions reviewed can have important co-benefits, both in relation to gross margins and environmental gains. The increased efficiency in the use of fertilisers through introducing nitrogen fixing crops into a rotation can deliver cost gains and benefit the environment (under specific conditions), as well as delivering significant mitigation benefits.

Such factors influence the likely implementation of those actions in different directions and impact the mitigation potential to be expected from them in practice. The next section reviews the challenges and opportunities arising from these different factors for four selected mitigation actions.

3.4 Challenges and opportunities associated with implementing selected mitigation actions

All of the actions in Table 4 can play a role in helping to mitigate GHG emissions in the agriculture sector. Some have greater mitigation potential in absolute terms, whereas others are applicable over a larger area. Four selected actions are used to illustrate the potential implications (positive and negative) of adopting different mitigation actions in practice, considering both those for cropland management and those relevant for livestock. The first three actions focus on the improved efficiency of nitrogen use on farms (nitrification inhibitors; cover/catch crops; and biological N fixation) and the fourth action addresses emissions from livestock through the use of feed additives. The potential barriers, benefits, implications and environmental and production risks of the actions can be found in Table 5 with a description provided below.

Table 5: Selected high potential mitigation actions for non-CO_2 GHGs in agriculture

Mitigation action	Primary sector (GHG)	Method	Technical barriers	Co-benefits	Cost implications	Environmental and production risks	Abatement rate potential from Table 4 (kt CO2 eq/year per additional % point of uptake)
Nitrification inhibitors	Cropland (N_2O)	• Reduced nitrification so that NO_3^- is formed at a rate that the crop can use; • Increasing N efficiency and reducing environmental losses via N_2O emissions and NO_3^- leaching	Low but guidance needed	• Reduced nutrient pollution	• High. Inhibitors are expensive, do not lead to increases in yield/ can even lead to yield reductions.	• None noted, however limited widespread use in the EU to test potential impacts.	470 – 1,400
Catch/cover crops	Cropland (N_2O)*	• Reduced soil erosion during fallow; • Reduced N leaching and thus reduced application to following crop	Low / none	• Weed suppression; • Reduced erosion; • Reduced nutrient pollution • Maintenance of productivity with soil retention; • Increase of soil carbon when incorporated	• Additional production effort compared to bare fallow; • Expected decrease in gross margins in the short term by €174.50/ha, but impacts range between +€16.60/ha to -€270/ha.	• Loss of bare fallow impact on biodiversity; • Potential yield reduction in following crop; • Possible use of herbicide	1,100 – 1,900
Biological N fixation	Cropland (N_2O)	• Use of nitrogen fixing crops to sequester atmospheric N and make it available to following crop, thus reduced fertiliser need.	Low / none (well established traditional technique). Some additional skills needed	• Reduced nutrient pollution • Biodiversity benefits from flowering legumes and increased structural diversity; • Improved soil health	• Increased gross margins as a result of decreased fertiliser application and profitability of crops; • Average increase +€78.90/ha with a range of +€76.90/ha to +€80.70/	• Increases in the area of grain legumes reducing overall farm production, which could lead to increased production elsewhere.	1,400 – 2,900
Livestock diet supplements and feed additives	Livestock (CH_4)	• Reduced CH_4 production during digestion through use of fat supplementation **	Low / none Applicability varies by livestock type	• No noted co-benefits	• Unclear, already used in some high productivity farms	• Possible increase in demand for vegetable oils	37 - 74

Source: Summarised from Martineau et al, 2016 **Notes:** * CO_2 benefits through carbon sequestration. ** Other dietary supplements are available, although not all are used in the EU and therefore were not included in the mitigation potentials.

3.4.1 Improved efficiency in the use of nitrogen

Nitrogen efficiency actions aim to make the best use of sources of nitrogen available on the farm with respect to both reducing the total amount of fertiliser applied and using what is applied most efficiently (reducing losses and increasing uptake).

Nitrification inhibitors are compounds that slow down (inhibit) the conversion (nitrification) of ammonium ions (NH_4^+) to NO_3^- (nitrate). The rationale of using nitrification inhibitors is that the rate of nitrification is slowed so that NO_3^- is formed at a rate that the crop can use, increasing N efficiency and reducing environmental losses via N_2O emissions and NO_3^- leaching. They have a relatively high abatement rate potential amongst non-CO_2 nutrient and soil management actions (470 – 1,400 kt CO_2eq/yr/%uptake) although this potential is variable depending on the biophysical context as they are not retained in wet / damp soils (Martineau et al, 2016).

