NET-ZERO AGRICULTURE IN 2050: HOW TO GET THERE

REPORT BY THE INSTITUTE FOR EUROPEAN ENVIRONMENTAL POLICY

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DISCLAIMER

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The **Institute for European Environmental Policy (IEEP)** is a sustainability think tank committed to advancing impact-driven policy across the EU and the world. With offices in Brussels and London, our team of economists, scientists, and lawyers work with partners across EU institutions, international bodies, academia, civil society and industry, to produce evidence-based research and policy insight.

NET ZERO 2050

DISCLAIMER

This report has been commissioned by the European Climate Foundation (ECF). It is part of the Net-Zero 2050 series, an initiative of the ECF with contributions from a consortium of experts and organisations.

The objective of Net-Zero 2050 is to start building a vision and evidence base for the transition to net-zero emission societies in Europe and beyond, by mid-century at the latest. The Paris Agreement commits us to making this transition, and long-term strategic planning shows that many of the decisions and actions needed to get us on track must be taken imminently.

Reports in the series seek to enhance understanding of the implications and opportunities of moving to climate neutrality across the power, industry, buildings, transport, agriculture, Land Use, Land-Use Change and Forestry (LULUCF) sectors; to shed light on some of the near-term choices and actions needed to reach this goal, and to provide a basis for discussion and engagement with stakeholders and policy-makers.

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EXECUTIVE SUMMARY

This report explores how the EU farming sector could look like in a net-zero world, what roles it would play and what is needed to make the transition by mid-century. It addresses a fundamental question: is it possible to reach carbon neutrality in agriculture alone and if so, what actions and policies are needed to reach that point? The work builds on a review of over 60 relevant scenarios from 18 different studies[1] in order to understand how and to what extent emissions from agriculture can be reduced, and whether there is consensus in the existing literature. This was complemented through the use of the Carbon Transparency Initiative 2050 Roadmap Tool (CTI tool) to explore four illustrative scenarios to test the potential for efficiency improvements, changes in production volume and/or mix, as well as increasing carbon sequestration potential on farmed land. A stakeholder platform in the EU, and in France was used to test ideas around potential mitigation options.

Agriculture along with other rural land-using sectors, is **unique in its ability to both reduce its own emissions, but also increase carbon removals from the atmosphere, and contribute to emission reductions in other sectors through the substitution of carbon intensive materials and energy.** As such, the sector (and rural land in general) is increasingly being seen as an essential means to reach net-zero, whether through the production of biomass to replace fossil products, or freeing up land to build carbon sinks. Our analysis considers first what could be done to reduce emissions within agriculture, before looking at its potential to support other sectors in the economy or rely on other land-using sectors (e.g. forestry) to offset any emissions.

Enabling agriculture to make a significant and proportionate contribution to the EU's climate mitigation efforts will require the deployment of all the tools and options available to the sector to drive down GHG emissions and increase the absorption of carbon from the atmosphere. Improving the efficiency of production, changing what and how commodities are produced, as well as increasing sequestration capacity, are all options available to the sector. The analysis undertaken using the CTI tool shows that no one of these approaches on its own can deliver the mitigation level necessary for a net-zero future. Used together, these options could lead to emission reductions of between 37% by 2030 and 46% by 2050 (compared to 2010 levels), without major changes in land use. This is commensurate with the wider review of existing EU-level scenario assessments which coalesce in the 35% to 55% range, excluding some outlying studies.

Thus, further steps are required. In fact, it is only by implementing actions across both the production and consumption (supply and demand) sides that we can transform the way agricultural products are conceived in response to the climate challenge and how the sector can support climate action. Enabling the necessary changes in agriculture requires clarity on what actions should be taken and by whom. It may therefore be necessary to develop an emission reduction hierarchy to guide and support actions across the agri-food sector following similar approaches taken towards waste and the EU's circular economy transition, for instance:

- **Avoiding emissions where possible.** Changing the types of commodities produced, reducing the consumption of livestock and other carbon-intensive products, and eliminating food waste;
- **Reducing emissions where they cannot be avoided altogether.** Increasing the resource-efficiency of production, lowering the per-unit GHG emissions of a commodity, producing seasonally and in the most optimal conditions in Europe, and reducing harvesting wastes;
- **Recovery of emissions where possible.** Increasing the sequestration potential on land to build carbon sequestration into standard production practices and ensuring its continued and permanent management on agricultural land. Developing circular-bioeconomies that recover post consumption and production nutrients, energy and materials as inputs to the sector, reducing the need for new inputs. Future agriculture must be different from that of today, sufficiently transformed to enable its contribution to the delivery of net-zero emissions, while providing adequate nutrition and other ecosystem services to an increasingly global society.

While this report focuses solely on agriculture's contribution to the mitigation of climate change, there are a number of other dimensions that will need to be considered in any approach taken. In particular, these include trade-offs and co-benefits with climate adaptation and wider planetary boundaries (e.g. water and biodiversity) as well as implications beyond EU borders. We reflect on these issues in our recommendations below.

RECOMMENDATIONS

Moving the sector towards net-zero emissions by mid-century, consistent with the ambition of the Paris Agreement, presents one of the most transformational challenges faced by the sector since the development of post-war agriculture. Not only does this imply coordinated action at the EU level, it also requires adequate resourcing, research and innovation to enable the changes needed, both in the sector and those that influence it. The following recommendations help address these needs. They have been developed as outputs from this study, and some tested with a range of stakeholders at the UNFCCC COP24 Climate Conference, and the IEEP Think2030 conference on the future of EU environmental policy.

Action in the agriculture sector

- To ensure a proportionate contribution from the sector, **agriculture should be target-driven** in the EU's ambition to move towards net-zero emissions by mid-century or before.
- The perceived high-cost and **'special nature' of agriculture should be reviewed** in light of the opportunities for growth by exploiting its unique potential to develop carbon sinks.
- Future agriculture and food policies should facilitate the **transition to sustainable farming by rewarding farmers for the environmental and climate public goods they deliver,** better reflecting the challenges faced (by farmers and society), the need for change, and to support farmers in making low carbon choices the norm.
- Enabling farmers with the tools for change is crucial – this requires **greater research and innovation support** for climate-smart agriculture solutions, including both production and system innovations.
- **Inclusion of farmers in climate action is crucial** in order to achieve global mitigation targets without compromising global food and nutrition security and the Sustainable Development Goals. **Transforming the sector will take time, requiring long term investment and commitments at all levels.**

Action outside the agriculture sectors and avoiding trade offs

- To **internalise the climate** (along with broader environmental and animal welfare) **impacts of production** in the cost of food commodities and products as a means of promoting more sustainable consumption patterns linked to climate goals.
- To **orient trade towards the supply and consumption of low carbon products** leading to new growth opportunities in an increasingly climate conscious world. This implies defining consistent standards for monitoring GHG emissions embedded in trade flows as a first step to address the climate impacts of the cross-country transactions of agricultural goods and commodities.
- To **address the inefficiencies of current production and supply systems,** particularly food waste, which results both in an inefficient use of the carbon budget and also represents a loss of revenue to farmers.
- To **ensure climate-coherence in the development of policies** that influence agricultural practices including sectoral policies as well as environmental, health, food and animal welfare legislation, and the approach taken to the EU's international commitments.
- Utilise the development of the **circular-bioeconomy to drive sustainability** in the agriculture sector, by ensuring developments take place within ecological limits, rather than leading to resource (and thus climate) pressures.

Recommendations for further research

In order to take forwards these recommendations, there is a need to better understand how and what action can be taken in some areas (such as consumption) and what future challenges may be faced as climate policy develops in the context of much broader range of social, environmental and economic priorities. To this end, the following non-exhaustive recommendations for further research are proposed, many of which would benefit from wide stakeholder engagement as a central element to further research.

- To continue the **development of models and scenario assessment tools** to integrate a wider range of existing and emerging measures available to the agriculture sector, in order to refine mitigation potential estimates and understand better the scale of unavoidable emissions.
- Defining truly **synergistic measures and practices** that benefit both the climate and wider environmental goals – providing clarity to investors, farmers and policy makers.
- Development of **carbon farming schemes based on results,** that encourage and promote the potential of the sector to sequester carbon (and avoid emissions) by changing the way agricultural commodities are produced.
- How to encourage a **change in consumption patterns** (and what role for policy) to ensure complementary action to existing initiatives focused on production. This can help minimise the risk of carbon leakage and at the same time deliver major health benefits.

1

CONTEXT AND SCOPE

Keeping global temperature increase well below 2 degrees and pursuing efforts to keep this to 1.5 degrees above pre-industrial levels – the goal set out by the Paris Agreement – requires global greenhouse gas (GHG) emissions to reach net-zero by 2055-2070. By referring to the principle of common but differentiated responsibilities, many argue that the EU should become climate neutral much earlier. Achieving a balance between emissions and removals by 2050 is in fact part of the portfolio of options considered by the European Commission in its recent proposal for an EU Long-term Strategy (LTS) [4, 5].

Building on different sets of measures, the LTS outlines eight scenarios, only two of which achieve economy-wide net-zero emissions by mid-century. Such deep decarbonisation requires emission reduction contributions from all sectors and implies a need to utilise the ability of the rural land-using sectors which, in addition to providing biomass for the replacement of carbon-intensive materials and products, can and should compensate for emissions through natural carbon removals, sequestration and storage in soils and biomass[2].

Compared to the current situation, the vision outlined in the EU LTS implies: greater production efficiency in agriculture; and maintaining and further increasing carbon stocks stored on farmed land. To this end, the strategy highlights a number of potential actions in the sector, including for example, digitalisation and smart technologies (as means of improving production efficiency) as well as ecosystem restoration (e.g. peatlands and wetlands), zero-tillage and the use of cover crops to enhance the absorption of CO_2. At the same time, land using sectors, including agriculture, will be called upon to supply increasing amounts of biomass for, among others, bioenergy production. EU LTS projections see an 80% rise in the consumption of bioenergy up to 250Mtoe in 2050. Meeting these multiple demands requires increased actions by the agriculture sector, whose potential to address climate mitigation has so far been underutilised.

