

The Sixth Carbon Budget

Agriculture and land use, land use change and forestry

This document contains a summary of content for the agriculture and land use, land use change and forestry sectors from the CCC's Sixth Carbon Budget Advice, Methodology and Policy reports.

Introduction

The Committee is advising that the UK set its Sixth Carbon Budget (i.e. the legal limit for UK net emissions of greenhouse gases over the years 2033-37) to require a reduction in UK emissions of 78% by 2035 relative to 1990, a 63% reduction from 2019. This will be a world-leading commitment, placing the UK decisively on the path to Net Zero by 2050 at the latest, with a trajectory that is consistent with the Paris Agreement.

Our advice on the Sixth Carbon Budget, including emissions pathways, details on our analytical approach, and policy recommendations for the agriculture and land use, land use change and forestry sectors is presented across three CCC reports, an accompanying dataset, and supporting evidence.

An Advice report: *The Sixth Carbon Budget – The UK's path to Net Zero*, setting out our recommendations on the Sixth Carbon Budget (2033-37) and the UK's Nationally Determined Contribution (NDC) under the Paris Agreement. This report also presents the overall emissions pathways for the UK and the Devolved Administrations and for each sector of emissions, as well as analysis of the costs, benefits and wider impacts of our recommended pathway, and considerations relating to climate science and international progress towards the Paris Agreement. [Section [1] of Chapter 3 contains an overview of the emissions pathways for the agriculture and land use, land use change and forestry sectors.

A Methodology Report: *The Sixth Carbon Budget – Methodology Report*, setting out the approach and assumptions used to inform our advice. [Chapter [2] of this report contains a detailed overview of how we conducted our analysis for the agriculture and land use, land use change and forestry sectors.

A Policy Report: *Policies for the Sixth Carbon Budget and Net zero*, setting out the changes to policy that could drive the changes necessary particularly over the 2020s. [Chapter [2] of this report contains our policy recommendations for the agriculture and land use, land use change and forestry sectors.

A dataset for the Sixth Carbon Budget scenarios, which sets out more details and data on the pathways than can be included in this report.

Supporting evidence including our public Call for Evidence, 10 new research projects, three expert advisory groups, and deep dives into the roles of local authorities and businesses.

All outputs are published on our website (www.theccc.org.uk).

For ease, the relevant sections from the three reports for each sector (covering pathways, method and policy advice) are collated into self-standing documents for each sector. A full dataset including key charts is also available alongside this document. This is the self-standing document for the agriculture and land use, land use change and forestry sector. It is set out in three chapters:

- 1) The approach to the Sixth Carbon Budget analysis for the agriculture and land use, land use change and forestry sectors.
- 2) Emissions pathways for the agriculture and land use, land use change and forestry sectors.
- 3) Policy recommendations for the agriculture and land use, land use change and forestry sectors.

Chapter 1

The approach to the Sixth Carbon Budget analysis for the agriculture and land use, land use change and forestry sectors

The following sections are taken directly from Chapter 7 of the CCC's Methodology Report for the Sixth Carbon Budget.

Introduction and key messages

This chapter sets out the methodology for the agriculture and land use, land use change and forestry (LULUCF) sectors for the Sixth Carbon Budget pathways.

The scenario results of our costed pathways are set out in our accompanying Advice report (*The Sixth Carbon Budget - The UK's path to Net Zero*), and policy implications in our accompanying Policy report (*Policies for the Sixth Carbon Budget & Net Zero*). For ease, these sections covering pathways, method and policy advice for the agriculture and land use sector are collated in *The Sixth Carbon Budget - Agriculture and Land Use*. A full dataset including key charts is also available alongside this document on the CCC website.

The key messages from this methodology chapter are:

- **Background.** GHG emissions in agriculture and land use were 54.6 MtCO₂e and 12.8 MtCO₂e respectively in 2018. The two sectors account for 12% of all UK emissions.
- **Options for reducing emissions and increasing removals.** These include behavioural change within wider society; productivity improvement; significant land use change for planting more biomass and restoring degraded peat; sustainable management of existing broadleaf woodlands and cropland peat; the take-up of technological options to reduce non-CO₂ emissions from soils, livestock and waste and switching away from fossil fuel use in agricultural machinery to low-carbon alternatives.
- **Analytical approach.** The analysis is based on a detailed review of available evidence, including academic research and literature, monitoring of latest developments and trends in the sectors, modelling conducted by the CCC and two research projects commissioned by the CCC, which are published alongside this report.¹
- **Uncertainty.** The scenario framework is used to test the impacts of uncertainties, to inform our Balanced Net Zero Pathway. The key areas of uncertainty include behaviour change; productivity improvements, scale of land use change and costs.