Nitrification Inhibitors can potentially be applied in a wide variety of situations: as part of mineral N fertiliser to crops; to manures in storage and when spread to land; be sprayed on grazed land periodically at critical times of enhanced nitrification; deployed at the same time as fertiliser or manure applications; or be given to animals directly.

Reducing the loss of nitrogen from soils and increasing the efficiency of its delivery to plants has additional environmental co-benefits, such as reducing nitrate leaching from soils and preventing nitrate pollution of adjacent water courses, ground water or vegetation. This can aid farmers in reducing the environmental impact of their farming practice and contribute to EU wide objectives of the Nitrates Directive (Council Directive 91/676/EEC) and under the Water Framework Directive (Directive 2000/60/EC).

From a technological perspective, the use of nitrification inhibitors are established but require appropriate application, particularly when used with livestock manures, in order to achieve the mitigation effect. The effectiveness of approach depends largely on temperature, moisture and soil type, but they are applicable to any crop systems that have additional nitrogen applications from farming, including annual and perennial crops, forage crops and grass. This means their applicability across the EU could be considerable.

From an economic viewpoint, nitrification inhibitors are expensive and can sometimes lead to decreased crop yields where applied incorrectly. The overall costs are difficult to estimate in practice, as the application rate will vary. Importantly the cost from impacts on crop yields or any initial capital costs need to be offset by any potential savings when adopting the approach, such as reduced fertiliser need, although this is small compared to the up-front costs. Overall, considering their potential abatement rate, applicability and costs, Martineau et al (2016) concludes that nitrification inhibitors are amongst the most promising non-CO_2 mitigation action for EU agriculture.

Capturing nitrogen within soils can also be approached through more conventional techniques, such as **using cover or catch crops** to absorb excess nitrogen between rotations and prevent erosion, or to increase the **biological fixation of nitrogen** by plants as part of those rotations. Both enable nitrogen to be made available to the next or current crop thereby reducing the need for fertiliser application.

As with nitrification inhibitors, these approaches have water quality co-benefits through reduced nitrate pollution and are already widely used by farmers in Nitrate Vulnerable Zones[50]. Importantly

[50] As per the Nitrates directive (91/676/EEC)

improving nitrogen efficiency results in less expenditure for nitrogen inputs and therefore has economic benefits for farmers. It may however require additional management time compared to 'just in case' over-application of mineral nitrogen fertilisers and technical advice and possibly soil analysis may also be required. Water quality may improve as a result of this mitigation action only if appropriate post-harvest management of the crops is in place to avoid a sudden increase of nitrogen leached into water courses after crops are harvested. Additional environmental benefits may be realised under specific conditions. For instance forage nitrogen fixing crops and green manure crops can provide some benefits to some wildlife species provided they are extensively managed (i.e. if the crop is kept in the ground for at least a year, if cutting is avoided in the summer and if pesticides are not applied) (Underwood and Tucker, 2016).

3.4.2 Reducing emissions from livestock through improved animal diets

Reducing emissions from livestock tend to focus on the metabolism and digestive process of the animals themselves or the management of manure. Improving animal diets has been a long-standing development in agriculture, although with the primary aim of producing high-yielding and good-quality milk and meat production. Until relatively recently, less attention has been given to reducing 'emissions'.

One potential option to reduce emissions from enteric fermentation is to use ***feed additives in ruminant diets***. This has potential for reducing CH_4 emissions in ruminants[51]. Many different types of feed additives exist including fat supplementation, probiotics or ionophores. The action mechanism in most cases is that additives react or interfere with the formation of CH_4 (methane) in the rumen, thereby reducing its production. Martineau et al (2016) only assesses the abatement potential of fat supplements, arguing that these are the "best validated of the additives" and that ionophores are currently forbidden in the EU[52].

As a technology, feed additives are well developed and used already by some high productivity beef and dairy units. One of the main barriers to uptake is that the cost of the additives is not necessarily reflected in improved productivity, therefore the overall impact on gross margins can be high. In addition, on cattle and sheep farms that are more reliant on forage grown on the farm (as opposed to bought feed) the effective use of additives require more skilled management because of the variability of the fodder quality. There are no other direct environmental benefits associated with using feed additives.