This report explores how the EU farming sector could look in a net-zero world, what roles it would play and what is needed to make the transition by mid-century. It addresses the fundamental question of whether it is possible to reach climate neutrality in agriculture alone (Box 1) and if so, what actions and policies are needed to reach that point. In the context of this work we use agriculture as a term to refer primarily to production systems, including both crops and livestock. Therefore, the aim to reach net-zero emissions focuses first on eliminating those emissions associated with agricultural land-use and management without expanding to consider the offsetting of agricultural emissions through other land-using sectors (such as forestry). While this work deliberately follows a specific approach and focuses solely on the sector's contribution to climate mitigation, we recognise that there are additional dimensions that will need to be considered in any approach taken. These include but are not limited to impacts on biodiversity, human health, animal welfare as well as potential income effects.

The findings presented in this report are based on the combination of desk-based analytical research complemented with scenario assessments using the Carbon Transparency Initiative 2050 Roadmap Tool alongside interactions with stakeholders that occurred through dedicated stakeholder platforms, one at the EU level and another in France. These two groups had representatives from the farming sector (including associations) as well as from the broader farming industry, farm advisors, non-governmental and research organisations, who were consulted a number of times. While participants had the opportunity to discuss and comment on elements of the work, this report represents only the views of the authors.

After providing an overview of climate action in the agriculture sector (section 2), the report presents some key findings from existing studies (section 3). This, together with a number of illustrative low-carbon scenarios developed by the CTI 2050 Roadmap Tool (section 4) as well as lessons learned from the ongoing consultations around the French Low Carbon Strategy (section 5) allow us to draw some conclusions and recommendations about how to enable a net-zero transition in the EU agriculture sector (section 6).

BOX 1: CLIMATE-NEUTRALITY AND NET-ZERO EMISSIONS

Climate neutrality requires a "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases" [2]. By setting climate neutrality as a long-term goal, it is recognised that not all sectors will be able to reduce GHG emissions to zero within the timeframes needed, thus requiring carbon sequestration and removals to play a role. Throughout this report climate neutrality is used interchangeably with net-zero emissions.

2

CLIMATE ACTION IN THE EU AGRICULTURE SECTOR

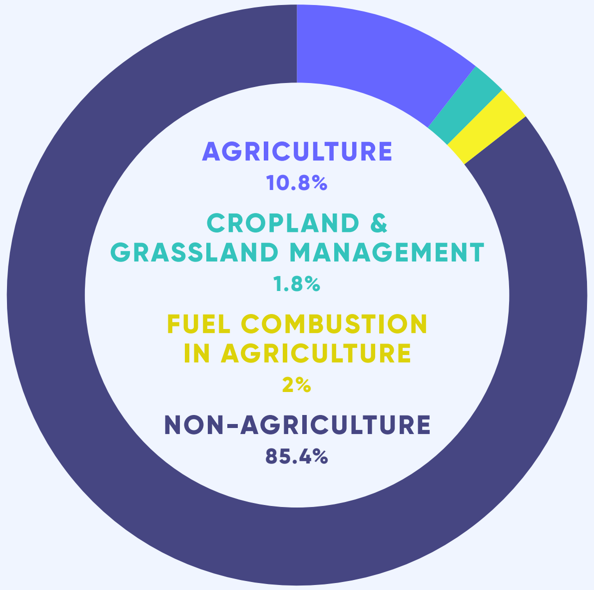
2.1 RATIONALE FOR ACTION – CLIMATE IMPACTS OF THE EU AGRICULTURE SECTOR

Agriculture is among the most exposed sectors to climate induced changes. As a primary production sector, farming activities are – to a great extent – dependent on the natural environment, including the weather, pollination by insects, and the availability of water and nutrients in soils. Changes in mean temperature and precipitation patterns, as well as more intense and extreme weather events, can pose a major challenge to the sector. Whilst some regions may see some limited and intermittent benefits arising from these changes, the overall effect on agricultural production in Europe is expected to be negative. The exceptionally warm and dry late spring and summer months in 2018 serve as the most recent example of this, following which cereal production in the EU was estimated to drop 8% below average [6]. In some MS yield losses were as high as 50% [7].

At the same time, the sector itself is a major contributor to GHG emissions. **In 2016[3], agricultural practices were responsible for approximately 10% of economy-wide GHG emissions in the EU.** There are, however, considerable variations between Member States, with agriculture accounting from ~3% to 33% of national GHG emissions. This is without considering emissions from on-farm energy use and changes in carbon stock stored in agricultural land (accounted for separately). With these combined sources the sector makes up approximately 15% of economy-wide GHG emissions in the EU (Box 2). Under the current EU climate policy framework (to 2020), non-CO_2 emissions from agriculture, together with emissions from transport, buildings, waste and small industry are covered under the Effort Sharing Decision (ESD) (Decision No 406/2009/EC) that sets binding targets for Member States but with flexibility on the potential contribution of individual ESD sectors. Accordingly, there are no sector specific mitigation targets for agriculture at the EU level.

BOX 2: ACCOUNTING OF AGRICULTURAL EMISSIONS

GHG emissions arising from agricultural production appear under multiple categories in national GHG inventory reports, which EU Member States and the EU as a whole are required to submit annually to the United Nations Framework Convention on Climate Change (UNFCCC). The "agriculture" category covers mainly non-CO2 emissions linked to enteric fermentation (from cattle, sheep and goats), fertiliser application and manure management. CO2 emissions arising from on-farm energy use for machinery, buildings and other activities are accounted for under the "energy" category. Changes in carbon stored in soils and biomass due to cropland and grazing land management practices are reported under the Land use, land use change, and forestry (LULUCF) category. Emissions arising from on-farm energy use for buildings and machinery are also accounted under other sectors.



The majority of agricultural emissions (~59%) are attributable to livestock production (including manure decomposition and enteric fermentation), as well as to microbial nitrification and denitrification processes in soils largely linked to the use of fertilisers (both organic and synthetic). These are primarily non-CO_2 emissions, i.e. methane (CH_4) and nitrous oxide (N_2O), which have significantly higher radiative forcing and longer atmospheric residence times than CO_2[4].

The overall emission trend in the agriculture sector is greatly influenced by changes in farm animal numbers and fertiliser use. Between 1990 and 2005, agricultural non-CO_2 emissions fell sharply in the EU owing to an overall reduction in livestock numbers over the same period, as well as declining fertiliser application and more efficient farming practices (including manure management). **Whilst GHG emissions from agriculture are now still below the level they were in 1990, reductions have slowed over the past decade and since 2012 emissions from the sector in the EU have started to rise again.** In addition to changing fertiliser management practices, this is due partly to a commensurate slowing in the reduction of livestock numbers. Compared to other sectors, agriculture has reduced its emissions the least since 1990 (Figure 2).

In reality however, climate impacts of the EU agriculture sector go beyond what appears under the agriculture category in the EU GHG inventory reports and what has been presented above. Accounting for emissions in this way masks the true impact of EU agriculture on the climate including the **large land use impact and consequently significant GHG footprint outside the EU's borders**[5]. The EU is highly import-dependent for a variety of different food commodities, for example protein imports to sustain its current livestock production. Up to 70% of high-quality protein feed is imported to the EU from third countries, including in particular the USA and some South-American states [8]. A recent life-cycle approach-based assessment suggests that 39% of the GHG emissions from the production of agricultural products in the EU occur outside the EU territory. These emissions are linked to the manufacturing of inputs used in EU production, including for example, feed imports, feed transport and emissions from land use change [9].

The current GHG inventory accounting framework under the UNFCCC deals separately with non-CO_2 and CO_2 emissions from cropland and grazing land management. Setting the boundaries in this way excludes changes in carbon stock stored in soils and biomass (of which agricultural practices are among one of the main driving forces) from commonly reported agriculture emission trends (mostly non-CO_2). Putting trees on agricultural land, draining peat lands, ploughing grasslands as well as tillage practices all have an impact on how these stocks develop over time. In the past years, soil carbon stocks in EU croplands and grasslands decreased, emitting around 70-80Mt CO_2 emissions annually[6], which is equivalent to around 17% of non-CO_2 emissions from EU agriculture.

In order to create a more real-world picture of the potential to reach net-zero emissions in the agriculture sector, we consider both CO_2 and non-CO_2 emissions footprints arising in the EU in relation to agricultural production. Thereby recognising the important role of increasing carbon stocks on agricultural land. More specifically, we account for non-CO_2 emissions from livestock production (including manure management) and crop production as well as changes in soil carbon stock that can result either in CO_2 emissions or removals[7]. Due to methodological reasons, we do not however include emissions from agricultural transport and buildings, as well as emissions arising beyond EU borders. Agriculture can also contribute to the decarbonisation of other sectors by providing biomass for the replacement of carbon-intensive materials and products. While this represents an important approach through which agriculture can contribute to the reduction of economy-wide emissions, these reductions are not accounted for under agriculture and hence are also beyond the scope of this study.