We set out our analysis in the following sections:

1. Current and historical emissions from agriculture and land use
2. Options to reduce emissions in these sectors
3. Approach to analysis for the Sixth Carbon Budget

1. Current and historical emissions from agriculture and land use

a) Agriculture

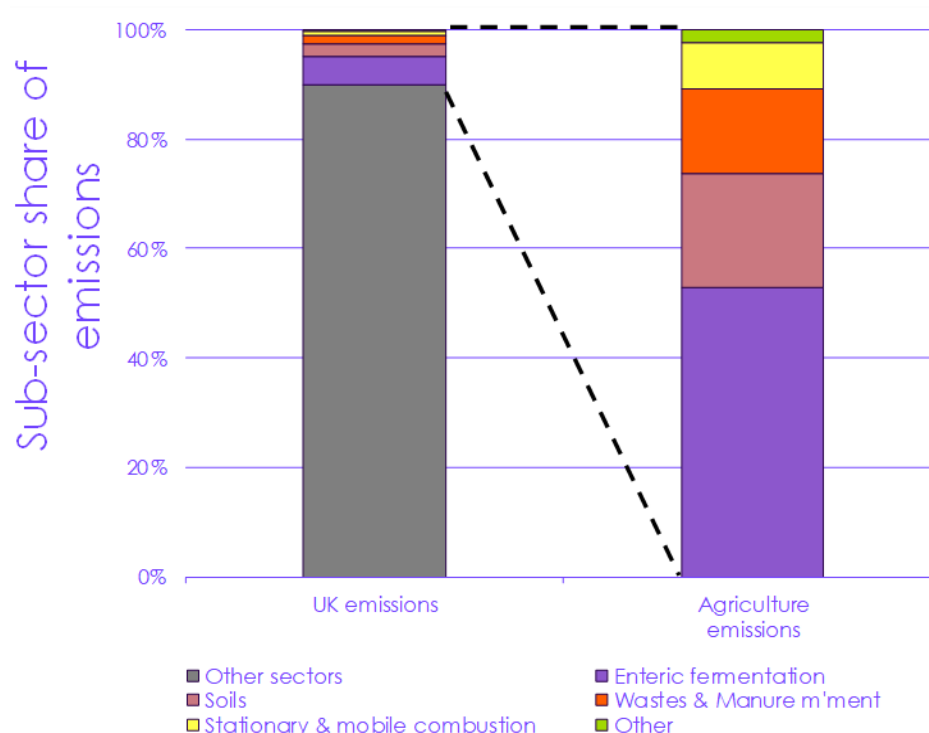
Agriculture GHGs as a share of all UK GHGs has increased from 7% in 1990 to 10% in 2018.

Agricultural emissions were 54.6 MtCO₂e in 2018 using the Global Warming Potential of AR5 for methane. This represents 10% of UK GHG emissions in 2018 compared to 7% in 1990. This increase reflects both the slow rate of progress in reducing the sector's emissions, and the faster pace of decarbonisation elsewhere in the economy. Agricultural emissions are mainly from livestock and soils. Key sources of emissions in 2018 were:

- 63% of emissions were methane from livestock, 26% are nitrous oxide (N₂O) mainly from soils and 11% are carbon dioxide (CO₂) from the use of fossil fuels.
- Enteric fermentation from the digestion process of ruminant livestock is the largest source (53%), agricultural soils (21%), wastes and manure management (16%), and mobile and stationary machinery 8% (Figure M.7.1).

Emissions have declined by 16% since 1990. This is mainly due to successive reform of the Common Agricultural Policy (CAP) in the 1990s and early 2000s, which reduced livestock numbers, coupled with changes in farming practices due to EU environmental legislation to address non-GHG pollutants (e.g. Nitrates Directives). There has been little change in emissions since 2008 (Figure M.7.2).