[51] Although of documented higher abatement potential, we have not focused on livestock disease management because this action targets an increased GHG efficiency – by avoiding production losses due to diseases - but does not aim to reducing emissions as such.

[52] In the EcAMPA 2 study, where two feed additives are considered and treated separately, it appears that using linseed may have more potential than using nitrates as feed additives.

4 Discussion

4.1 Agriculture and the mitigation of climate change

The research reviewed in this study shows that not only can agriculture contribute in a significant way to the EU's climate mitigation efforts under the ESR, but also that some of the actions with potential to be adopted could deliver much broader environmental (such as reduced diffuse pollution) and economic (such as reduced fertiliser consumption) benefits. To suggest that increasing mitigation effort in the sector is too costly or too difficult is therefore not entirely accurate. The question, however, is how much can it contribute? In this regard, there are clear challenges to adopting mitigation activities in the sector at the scale which are likely to be required to meet longer-term emission reductions by mid-century.

Climate mitigation efforts in the agriculture sector have been relatively modest to date compared to those in other sectors and have largely been brought about through reductions in livestock numbers and increased efficiency in the use of fertiliser inputs. The challenges, both technical and political, of achieving cost effective reductions of GHG emissions in the agriculture sector have meant that little proactive large-scale action on climate mitigation in the agricultural sector has been taken to date. Those measures that have been adopted generally have reflected a mixture of national and international policy drivers as well as commercial pressures, rather than being set in the context of concerted action to achieve emissions reduction from the sector as a whole (Hart et al, 2017). There is a clear challenge in the sector to balance the production of commodities with emission reductions, and to understand what the right balance should be in a low-carbon agriculture future. Yet limited political effort to address this challenge has only served to place it behind other sectors in the ESR and economy as a whole, which will become more pressing as the share of agriculture emissions in the economy increases.

The mitigation potential in the agriculture sector changes over time and will evolve as new technology becomes available or more affordable. The greatest challenges are therefore both how agriculture can contribute to emissions reductions while continuing to produce food, as well as the level of ambition there is to support mitigation in the sector, how agriculture is perceived in the climate change debate and the way in which it is incorporated into the policy frameworks.

At the UNFCCC level, agriculture is accounted for alongside forest and other land uses (AFOLU), which are some of the only sectors that have the potential to both reduce emissions but also increase removals from the atmosphere in above and below ground biomass. The longer there is a delay to action on non-CO_2 gases from agriculture the greater the effort that will have to come from carbon removals from the atmosphere via land management (both from agricultural and forestry land use). This is because if net zero emissions are to be achieved by 2050 (as would be required to meet the Paris Agreement target), aggressive cuts in emissions will have to take place in the coming decades, also from the agricultural sector. If these do not occur, emissions will have to be heavily compensated through carbon removals, sequestration and storage. Carbon sequestration and storage will, in turn, face a number of challenges including increasing competition for land where removals can take place and increasing competition for resources (e.g. water) needed to maintain or increase storage stock, and the saturation of existing carbon sinks. A key question is therefore what a sustainable and realistic level of removals in the land using sectors is likely to be and from an accounting perspective, what share should be made available to agriculture to aid its mitigation efforts. The alternative route would be to compensate agricultural emissions through requiring more ambitious reductions elsewhere in the ESD/ESR sectors, which would put a disproportionate burden on other economic sectors.

At least some mitigation effort will very likely have to come from the agriculture sector in the short term, at least in some Member States more than others, particularly where agriculture represents a significant share of total greenhouse gas emissions. The degree of effort required will also be influenced by the level of achievement of overall mitigation efforts in other sectors (Matthews, 2016). The question arising is therefore what can the EU do in order to promote mitigation effort in the sector through policy.

4.2 Key policy instruments to deliver mitigation efforts in the agriculture sector

The policies and strategies that influence climate mitigation in agriculture include globally binding agreements, such as the Kyoto Protocol (to 2020) and the Paris Agreement (to 2030) - which in the EU led to the introduction of the Emission Trading System, the Effort Sharing Decision (and the proposed Regulation) and the LULUCF proposal; long term strategies, such as the EU's low carbon roadmap; climate and energy policy, such as the Renewable Energy Directive (RED) that incorporates targets for the production of energy potentially based on agricultural commodities; and sector strategies, such as the Circular Economy Action Plan and Bioeconomy strategy.