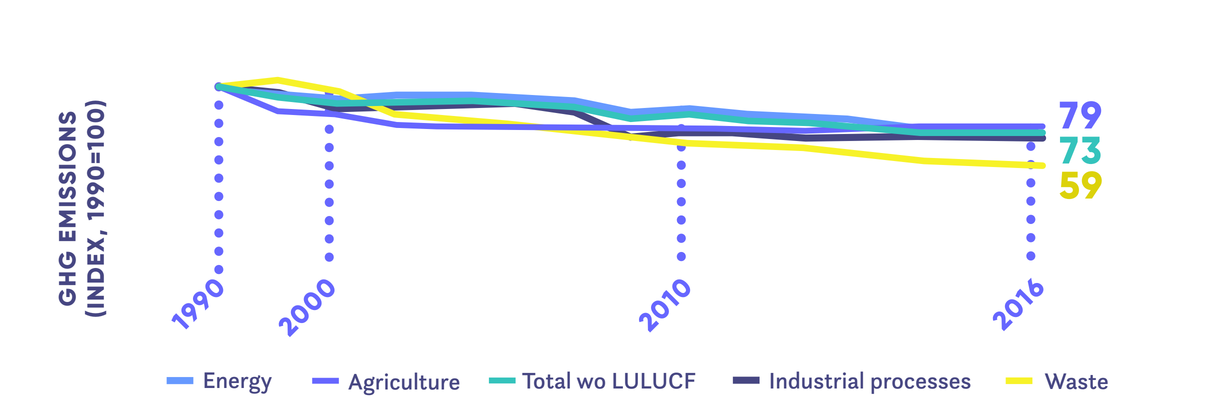


FIGURE 2: *Emission trends in the EU agriculture & other sectors between 1990 and 2016*

2.2 CLIMATE MITIGATION AND AGRICULTURE: POTENTIAL APPROACHES

Agriculture (together with other rural land using sectors) can naturally remove and store carbon in soils and biomass, its overall climate performance depends not only the level of GHG emissions but also the quantity of carbon it absorbs and retains from the atmosphere. This is a unique feature that increases the range of climate mitigation opportunities beyond those in other sectors. With this in mind, **mitigation in agriculture can rely on three fundamental approaches:**

1 CHANGING WHAT THE SECTOR PRODUCES TO MOVE TOWARDS COMMODITIES THAT HAVE A LOWER GHG FOOTPRINT.

Shifting towards less GHG intensive products inevitably implies a reduction in the production of certain commodities with a greater GHG footprint although it does not necessarily entail a reduction in overall production. Whilst this approach can lead to an absolute reduction in agricultural emissions in the EU, in order to avoid simply displacing production to non-EU countries (i.e. emission leakage), it is clear that there is concurrently a need for action beyond agricultural production to change consumption patterns, both in the EU and globally.

2 CHANGING THE WAY AGRICULTURE COMMODITIES ARE PRODUCED TO INCREASE THE PER UNIT GHG EFFICIENCY OF PRODUCTION.

Increased GHG efficiency refers to the reduction of GHG emissions per unit of output, i.e. the same quantity of output can be produced with lower GHG emissions. These positive impacts however, can, in part or in full, be eliminated by increased production levels making the direction of the overall impact more uncertain, which is often referred as rebound effect or Jevons paradox. From an economic perspective, improved GHG efficiency does not necessarily lead to more resource efficient production overall, i.e. it does not imply an increase in yields or overall output. For example, there might be feed additives that help mitigate methane emissions without having an effect, either positive or negative, on production and productivity.

3 INCREASING THE CARBON SEQUESTRATION POTENTIAL ON AGRICULTURAL LAND.

Unlike the other two approaches, increased carbon sequestration does not reduce the actual level of GHG emissions from the sector, but has the potential to lower the net climate impacts of agricultural production by removing and storing carbon in soil and biomass. This could be achieved through, among others, the protection of organic soils, introduction of trees into agricultural production (e.g. agroforestry) and changing tillage practices as well as by converting croplands to grasslands. Converting agricultural land to forest could yield higher mitigation benefits, however it implies a more significant change of land use with implications for agricultural production and for farm business models.

The three approaches described above constitute potential approaches within the agriculture sector to reduce GHG emissions and increase carbon removals. At the same time, mounting evidence points towards the need for action outside the sector to enable the transition to a low-carbon EU agriculture. Throughout this work, we refer to these issues as drivers of change as they influence how the agriculture sector develops. Consumption falls into this category, but there are a number of other examples that are discussed in section 6.

3

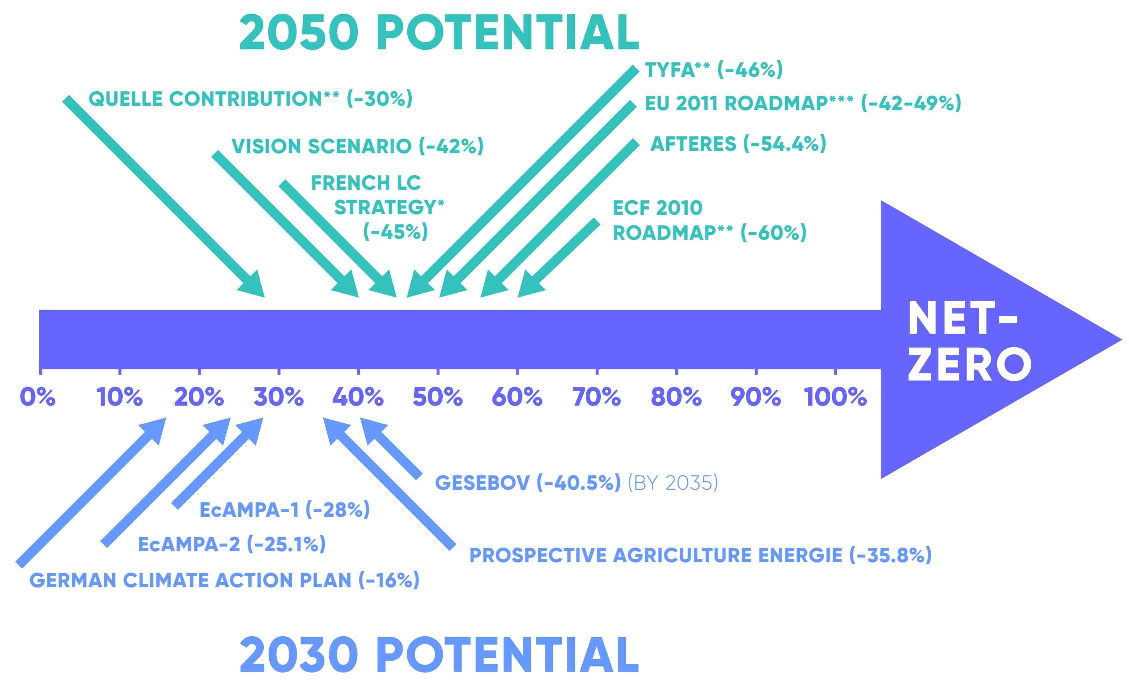
EXISTING SCENARIOS:

EXPECTATIONS AND POTENTIALS IN THE AGRICULTURE SECTOR

The latest assessments carried out by the European Commission, including the 2016 EU Reference scenario (Ref2016) [11] and the EU Agricultural mid-term outlook [12] based on the current policy framework, suggest only a moderate decline in agricultural emissions in the coming decades. A common characteristic of these scenarios is that they are consistent with the accounting rules described in Box 2 and mainly consider non-CO_2 GHGs as agricultural emissions, arising largely from enteric fermentation, manure decomposition and soils. Ref2016, which was used in the Impact Assessment of the Commission's LULUCF Regulation and Effort Sharing Regulation (ESR) proposals, forecasts a reduction of 2.8% in agricultural emissions by 2050 compared to 2005. This drop is in part attributable to declining mineral fertiliser use, while livestock emissions are expected to stagnate as a result of increasing animal numbers and productivity as well as of higher uptake of anaerobic digestion (AD) technology. The more recent EU agricultural mid-term outlook predicts a similarly modest reduction in agricultural emissions (i.e. -0.3% by 2030 compared to 2012). Both scenarios suggest that without additional efforts, emissions from EU agricultural activities will remain high in absolute terms and grow in relative terms as other sectors deliver continued emission reductions.

3.1 EMERGING CONSENSUS FROM EXISTING STUDIES

Over 60 relevant scenarios from 18 different studies[8] were reviewed in order to understand how and to what extent emissions from agriculture can be reduced, and whether there is consensus in the existing literature (Figure 3). In addition to climate considerations, the review also covered the wider environmental and socio-economic implications of the proposed pathways, including for example impacts on biodiversity and farm income.



All reductions are in comparison to 2005 figures with the exception of: *2015; **2010; ***1990
source: own compilation

FIGURE 3: *Reviewed studies and their most ambitious scenarios for the agriculture sector*

Of all the scenarios reviewed, most results coalesce into the 35-55% emission reductions by 2030 or 2050, leaving a significant gap to reaching net-zero. Of course, the scenarios have varying geographical scope and system boundaries, which limit or expand the potential mitigation approaches considered. Those that focus only on non-CO_2 emissions cannot benefit from the CO_2 sequestration potential provided by the sector, and thus the potential to offset 'unavoidable emissions' from production. **Reaching net-zero emissions requires a broader consideration of the tools and options available to the agriculture sector,** including land use change and ecosystem restoration. In general, the wider the system boundary, the more likely it is to see greater emission reductions in the different scenarios.

3.2 GOING BEYOND CLIMATE CONSIDERATIONS:
TRADE-OFFS AND CO-BENEFITS

While climate actions are broadly synergistic with several other policy objectives conflicts can arise if care is not taken to ensure coherence, especially during implementation. Scenarios vary in how explicit they are regarding trade-offs and co-benefits, whether environmental such as biodiversity, or socio-economic like farm incomes. Economy-wide decarbonisation scenarios tend to focus on socio-economic trade-offs and co-benefits (e.g. energy costs, job creation, etc.) and, to a lesser extent, on environmental ones (often limited to air quality). As such, they do not necessarily provide a comprehensive overview of the implications of the measures specifically proposed in the agriculture sector, although they might have considerable impacts, for example, on biodiversity or land-use (Table 1).

Scenarios with broader objectives than climate mitigation, such as Poux and Aubert (2018) [13], Muller et al. (2016) [14] or Westhoek et al. (2014) [15], are, of course, often more explicit on co-benefits of a wider nature, including impacts on biodiversity, human health, land footprint, air and water pollution. Associated trade-offs usually concentrate on decreases in yield and associated economic impacts, especially for livestock farmers and other actors of the food chain with related activities (Table 1).

The above assessment confirms that while climate action in the agriculture sector can contribute to other policy objectives, some practices beneficial from a climate mitigation point of view might have negative consequences for farm income, biodiversity and other environmental, social and economic objectives. It is therefore essential that throughout the design and implementation of climate mitigation policies in the agriculture sector, care is taken to balance the multiple ways of achieving net-zero emissions without threatening other social and environmental objectives.