Figure M.7.1 Breakdown of agriculture emissions (2018)



Source: BEIS (2020) Provisional UK greenhouse gas emissions national statistics 2019; CCC analysis.

Figure M.7.2 UK agricultural emissions (1990-2018)



Source: BEIS (2020) Provisional UK Greenhouse Gas National Statistics for the UK; CCC analysis.

b) Land use, land use change and forestry

Land can remove CO₂ from the atmosphere, which makes it unique among sectors in the GHG Inventory.

The land use, land use change and forestry sector (LULUCF) captures carbon removals and GHG emissions from the use and change in use of different land types in the UK. The main land categories are forestry, cropland, grassland, wetlands and settlements. There is also an additional category that captures changes in carbon stocks of harvested wood products (HWP).

Under the current methodology of the Greenhouse Gas Inventory, the LULUCF sector is a net carbon sink.² The sector sequestered 10.3 MtCO₂e in 2018, which is equivalent to abating 2% of UK emissions.

Future improvements to the GHG LULUCF inventory will move the sector from a net sink to a net source of emissions:

- Only about 6% (1.5 MtCO₂e) of peatland emissions are currently reported in the inventory. Capturing all sources of peatland emissions would bring total peat emissions to between 18.5 and 23 MtCO₂e in 2018 depending on the method to estimate forestry peat.
- The adoption of the new Global Warming Potential (GWP) values in 2024, in line with IPCC guidance, will increase methane emissions by 36% and N₂O emissions will be unchanged if the GWP values include for feedbacks on the carbon cycle.³

Including all peatland emissions in the GHG inventory will turn the sector from a net sink to a net source of emissions.

Including the higher estimate of peatland emissions of 23 MtCO₂e would leave the LULUCF sector a net source of emissions of around 11 MtCO₂e in 2018. This rises to 12.8 MtCO₂e (2% of UK emissions) using the new GWP AR5 values, which we use as the starting point in our analysis.

A breakdown of land emissions and removals in 2018 shows the dominance of peatland and forestry (Figure M.7.3):

- Peatlands are the largest emissions source (24.5 MtCO₂e), followed by non-organic cropland (9.8 MtCO₂e) and settlements (7 MtCO₂e).
- Forestry is the largest net sink at around 18 MtCO₂e, which is equally split between broadleaf and conifer woodlands. Non-organic grassland sequesters a further 9 MtCO₂e, and HWP just over 2 MtCO₂e.

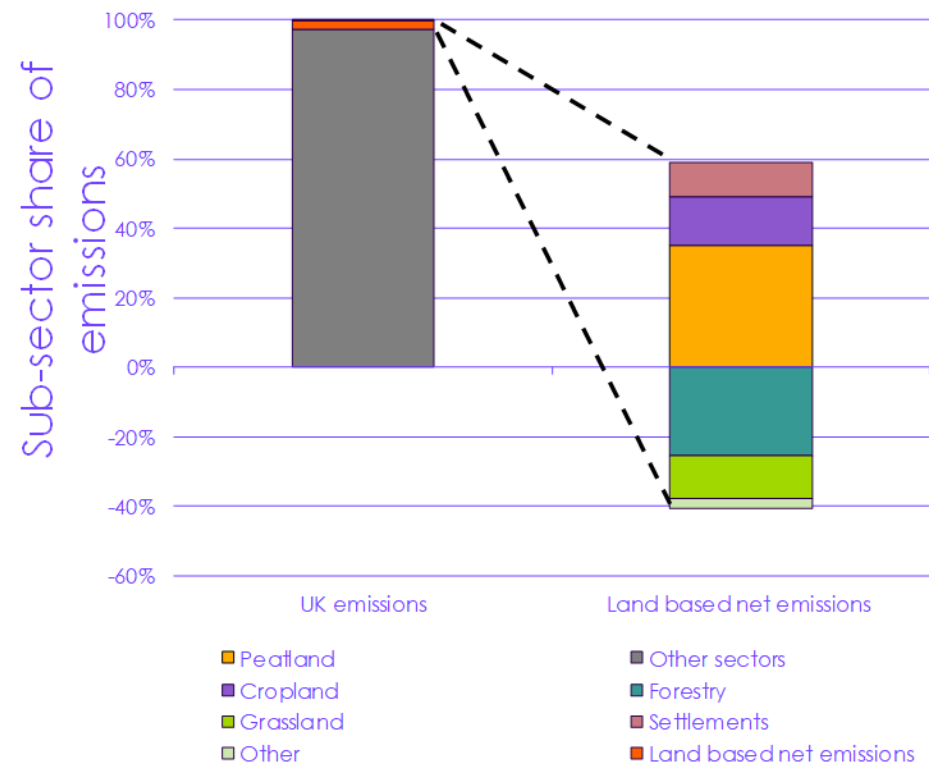
The ageing profile of existing woodlands in the UK is weakening the strength of forests to absorb CO₂.