These policies and strategies help support or provide regulatory incentives to undertake climate mitigation activities in the agriculture sector in the short term. For example, the Nitrates Directive which limits the amount of nitrogen that can be applied on agricultural soils, the National Emissions Ceiling Directive (Directive 2001/81/EC) which sets ceiling on ammonia (a precursor to N_2O), or activities under the Circular Economy Action Plan which may result, for example, in increased nutrient recycling within and between farms. These policies have specific objectives and many include and are coherent with climate mitigation. Through their implementation most actions will be likely to result in some positive impacts on non-CO_2 emissions (mainly N_2O). However the tools and support available to deliver activities under these policies are often limited and rely on targeted interventions, such as those provided through the CAP. In the absence of a sectoral target for reducing agricultural emissions, the implementation of climate actions relies on Member States prioritising the use of policy measures (e.g. under the CAP) to promote climate action and the voluntary uptake of such measures by farmers.

In 2016 the European Commission introduced the winter package of proposals for a clean energy transition in Europe. This includes a variety of proposed updates to existing legislation, such as revisions to the Renewable Energy Directive, as well as setting out a new proposed Governance Regulation (COM(2016) 759 final/2). Article 14 of the proposed Regulation requires Member States to prepare and report to the Commission their long-term emission strategies with a 50-year perspective to contribute to emission reduction and removals within the Union. Specifically for ESR sectors this includes the requirement for a long-term low emission strategy to cover: emissions reductions and enhancement of removals in individual sectors including electricity, industry, transport, the buildings sector (residential and tertiary), agriculture as well as land use, land-use change and forestry. Having a long-term plan for emission reductions in the ESR sectors will be useful to help frame the contribution necessary from agriculture and what level of removals are expected in the wider land-using sectors. However, without specific targets for the sector, there is a risk that ambition will remain limited given the reticence by many Member States, farmer and landowner organisations for a more targeted approach to mitigation in the agriculture sector.

The main policy that directly influences management decisions made in the agriculture sector is the CAP. Established in 1962 it has supported and influenced the way in which agricultural production has developed in the EU. Climate action now forms one of the three core objectives of the CAP across both Pillars: viable food production; ***sustainable management of natural resources and climate action***; and balanced territorial development. Support through the CAP is divided into two main 'pillars'.

- Pillar 1 takes the form of Direct Payments and provides income support to farmers and land managers contingent on adhering to EU legislation pertaining to agriculture and some additional basic agricultural, animal welfare and environmental standards (cross compliance) mostly determined at the Member State level. Thirty per cent of direct payments are allocated to 'green' measures, which farmers must carry out on eligible land, some of which have the potential to influence GHG emissions. For example, nitrogen fixing crops or catch and cover crops options are both available for Member States to implement as part of the Ecological Focus Areas (EFA) requirement, under Pillar 1 greening. Both of these options can have climate mitigation benefit as they capture nitrogen (either from the atmosphere or in the soil) and therefore reduce N_20 emissions as well as the need for fertilisers in the next crop[53].
- Pillar 2 of the CAP encompasses a much wider range of activities supported through the European Agricultural Fund for Rural Development (EAFRD) (Regulation (EU) No 1305/2013) that are designed at the regional (BE, FR, DE, IT, ES and UK) or Member State level through 118 Rural Development Programmes for 2014-2020. EAFRD support provides a more adaptable approach and broader scope to delivering climate mitigation activities with support for capital investments, land management and land use, and capacity building through Measures programmed under Rural Development Programmes (RDPs).

The extension of climate priorities to Pillar 1 in the CAP has been helped by the commitment under the Multiannual Financial Framework (MFF) for the period 2014-2020 to mainstream climate action into all EU expenditure, with a particular commitment to devote at least 20 % of the Union budget to support for climate change objectives (Hart et al, 2017). However the way in which the CAP's contribution to this target has been calculated (or tracked) has been criticized as overestimating the likely scale of climate expenditure under both Pillar 1 and rural development policy (ECA, 2016). For the second Pillar, the 2014-2020 CAP, six Union Priorities, all of which are required to contribute to the objectives of climate change mitigation and adaptation (alongside environment)[54]. For climate mitigation in the context of non-CO_2 GHG mitigation, Priority 4 and 5 have most relevance.