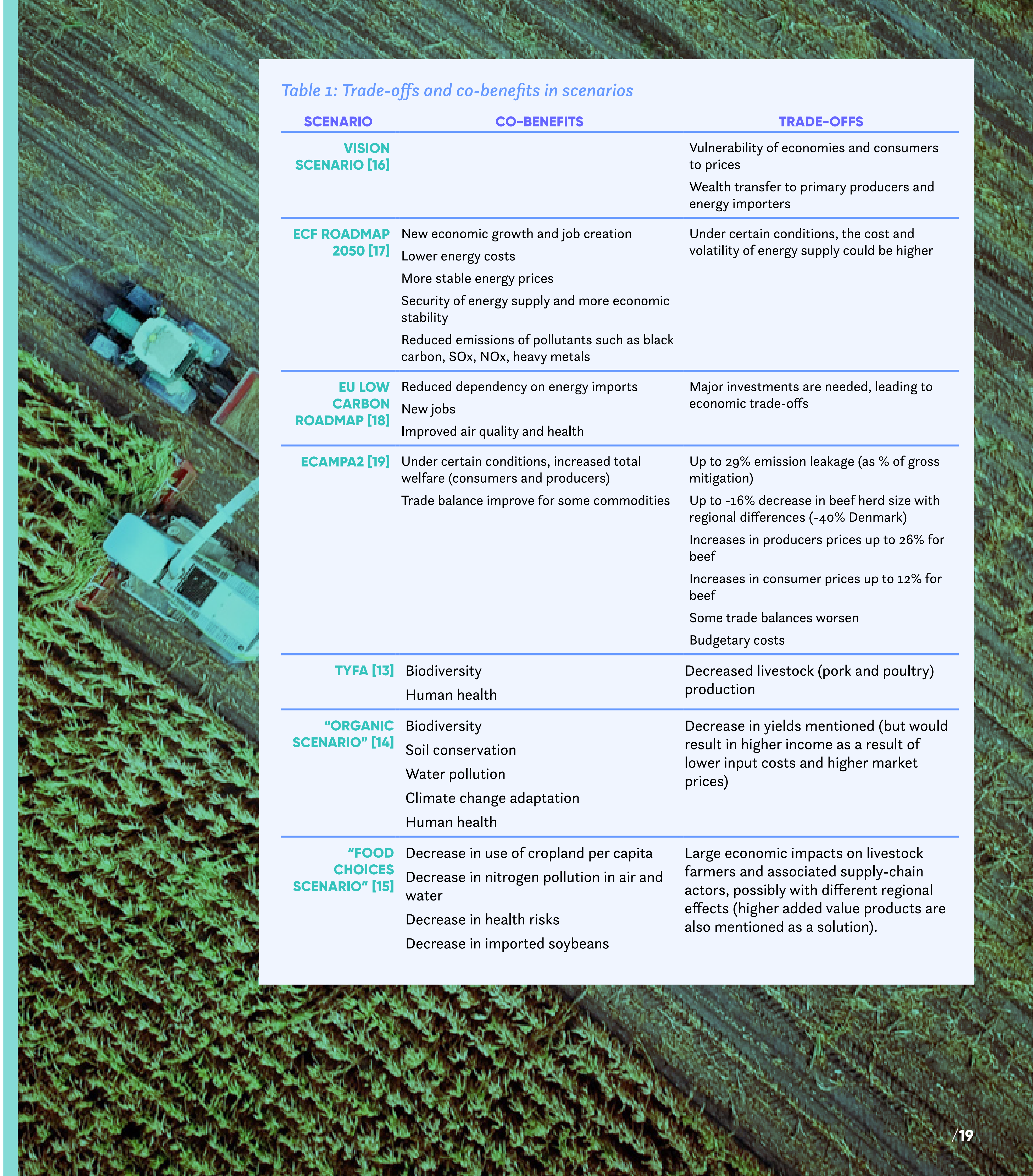


Table 1: Trade-offs and co-benefits in scenarios

SCENARIO	CO-BENEFITS	TRADE-OFFS
VISION SCENARIO [16]		Vulnerability of economies and consumers to prices Wealth transfer to primary producers and energy importers
ECF ROADMAP 2050 [17]	New economic growth and job creation Lower energy costs More stable energy prices Security of energy supply and more economic stability Reduced emissions of pollutants such as black carbon, SOx, NOx, heavy metals	Under certain conditions, the cost and volatility of energy supply could be higher
EU LOW CARBON ROADMAP [18]	Reduced dependency on energy imports New jobs Improved air quality and health	Major investments are needed, leading to economic trade-offs
ECAMPA2 [19]	Under certain conditions, increased total welfare (consumers and producers) Trade balance improve for some commodities	Up to 29% emission leakage (as % of gross mitigation) Up to -16% decrease in beef herd size with regional differences (-40% Denmark) Increases in producers prices up to 26% for beef Increases in consumer prices up to 12% for beef Some trade balances worsen Budgetary costs
TYFA [13]	Biodiversity Human health	Decreased livestock (pork and poultry) production
"ORGANIC SCENARIO" [14]	Biodiversity Soil conservation Water pollution Climate change adaptation Human health	Decrease in yields mentioned (but would result in higher income as a result of lower input costs and higher market prices)
"FOOD CHOICES SCENARIO" [15]	Decrease in use of cropland per capita Decrease in nitrogen pollution in air and water Decrease in health risks Decrease in imported soybeans	Large economic impacts on livestock farmers and associated supply-chain actors, possibly with different regional effects (higher added value products are also mentioned as a solution).

![4]

POTENTIAL PATHWAYS FOR A LOW CARBON EU AGRICULTURE

The range of potential emission reductions from agriculture set out in existing scenarios, do not reach consensus on which approach could be leveraged to deliver the greatest emission reductions, or the impacts of doing so.

Based on modelling work undertaken with the Carbon Transparency Initiative 2050 Roadmap Tool (CTI tool; see Box 3) four illustrative scenarios[9] have been developed and analysed to test the potential for moving the EU agriculture sector closer to net-zero by 2050 through efficiency improvements; changes in production volume and/or mix; as well as increasing carbon sequestration potential on farmed land on. These are:

1) *Efficiency improvements and carbon sequestration with no major land use changes*
2) *Production changes and carbon sequestration with no major land use changes*
3) *Efficiency improvements, production changes and carbon sequestration with no major land use change*
4) *Efficiency improvements, production changes and carbon sequestration with major land use change*

Scenarios 1 & 2 rely solely on efficiency measures and production changes respectively, while scenario 3 combines the two approaches. In all three cases, the area needed for crop production becomes smaller and the surplus land is mainly utilised as pasture. Scenario 4 is, to a large extent, similar to that of scenario 3 but the majority of surplus land is converted to forest.

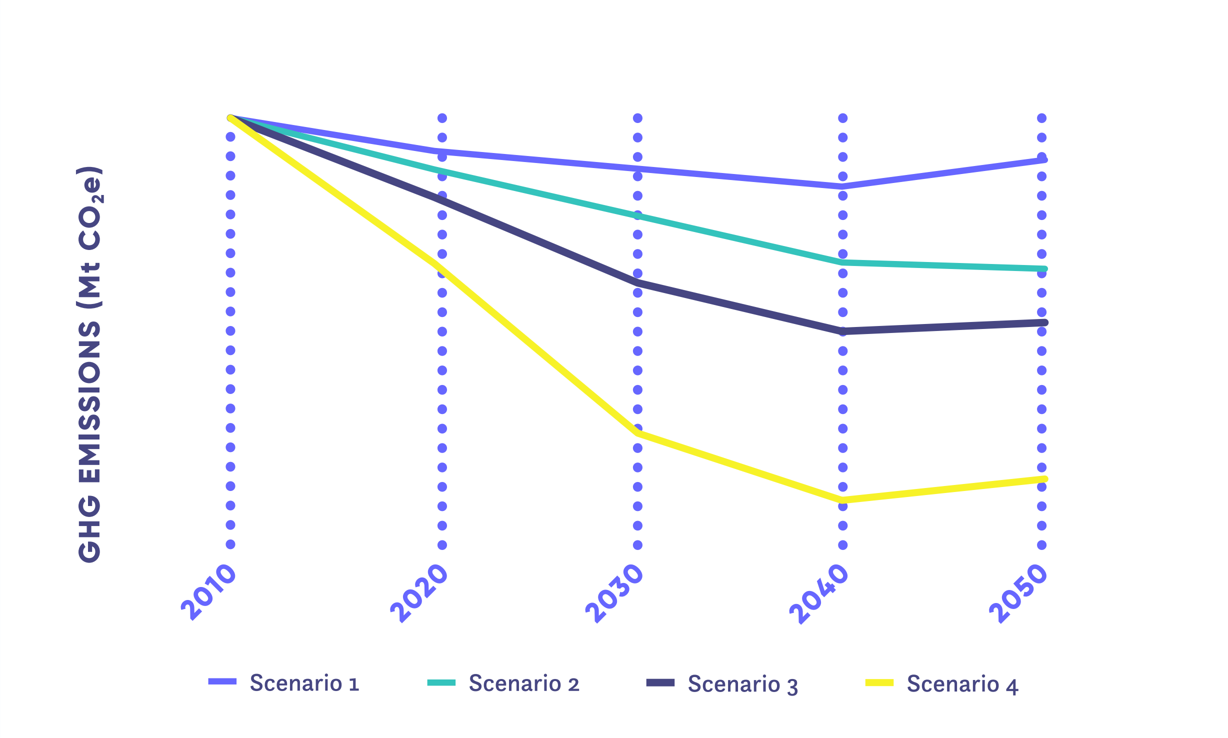


FIGURE 4: *Illustrative mitigation scenarios assessed in the report for the EU agriculture sector*

BOX 3: THE CTI 2050 ROADMAP TOOL

The publicly available webtool is the outcome of a year-long effort involving both in-depth analytical work and engagement with stakeholders. It builds on the model developed as part of the Carbon Transparency Initiative (CTI) by the ClimateWorks Foundation and has been extended and upgraded for the EU with the support of the European Climate Foundation (ECF), in consultation with key experts in the field.

The outcome is an economy-wide model covering the same emissions sources as national greenhouse gas inventories, including international aviation, shipping, and Land Use, Land-Use Change and Forestry (LULUCF). For each sector of the EU economy that emits GHGs, the GHG emissions drivers and means of reducing them – referred to as 'levers'- are modelled. Rather than calculating optimal pathways, the model allows the user to choose the ambition level of each individual lever, from a reference level up to a maximum technical ambition level, and thereby explore different scenarios or pathways by 2050.

Considering specifically the agriculture and land using sectors, the model takes exploitable land (~EU surface less urbanized and unexploitable areas; e.g. desert) as a starting point, deducts the area needed for food production (export inclusive) and allocates any potential surplus land according to the user's decision. A sustainable bioenergy potential is calculated based on the land use and compared to the demand from sectors. With the exception of total available (exploitable) land area (which is driven mainly by urbanisation patterns) and population, all other allocation steps are directly or indirectly (e.g. through making assumptions around dietary patterns) defined by the user. As is the case of any modelling-based approach, the CTI tool also works on the basis of observations and assumptions, which should be kept in mind when interpreting the results. The most important assumptions are stated under the individual scenarios. For a complete list see Climact (2018) [3].

4.1 MITIGATION POTENTIAL THROUGH EFFICIENCY IMPROVEMENTS AND CARBON SEQUESTRATION EFFECTS WITHOUT MAJOR LAND USE CHANGE

Further increasing production efficiency (e.g. increasing yields) is often at the forefront of measures proposed to address the climate mitigation challenge in agriculture. In this scenario, most of the surplus land is utilised as temporary grassland, while only a smaller share is converted to forest and permanent grassland, yet there are some carbon sequestration benefits as a result of soil carbon stock changes.

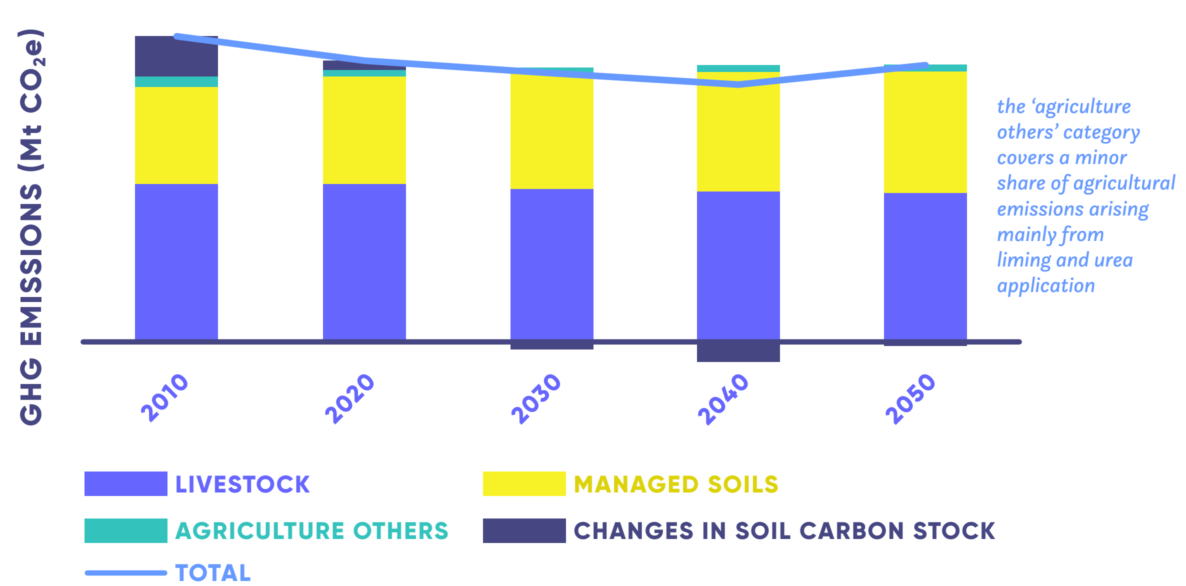


FIGURE 5: *Scenario 1 - GHG emissions and removals by source in the EU agriculture between 2010 and 2050*

RESULTS: ~10% REDUCTION BY 2050 (COMPARED TO 2010)

Assuming similar production patterns as today, our estimations based on the CTI tool show relatively modest mitigation potential (10% reduction by 2050 compared to 2010) resulting from production efficiency increases even with a substantial and sustained 40% increase of current yields by 2050. This is partly due to elevated fertiliser use and thus greater input emissions, despite the freeing up of some productive land[10].

The climate performance of EU agriculture could potentially be further improved through the adoption of more GHG efficient production systems, and the use of more widespread availability and deployment of specific mitigation technologies currently not considered by the CTI tool (e.g. anaerobic digesters). For example, the 2011 EU Low-carbon Roadmap projected a decline of around 30% in agricultural non-CO_2 emissions by 2050 linked to the implementation of measures like farm-scale anaerobic digestion, precision farming and better feed mixes (which are not fully integrated into the CTI tool). However, even by adopting these practices, and a greater mitigation potential, it is unlikely that relying solely on efficiency measures will be able to lead the agriculture sector to net-zero emissions by mid-century.

KEY ASSUMPTIONS

1. Only a limited set of potential measures is considered (see points 2-4 below)
2. Intensification of livestock production (both feedlot and pasture fed)
   - Maximum[11] increase of feedlot systems (i.e. 50% of cows and bovines; 20% of goat and sheep in 2050) and feed conversion ratio (+40% by 2050 vs 2015)
   - Maximum increase of pasture fed animal concentration (i.e. +50% by 2050 vs 2015) and feed conversion ratio (+20% by 2050 vs 2015)
   - Constant emission per livestock unit (LSU)
3. Large increase of annual crop yields, of which 30% is assumed to come from additional fertiliser use
   - Linear increase of 40% in 2050 vs 2015
   - 1.5% p.a. for bioenergy crops
4. Large improvement of on-farm and post-farm waste collection
   - 50% of on-farm waste collected in 2050
   - 80% of post-farm meat waste collected in 2050 vs 40% in 2015
5. Agricultural lands producing bioenergy, food and non-food crops (i.e. temporary grassland) are assumed to have identical soil carbon stock, which remains unchanged over time. This implies that mitigation benefits linked to changes in soil carbon stock only arise if cropland is converted to permanent grassland or forest.
6. Freed-up land is assumed to be utilised mainly as temporary grassland/pasture and, to a much lesser extent, as forest and permanent grassland. All soil carbon stock changes in the LULUCF sector are attributed to agriculture.

4.2 MITIGATION POTENTIAL THROUGH CHANGES IN PRODUCTION AND CARBON SEQUESTRATION WITH NO MAJOR LAND USE CHANGE

Changing production volumes and at the same time moving towards less carbon intensive products could substantially reduce the climate impacts of agricultural production, mainly by reducing non-CO_2 emissions from the sector[12]. However, changing the production of agricultural commodities also requires action to address the consumption of those commodities, lest they be substituted through imports and thus lead to the leakage of GHG emissions out of the EU.

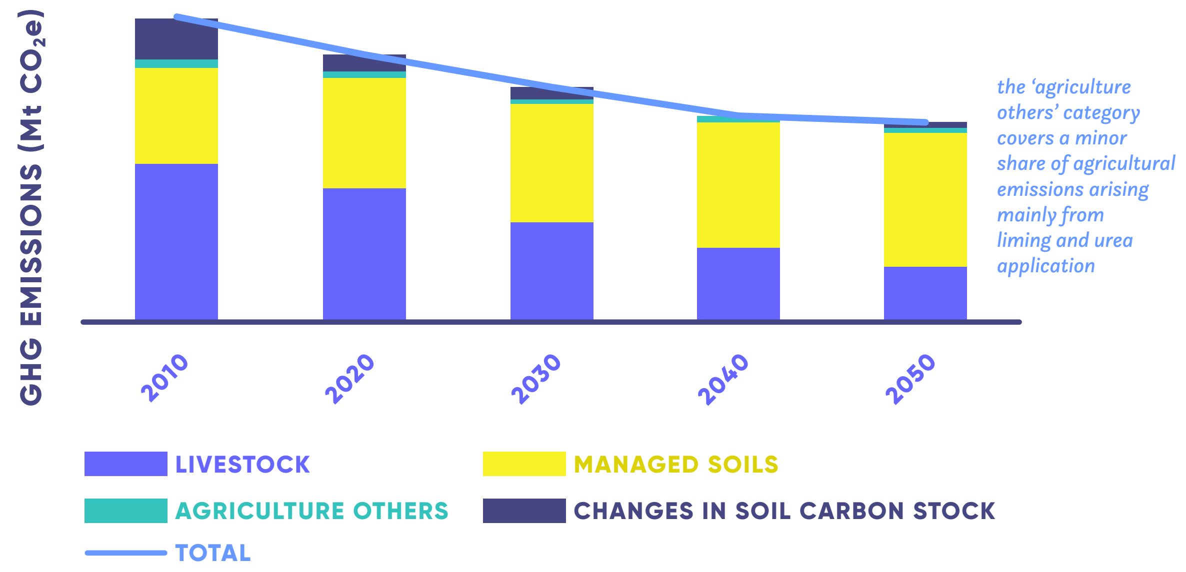


FIGURE 6: *Scenario 1 - GHG emissions and removals by source in the EU agriculture between 2010 and 2050*

RESULTS: ~ 33% REDUCTION BY 2050 (COMPARED TO 2010)

One area that has gained particular attention in the climate debate in recent years, is livestock. Whilst the consumption of different types of animal products has been changing (such as increased cheese and poultry consumption, while the consumption of bovine meat has been decreasing), on average EU meat consumption is still twice as large as the World Health Organisation recommendations (although consumption patterns vary considerably across MS). A 10% reduction in total calories consumed by EU inhabitants coupled with a more substantial decrease in meat consumption (with a lower share of ruminants) could cut agricultural emissions by about one third by 2050 (compared to 2010 levels) as modelled with the CTI tool. This includes some limited mitigation benefits arising from increased soil carbon stocks but without necessitating any major land use change. In order to limit export-driven production, the EU is assumed to be self-sufficient in food and meat production by 2050 (i.e. zero net ratio of domestic food/meat production over consumption).