Box 4: Union Priorities 4 and 5 of the EAFRD

Priority 4 "restoring, preserving and enhancing ecosystems related to agriculture and forestry" can make a contribution to climate objectives through Focus Area 4c, which prioritises "preventing soil erosion and improving soil management".

Priority 5 is concerned explicitly with "promoting resource efficiency and supporting the shift toward a low-carbon and climate-resilient economy in the agriculture, food and forestry sectors", under which lie five Focus Areas that deal respectively with increasing the efficiency in water use by agriculture (5A), increasing the efficiency in energy use in agriculture and food processing (5B), facilitating the supply and use of renewable sources of energy, by-products, wastes, residues and other non-food raw materials for the bio-economy (5C), reducing nitrous oxide and methane emissions from agriculture and fostering carbon conservation (5D) and fostering carbon sequestration in agriculture and forestry (5E).

Source: Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005

Most of the mitigation actions described in this report can already be supported via the CAP. However, relatively few are compulsory, with discretion given to Member States on what and how they choose to implement these activities, how they design the detailed rules, definitions and

[53] Other Pillar 1 instruments can help reduce emissions, but often these are CO2 emissions, through carbon sequestration and/or avoidance of CO2 emissions e.g. by maintaining or planting hedges or trees, through the ban on ploughing environmentally sensitive permanent grassland, etc.

[54] Article 5 of Regulation 1305/2013

support measures. As such CAP measures can help support the adoption of climate mitigation actions by farmers but they are not always deployed in a way that promotes a widespread uptake (Martineau et al, 2016).

Multi-annual commitments are important when addressing emission reductions that can take multiple years to realise in practice. Support provided under the RDPs compensates farmers for the income forgone (potential production or profit loss) and costs incurred when implementing new activities. The agri-environment-climate measure is a particularly important measure, allowing support for a wide range of activities for climate mitigation, including the appropriate management of soils. Organic farming is also supported (both conversion and maintenance) through RDPs, which can help to introduce more climate friendly rotations and reduce the use of mineral fertilisers. Cooperation, where multiple farmers need to work together is supported as well as capacity building and information and advice support. Up-front capital investments, such as for infrastructure are supported as well (often as 'non-productive investments'), and can help farmers to overcome the initial cost burdens of implementing new activities and processes.

Targeting of activities to areas where they are most relevant or necessary is important, and particularly ensuring that advice and awareness raising is given to those who may not be aware of the opportunities for climate mitigation activities on their farm, or that support is available. To encourage the design by authorities of climate mitigation actions, the sharing of best practices of how the CAP has been used to support climate mitigation actions in different regions of the EU should be promoted at EU level, for example via the European Network for Rural Development's Contact Point. Research and pilot projects (supported via the cooperation measure) could also be initiated and encouraged in Member States to demonstrate innovative ways to improve the efficient and effective use of CAP support for climate mitigation purposes.

Beyond policy incentives or regulatory targets, farmers respond to the market, which in turn is influenced by consumer trends. Labelling can be an important tool to help consumers understand better the climate impact (positive and negative) of the products they purchase which can help stimulate demand for climate friendly and more environmentally sustainable produce (see Baldock and Mottershead, 2017). This could also enable farmers to access new markets with potential price premiums, providing additional stimulus for climate action in the sector.