KEY ASSUMPTIONS

1. Lower production levels and changing production mix primarily triggered by changing consumption patterns and trade balance:
   - Up to 10% linear reduction of calories consumed (by 2050 vs 2015)
   - -75% of meat consumption by 2050 vs 2015
   - Low share of ruminant in total meat consumption (i.e. 10% in 2010)
   - EU self-sufficiency in food and meat; i.e. net-zero trade balance in 2050
2. Agricultural lands producing bioenergy, food and non-food crops (i.e. temporary grassland) are assumed to have identical soil carbon stock, which remains unchanged over time. This implies that mitigation benefits linked to changes in soil carbon stock only arise if cropland is converted to permanent grassland or forest.
3. Freed-up land is assumed to be utilised mainly as temporary grassland/pasture and, to a much lesser extent, as forest and permanent grassland. All soil carbon stock changes in the LULUCF sector is attributed to agriculture.

4.3 MITIGATION POTENTIAL THROUGH A COMBINATION OF EFFICIENCY AND PRODUCTION MEASURES WITHOUT MAJOR LAND USE CHANGE

Agricultural emissions can be halved by 2050 by increasing efficiency and changing what commodities we produce and how we produce them. This is achieved through the combination of reduced emissions and increased carbon sequestration in soils whilst maintaining agricultural area (i.e. without significant changes in land use).

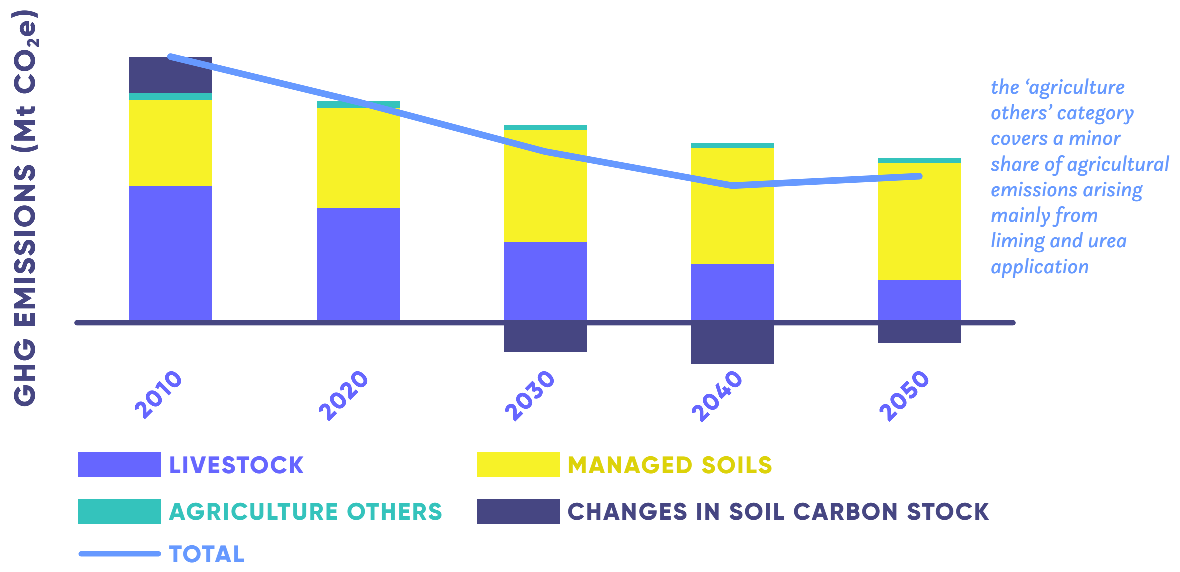


FIGURE 7: *Scenario 3 – GHG emissions and removals by source in the EU agriculture between 2010 and 2050*

RESULTS: ~ 46% REDUCTION BY 2050 (COMPARED TO 2010)

This scenario combines the approaches of the two previous pathways (scenarios 1 & 2) leading to a slightly higher reduction in emissions than the aggregated potential of individual pathways. This difference stems mainly from the positive changes in soil carbon stock, which unlike under the previous scenarios, becomes a major sink of emissions starting from 2030. This is of course linked to the size of surplus land, of which 80% is utilised as pasture/temporary grassland and only a small share is converted to permanent grassland and forest. At the same time, livestock emissions are also reduced, approximately three-fold by 2050 (compared to 2010. Despite these significant reductions, this suggests that without major land use changes, residual emissions from the sector will remain high in 2050 (i.e. around 250Mt CO_2e).

KEY ASSUMPTIONS

1. Intensification of livestock production (both feedlot and pasture fed)
   - Maximum increase of feedlot systems (i.e. 50% of cows and bovines; 20% of goat and sheep in 2050) and feed conversion ratio (+40% by 2050 vs 2015)
   - Maximum increase of pasture fed animal concentration (i.e. +50% by 2050 vs 2015) and feed conversion ratio (+20% by 2050 vs 2015)
2. Large increase of annual crop yields, of which 30% is assumed to come from additional fertiliser
   - Linear increase of 40% in 2050 vs 2015
   - 1.5% p.a. for bioenergy crops
3. Large improvement of on-farm and post-farm waste collection
   - 50% of on-farm waste collected in 2050
   - 80% of post-farm meat waste collected in 2050 vs 40% in 2015
4. Agricultural lands producing bioenergy, food and non-food crops (i.e. temporary grassland) are assumed to have identical soil carbon stock, which remains unchanged over time. This implies that mitigation benefits linked to changes in soil carbon stock only arise if cropland is converted to permanent grassland or forest.
5. Freed-up land is assumed to be utilised mainly as temporary grassland/pasture and, to a much lesser extent, as forest and permanent grassland. All soil carbon stock changes in the LULUCF sector is attributed to agriculture.
6. Lower production levels and changing production mix primarily triggered by changing consumption patterns and trade balance:
   - Up to 10% linear reduction of calories consumed (by 2050 vs 2015)
   - -75% of meat consumption by 2050 vs 2015
   - Low share of ruminant in total meat consumption (i.e. 10% in 2010)
   - EU self-sufficiency in food and meat; i.e. net-zero trade balance in 2050

MITIGATION POTENTIAL THROUGH A COMBINATION OF EFFICIENCY AND PRODUCTION MEASURES WITH MAJOR LAND USE CHANGE

4.4

Major emission reductions can be achieved when more transformational changes are made to the agriculture sector. This scenario considers the combination of significantly increased yields and production efficiency, allowing concentrated production to free up agricultural land for conversion to forest. The difference between the third scenario and this one is linked to the allocation of surplus land. In the previous scenario, the freed up land has been almost entirely utilised for agricultural purposes (i.e. as temporary grassland/pasture) leading to more limited carbon sequestration benefits. Using the CTI tool, it is possible to simulate the impact of converting almost all (80%) of the freed-up land from production to forest land, and thus demonstrate the carbon sequestration potential that could be realised in such a scenario. Yet, even with such extreme changes, emission reductions do not reach net-zero and therefore reaching a climate-neutral agriculture may require the sector to compensate some unavoidable emissions through existing carbon sinks in other land using sectors such as forestry.

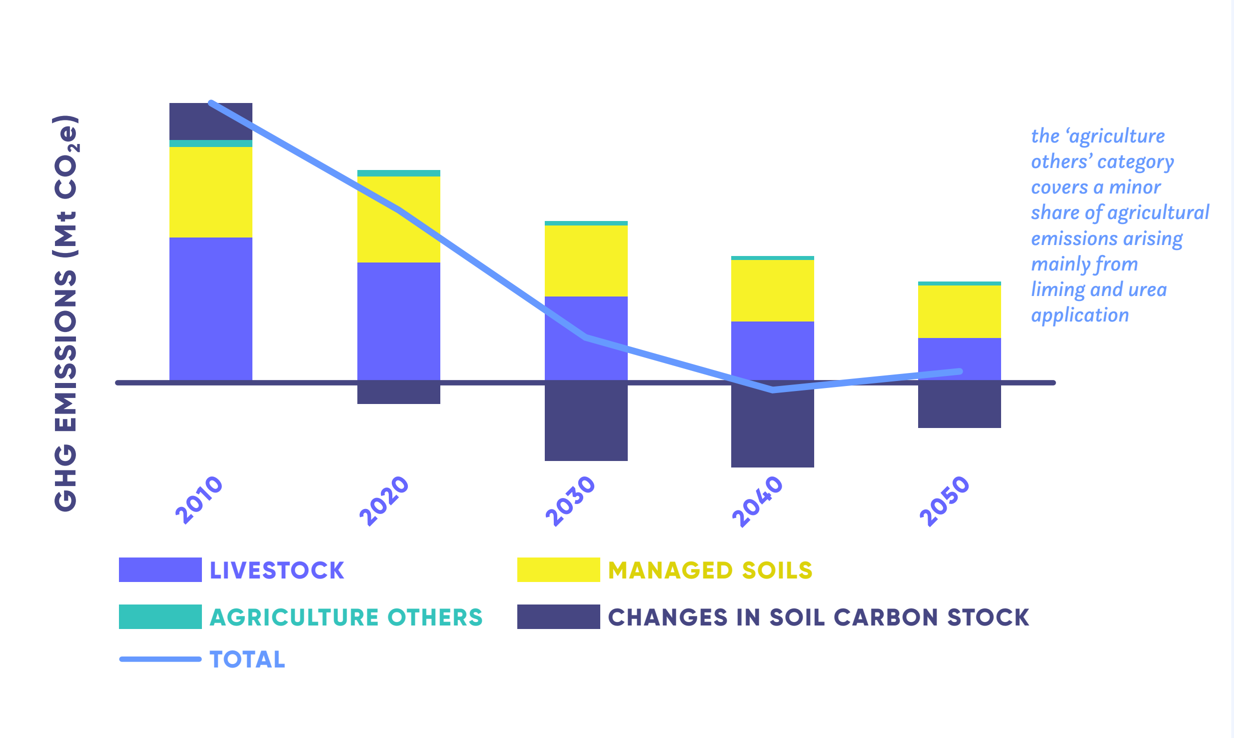


FIGURE 8: *Scenario 4 – GHG emissions and removals by source in the EU agriculture between 2010 and 2050*

RESULTS: ~81% REDUCTION BY 2050 (COMPARED TO 2010)

KEY ASSUMPTIONS

1. Intensification of livestock production (both feedlot and pasture fed)
   - Extreme increase of feedlot systems (i.e. 50% of cows and bovines; 20% of goat and sheep in 2050) and feed conversion ratio (+40% by 2050 vs 2015)
   - Extreme increase of pasture fed animal concentration (i.e. +50% by 2050 vs 2015) and feed conversion ratio (+20% by 2050 vs 2015)
2. Large increase of annual crop yields, of which 30% is assumed to come from additional fertiliser
   - Linear increase of 40% in 2050 vs 2015
   - 1.5% p.a. for bioenergy crops
3. High improvement of on-farm and post-farm waste collection
   - 50% of on-farm waste collected in 2050
   - 80% of post-farm meat waste collected in 2050 vs 40% in 2015
4. Agricultural lands producing bioenergy, food and non-food crops (i.e. temporary grassland) are assumed to have identical soil carbon stock, which remains unchanged over time. This implies that mitigation benefits linked to changes in soil carbon stock only arise if cropland is converted to permanent grassland or forest.
5. Freed-up land is assumed to be utilised mainly as forest (80%) and permanent grassland (20%). All soil carbon stock changes in the LULUCF sector is attributed to agriculture.
6. Lower production levels and changing production mix primarily triggered by changing consumption patterns and trade balance:
   - Up to 10% linear reduction of calories consumed (by 2050 vs 2015)
   - -75% of meat consumption by 2050 vs 2015
   - Low share of ruminant in total meat consumption (i.e. 10% in 2010)
   - EU self-sufficiency in food and meat; i.e. net-zero trade balance in 2050

SCENARIO METHODOLOGIES & CONSULTATIVE PROCESSES:

A FRENCH EXAMPLE

Models provide a coherent and internally consistent approach to develop and assess alternative future pathways and thus they play a key role in the development of climate mitigation policies. However, while scenarios show what could be delivered in a modelled world, the feasibility of these outcomes require a reality check by a wider group of stakeholders. For example, intensifying production and converting the majority of surplus land to forest can substantially reduce GHG emissions, yet it is unlikely to happen. Discussions around the new French National Low Carbon Strategy serve as a good example of the role and benefits of such consultations.

BOX 4: CONTEXT AND ORGANIZATION OF THE FRENCH CONSULTATIVE PROCESS

The French National Low Carbon Strategy, first published in 2015, has been reviewed recently in order to better align its objectives with the Paris Agreement. Between October 2017 and June 2018, five workshops were organized, addressing mitigation ambition in the agriculture sector. More specifically, participants, including representatives from the farming sector, technical institutes, environmental NGOs and local agricultural chambers, explored how emissions from the sector could be halved by 2050 compared to 1990 levels. The ClimAgri [20] calculator was used to assess the mitigation potential of various measures going beyond a business as usual scenario. Input variables to the calculator, such as land use, yields, livestock population, had been initially defined based on the review of relevant literature (e.g. foresight exercises) but they were reassessed and changed if needed to reflect the feedback received from stakeholders. There are currently three scenarios on the table, the first one focusing on agroecology, the second on precision agriculture and the last one targeting the demand side (the main levers are listed below). Further engagement with stakeholders will aim at combining the above mentioned three approaches into one scenario leading to a 50% reduction in agricultural emissions by 2050 compared to 1990.

Table 2: Main levers in the agriculture sector discussed by stakeholders in the context of the new French National Low Carbon Strategy

PRODUCTION SIDE	DEMAND SIDE
An expansion of organic farming reaching 44% of cropland by 2050	A move towards healthy diets
An expansion of protein crops (mainly for feed)	No major changes in the size of area used for biofuel production
An expansion of agroforestry and hedges	Decreasing import of animal feed reaching 5% of the volumes imported in 2015
A more widespread use of anaerobic digesters	Export patterns of agricultural products remain unchanged
Decrease of cattle population by approximately one third	

The mix of measures discussed in the new French National Low Carbon Strategy (FNLCS) (Box 4) would fundamentally change what agricultural commodities are produced in the country and also the way those goods are produced. Stakeholders tend to perceive individual measures differently depending on whether they affect production volumes or not. In general, the more technical interventions, including for example low protein livestock feed and reduced tillage practices, seem to be well accepted, while measures leading to a reduction in livestock production have raised concerns (especially among beef and dairy producers). Stakeholders have called on the FNLCS to provide more information about the potential negative socio-economic impacts of the measures proposed and include actions to minimize these effects. It was also highlighted during the consultations that the modelling work conducted for the revision of the FNLCS only provides information about how land use may change at the national level but very little is said about what these changes could mean at the farm/food chain level.

Whilst the above discussions have taken place specifically in the French context, they illustrate well the challenges that might be faced in designing net-zero pathways in agriculture in general. Existing scenarios, including the illustrative ones described in section 4, indicate large mitigation potential in the sector, however their implementation may prove to be difficult, which is partly related to the low acceptance of measures often linked to economic or other trade-offs. This calls for the careful consideration of trade-offs and co-benefits (see also section 3.2) and for regular consultation with stakeholders throughout the design and implementation of climate mitigation policies and practices in agriculture.

6

CONCLUSIONS AND DRIVERS OF CHANGE:

HOW TO ENABLE THE TRANSITION TO A NET-ZERO AGRICULTURE SECTOR?

Agriculture along with other rural land-using sectors, is **unique in its ability to both reduce its own emissions, but also increase carbon removals from the atmosphere, and contribute to emission reductions in other sectors through the substitution of carbon intensive materials and energy.** This study has focussed on first understanding what could be done to move the agricultural sector emissions towards net-zero, before looking at its potential to support other sectors in the economy or rely on those sectors to offset any unavoidable emissions.

Improving the efficiency of production, changing what and how commodities are produced, as well as increasing sequestration capacity, are all options available to the sector. The analysis undertaken using the CTI 2050 Roadmap Tool (providing consistent assessment) shows that none of these approaches on their own can deliver the mitigation level necessary for a net-zero future. Whilst the absolute potential of individual approaches may change depending on implementation choices, it is clear from our analysis that only by combining these options can the sector move further towards becoming climate-neutral. **To enable agriculture to make a significant and proportionate contribution to the EU's climate mitigation efforts will therefore require the deployment of all the tools and options available to the sector to drive down GHG emissions and increase the absorption of carbon from the atmosphere.** The assessment undertaken in this study suggests emissions could be reduced by up to 37% by 2030 and 46% by 2050 (compared to 2010 levels), without major changes in land use. This is commensurate with the wider review of existing EU-level scenario assessments which coalesce in the 35% to 55% range, excluding some outlying studies.

Whilst a major step forward, this still presents a significant emission gap by 2050 of between 323Mt and 265 Mt. Closing this gap, at least partially, calls for a more fundamental change in the way we utilise rural land and consume the products it produces. The above-discussed approaches provide opportunities for converting some areas currently used for crop and livestock production to forests. In the most extreme scenario, ~81% emission reductions (~400Mt) from the agriculture sector are addressed by utilising 80% of the freed upland as forests (and the remaining 20% as permanent grasslands), increasing the EU forest area up to 57% compared to 2010. This significant shift relies freeing up agricultural land through changing the type of agricultural commodities that are produced and doing so more efficiently as well as reducing overall production linked to changed consumption patterns. With such widespread afforestation, this approach also begins to blur the lines between changes in agricultural practices and the development of forestry.

Yet event with such extreme changes, there remain at least 20% (90Mt) of emissions to address before net-zero could be reached. Whether this gap can be closed by those measures that are currently not integrated into the CTI 2050 Roadmap Tool is still to be assessed. Nevertheless, there might be a need to compensate some agricultural emissions through other land-using sectors (such as forestry). It is therefore important to consider what additional sink potential agriculture can appropriate (both within a Member State and across the EU), and what implications this has for those sectors and others in the economy that may look to the same sinks for the same purposes.

Only by coordinating actions across both the production and consumption (supply and demand) sides can we transform the way agricultural products are conceived in response to the climate challenge and how the sector can therefore support climate action. Enabling the necessary changes in agriculture requires clarity on what actions should be taken and by whom. It can be difficult to understand when to avoid emissions, where it is reasonable to increase efficiency to reduce per-unit emissions, or when it is appropriate to off-set emissions. **It may therefore be necessary to develop an emission reduction hierarchy to guide and support actions across the agri-food sector** following similar approaches taken towards waste and the EU's circular economy transition, for instance:

- **Avoiding emissions where possible.** Changing the types of commodities produced, reducing the consumption of livestock and other carbon-intensive products, and eliminating food waste;
- **Reducing emissions where they can-not be avoided.** Increasing the resource-efficiency of production, lowering the per-unit GHG emissions of a commodity, producing seasonally and in the most optimal conditions in Europe, and reducing harvesting wastes;
- **Recovery of emissions where possible.** Increasing the sequestration potential on land to build carbon sequestration into standard production practices and ensuring its continued and permanent management on agricultural land. Developing circular-bioeconomies that recover post consumption and production nutrients, energy and materials as inputs to the sector, reducing the need for new inputs. Future agriculture must be different from that of today, sufficiently transformed to enable its contribution to combating climate change and the delivery of net-zero emissions, while providing adequate nutrition and other ecosystem services to an increasingly global society.

RECOMMENDATIONS

Moving the sector towards net-zero emissions by mid-century, consistent with the ambition of the Paris Agreement, presents one of the most transformational challenges faced by the sector since the development of post-war agriculture. Not only does this imply coordinated action at the EU level, it also requires adequate resourcing, research and innovation to enable the changes needed, both in the sector and those that influence it. The following recommendations help address these needs. They have been developed as outputs from this study, and some tested with a range of stakeholders at the UNFCCC COP24 Climate Conference, and the IEEP Think2030 conference on the future of EU environmental policy.

ACTION IN THE AGRICULTURE SECTOR

To ensure a proportionate contribution from the sector, **agriculture should be target-driven** in the EU's ambition to move towards net-zero emissions by mid-century or before. The prerequisite for this is greater clarity on where the boundaries of the sector lie; i.e. which sources and sinks that sector has control over. This may not be fully in line with the current accounting framework.