4.3 Key messages

- ***The agriculture sector can make a significant contribution to the EU's climate mitigation efforts***. While it is widely acknowledged that agriculture can contribute to mitigation by increasing carbon removals on agricultural land (reported under LULUCF), this study shows that there is also a significant untapped potential for the agriculture sector to contribute through reducing its non-CO_2 emissions.
- ***The extent of the sector's contribution will largely depend on the level of ambition of the sector, the costs of the mitigation action and the level of public support available***, but studies show that agriculture can achieve significant climate mitigation even in situations where the financial incentive for mitigation is low and where actions are not supported through policy. Mitigation actions that are available as well as their mitigation potential and costs will evolve over time, as new technology becomes available or more affordable.
- ***A wide range of mitigation actions are already available to the agriculture sector,*** but have yet to be adopted at the scale and intensity necessary to deliver lasting emission reductions.
- ***Care must be taken to balance climate mitigation with the potential impacts on production and to look for the environmental and economic co-benefits of mitigation efforts***. An important point to acknowledge is the evolving nature of all these factors, e.g. a mitigation action may only have short term production impacts.
- ***Focusing on non-CO_2 emissions, there is a great deal of variation in the mitigation potential of individual climate mitigation actions in the agriculture sector. This variation exists both in the potential of an action per unit of uptake as well as uncertainties regarding the overall potential applicability of that action,*** as a result of the differing emission effects of individual actions in different environmental, biogeographical and socioeconomic contexts as well as different baselines of current farming practice.
- ***Better information is needed to determine the precise level of mitigation potential in the agricultural sector.*** More effort should be devoted to monitoring climate action and its impact at the EU and Member State level.
- ***The cost of mitigation actions and the impact they have on production are important considerations in relation to their likely uptake and therefore overall potential.*** Some mitigation actions will be low cost and therefore could be adopted by farmers without significant investment or impact on production; some may have higher costs but result in greater efficiency or new revenue streams, whereas some will be high cost without being necessarily rewarded by gains in production or other cost savings or income generation – this is where financial support may be required. Where this is the case, different types of financial support may be required to compensate for the costs incurred. For instance, some actions may involve high costs in the form of one-off investments, some may have short-term only production impacts while other actions may lead to longer term costs or production effects.
- ***Supporting mitigation activities in the sector can have high costs in some cases, yet climate mitigation actions can achieve environmental co-benefits provided they are implemented in a way that is complementary to broader environmental goals and societal objectives.*** These co-benefits, particularly those for the environment, will only be provided under specific, often context-dependent, conditions.
- ***The existing studies reviewed in this report do not provide the information to support the widely held view that mitigation in agriculture is (or is not) more technically challenging or***

more cost-ineffective compared to other ESD sectors, particularly when environmental co-benefits are considered. The studies do show however that there are potentially significant impacts on production for some actions that should be balanced with mitigation effort and overall impact on GHG emissions.

- ***The influence of individual choices is significant. Unlike many other sectors, promoting climate mitigation actions in agriculture relies on the adoption of actions by millions of individuals and small businesses.*** Support and information awareness raising to farmers is therefore essential to engage farmers in climate mitigation actions and help deliver a range of environmental and economic co-benefits.
- ***Support for implementing mitigation activities is available through the CAP and can provide complementarity to other objectives and Union priorities.*** This includes advice and support frameworks, opportunities for testing innovative approaches, enhancing collaboration and financial support for the actions themselves.
- ***The right mix of supporting conditions is necessary to ensure that mitigation efforts are adopted and implemented correctly, to avoid any long-term production impacts which may lead to carbon leakage effects (production in third countries),*** reducing the overall mitigation effort at the global level, and ensure coherence with other environmental and economic objectives.
- ***Addressing climate mitigation from the agriculture sector requires consideration of both supply (i.e. production) and demand (i.e. consumption) side.*** The agriculture sector, like many others, responds to market demands and demographic changes. This study has not looked at the tools available to support mitigation action on the demand side, but these will need to be allied to measures on the production side, so as to reduce pressure on the sector as a whole.
- ***A clear decarbonisation agenda for the sector is necessary. Articulating this through a long-term low emission strategy for the agricultural sector should provide the necessary framework in which emission reductions and removals are to be achieved and by when.*** Setting a quantitative target for agriculture would give clarity to farmers and Member States about the necessary effort needed and set clear ambition. Any long-term strategy will need to consider the trade-offs between mitigation, production and the cost to society (and Member States). This will require a fresh look at the role of the sector both in terms of reducing emissions and increasing removals, as well as the role of society as a whole.
- ***Taking mitigation action in agriculture cannot be ignored and the sector must increase its contribution to emission reductions and removals***. There is only so long that agriculture emissions can be compensated by emission reductions in other ESD sectors or through sequestration and storage of carbon in other land-using sectors. Over time, there will be increasing competition to use removals from the land-using sectors to address increasingly challenging reductions in other sectors, beyond agriculture. A key question for research and policy is therefore what level of emission removals is possible within the land-using sectors and how (if at all) should this be shared out amongst other sectors as they reach the limits of mitigation (which the agricultural sector is far from having achieved to date).

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