The perceived high-cost and **'special nature' of agriculture should be reviewed** in light of the pressing need to achieve emission reductions in the sector and the opportunities for growth by exploiting its unique potential to develop carbon sinks in combination with territorial development and commodity production.

Future agriculture and food policies should facilitate the **transition to sustainable farming by rewarding farmers for the environmental and climate public goods they deliver,** better reflecting the challenges faced (by farmers and society), the need for change, and to support farmers in making low carbon choices the norm. Farms and farm-businesses should be made more resource efficient, low carbon, ecologically sound, sustainable and resilient. In turn this should enable farms to become more independent and able to align themselves with what European citizens want from their rural environment.

Enabling farmers with the tools for change is crucial – this requires **greater research and innovation support** for climate-smart agriculture solutions, both at the EU level and in Member States with investments focussed across the three levers for change, emission reductions, increased removals and changes in production composition. In addition to product innovation and technological changes, this might also include **'system innovation'**, a larger scale transformation covering the wider organisational and institutional aspects of how our society functions. At the same time, dissemination, capacity building and increased uptake of existing mitigation technologies and practices should be considered as important as developing new and innovative approaches.

Inclusion of farmers in climate action is crucial in order to achieve global mitigation targets without compromising global food and nutrition security and the Sustainable Development Goals. **Transforming the sector will take time, requiring long term investment and commitments at all levels.**

NEED FOR ACTION OUTSIDE AGRICULTURE

Moving towards the production of commodities with lower carbon footprint to avoid emissions from agriculture implies a commensurate change in **consumption**, in order to avoid emission leakage through imports. Altering consumption requires the gap between the retail price of food and its true cost to sustainability, the environmental, climate and animal welfare impacts of producing cheap food to be addressed, internalising these impacts in the cost of food commodities and products. This would serve to rebalance the cost of food where sustainable products becomes cheaper and more convenient to consumers, whilst unsustainable ones more expensive and difficult to obtain.

Trade is also an important driver of both producer and consumer behaviour. A low-carbon transition in the agriculture sector does not imply a reduction in trade, but a need for it to become orientated towards the supply and consumption of low carbon products leading to new growth opportunities in an increasingly climate conscious world. Consistent standards for monitoring GHG embedded in trade flows would be an important staring point in this regard.

In addition to addressing consumption through markets and trade, there is also a need to reduce inefficiencies in current systems, particularly food waste. **Food waste** represents a loss of revenue to farmers, a reduction of the food available to the wider society and an inefficient use of our carbon budget. Wasted food generates GHG emissions during production, harvest and processing; needlessly adding to sectoral emissions. Addressing food waste starts with better planning and risk assessment, determining what crops are needed and what crops are viable as climatic conditions change.

AVOIDING TRADE-OFFS

The climate challenge is significant, but so too is the need to produce healthy and sustainable food, enable the development of rural areas, and address the environmental challenges faced in Europe. The level of emission reductions possible in the sector must be qualified in the context of other environmental and social priorities in Europe and not lead to trade-offs with conflicting drivers of change.

The development of a circular bioeconomy in Europe is a solution to address a number of the EU's environmental, economic and social challenges. Done right, the circular bioeconomy should drive sustainability in the agriculture sector through adherence to sustainability criteria for the production and use of bioresources, and reward the contribution of primary producers to increasing value-added from primary products, as well as climate action. In order to avoid the development of new bioeconomies from increasing the emission reduction challenge (through increased or changed production) farm level solutions must develop within ecological limits.

Ensuring climate action in agriculture is itself sustainable requires coherence between those policies that influence agricultural practices (e.g. the CAP, trade policy, etc.) and the EU's international commitments (e.g. UNDP SDGs, Paris Agreement, etc.), environmental acquis, health, food and animal welfare legislation.

RECOMMENDATIONS FOR FURTHER RESEARCH

In order to take forwards these recommendations, there is a need to better understand how and what action can be taken in some areas (such as consumption) and what future challenges may be faced as climate policy develops in the context of much broader range of social, environmental and economic priorities. To this end, the following non-exhaustive recommendations for further research are proposed, many of which would benefit from wide stakeholder engagement as a central element to further research.

- To continue the **development of models and scenario assessment tools** to integrate a wider range of existing and emerging measures available to the agriculture sector, in order to refine mitigation potential estimates and understand better the scale of unavoidable emissions.
- Defining truly **synergistic measures and practices** that benefit both the climate and wider environmental goals – providing clarity to investors, farmers and policy makers.
- Development of **carbon farming schemes based on results,** that encourage and promote the potential of the sector to sequester carbon (and avoid emissions) by changing the way agricultural commodities are produced.
- How to encourage a **change in consumption patterns** (and what role for policy) to ensure complementary action to existing initiatives focused on production. This can help minimise the risk of carbon leakage and at the same time deliver major health benefits.

GLOSSARY OF AGRICULTURAL TERMS USED IN THIS REPORT

Agriculture: a term to refer primarily to production systems, including both crops and livestock.

Agricultural land: the area used for farming or that could be brought back into cultivation using the resources normally available on an agricultural holding, excluding forested area.

Agroecology: the study of ecological processes applied to agricultural production systems.

Cover crops: crops that are sown to provide cover between the production of the main crop – these aid in reducing soil erosion and the loss of GHGs from bare soils.

Cropland and grazing land management: Terms used to specifically in the context of the Land Use, Land Use Change and Forestry categories for emission reporting from croplands and grazing lands.

Emissions from managed agricultural soils: emissions of greenhouse gases, primarily N_2O arising as a result of nitrification and denitrification processes in soils driven mainly by natural circumstances and land management practices (e.g. fertiliser use).

Greenhouse gas emission (GHG) efficiency: GHG emissions per unit of agricultural output.

Intensification: the process of increasing the use of capital and labour (e.g. fertilisers, pesticides, machinery) relative to land area, to increase agriculture production per hectare.

Livestock emission: emission of greenhouse gases, primarily N_2O and CH_4, arising from enteric fermentation in ruminant animals and from manure decomposition.

Livestock unit (LSU): a reference unit which facilitates the aggregation of livestock from various species and age as per convention. 1 LSU is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs.

Measures: used in this report to describe the land management actions, or actions that can be taken in the sector to reduce emissions and increase removals.

Microbial nitrification and denitrification processes: Nitrification is the biological oxidation of ammonia or ammonium to nitrite followed by the oxidation of the nitrite to nitrate. Denitrification is a microbially facilitated process where nitrate (NO_3^-) is reduced and ultimately produces molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products.

Natural carbon sequestration: the ability of plants and micro-organisms to remove CO_2 from the atmosphere and store it in vegetative biomass and in soils.

Permanent grassland: land permanently used for growing herbaceous forage crops or for grazing. The lack of ploughing and cultivation leads to generally higher soil carbon content than temporarily grasslands.

Productivity: the ratio of agricultural outputs to agricultural inputs.

Production pattern: characteristics of the agricultural production in a country or region, including the types of agricultural commodities that are produced and their ratio.

Soil carbon stock: the amount of organic carbon stored in soils.

Temporary grassland: land sown with annual, biennial or perennial forage species, often integrated into crop rotations.

Yield: harvested production per area under cultivation.

Zero tillage: a practice whereby crops are produced without ploughing or turning of the soil.

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ENDNOTES

1 Covering either the EU as a whole or focusing on a particular MS

2 Natural carbon sequestration refers to the ability of plants and micro-organisms to remove CO_2 from the atmosphere and store it in biomass and in soils.

3 I.e. the latest year for which verified greenhouse gas emissions data is available

4 Global warming potential (GWP), which is an indicator comparing the potency of different greenhouse gases with that of CO_2. This indicates that methane has 28 times the warming impact of CO_2, while nitrous oxide is roughly 265 times more potent than CO_2 [10].

5 Which is not reflected in EU emission accounting, although accounted for within the global framework

6 There are some uncertainties as it is challenging to measure and monitor soil carbon at scale and over short periods.

7 The following agricultural emission sources and GHGs are covered: enteric fermentation (CH_4), manure management (N_2O and CH_4), managed agricultural soils (N_2O), urea application (CO_2), liming (CO_2), cropland and grassland management (CO_2)

8 covering either the EU as a whole or focusing on a particular MS (the full list is available in the Annex)

9 The creation of scenarios using the ClimateWorks/CTI 2050 Roadmap Tool, that has been developed by Climact and the European Climate Foundation, does not imply endorsement of those scenarios by either Climact nor the ECF, nor endorsement of any conclusions based on those scenarios.

10 In this case, freed up land is not significantly afforested nor converted to grasslands.

11 As assumed by the CTI model and validated by the consulted experts.

12 The CTI tool relies on proxy variables to model production, including changes in diet (e.g. calories consumed as well as quantity and type of meat consumed) and trade balance.

ANNEX

EU-LEVEL STUDIES AND SCENARIOS COVERED BY THE REVIEW

The Vision Scenario for the European Union 2017 update for the EU-28 (2018)

Ten Years for Agroecology (2018)

Organic Farming, Climate Change mitigation and beyond (2016)

EU 2016 Reference scenario (2016)

Scenar 2030: Pathways for the European Agriculture and Food Sector Beyond 2020

An economic assessment of GHG mitigation policy options for EU agriculture (‘EcAMPA-1’ in 2014 and ‘EcAMPA-2’ in 2016)

Food choices, health and environment: effects of cutting Europe’s meat and dairy intake (2014)

EU Low carbon roadmap (2011)

Roadmap 2050: practical guide to a prosperous, low carbon Europe (2010)

MEMBER STATE (MS)-LEVEL STUDIES AND SCENARIOS COVERED BY THE REVIEW

(revised) French Low Carbon Strategy (2018, not yet published)

Gesebov, covering France (2016

German climate action plan 2050 (2016)

UK Climate Action following the Paris Agreement (2016)

Afterres, covering France (2016)

Quelle contribution de l’agriculture française à la réduction des émissions de gaz à effet de serre?, covering France (2013)

Carbon-neutrality as a horizon point for Irish Agriculture: A qualitative appraisal of potential pathways to 2050 (2013)

Prospective Agriculture Energie 2030, covering France (2011)

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