The sector's net emissions decreased by 1% on the previous year. Since 1990 net emissions have fallen by 43% (equivalent to 9.6 MtCO₂e) since 1990 (Figure M.7.4):

- A strengthening of the forestry sink by around 3 MtCO₂e, driven by a steady programme of afforestation from the 1960s saw annual planting rates reach 40,000 hectares in the early 1970s and close to 30,000 hectares in the 1980s. The non-organic grassland sink increased by 2 MtCO₂e over the period.
- Emissions from non-organic croplands have fallen by 4 MtCO₂e.
- The pace of emissions reduction has slowed since 2011. This is due to the weakening of the forestry sink with the ageing profile of existing woodlands and the decline in planting rates, with an annual average of 9,000 hectares planted between 2008 and 2018.

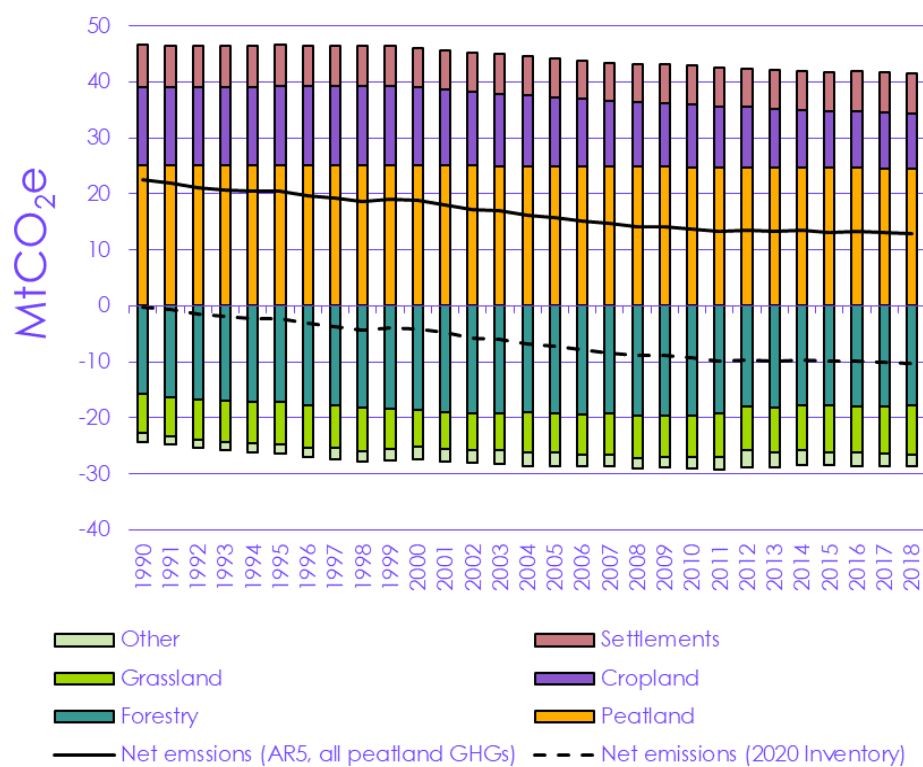
Peatlands are the largest source of land emissions and forests the largest sink.

Figure M.7.3 Breakdown of land emissions (2018)



Source: BEIS (2020) Provisional UK Greenhouse Gas National Statistics for the UK; CEH (2020) CCC analysis.

Figure M.7.4 Land based emissions and removals (1990-2018)



Source: BEIS (2020) Provisional UK greenhouse gas emissions; CCC analysis.

2. Options to reduce emissions in these sectors

Meeting Net Zero and other key objectives of land means we need to change the way we use and manage our land.

Our previous work (*Land Use-Policies for a Net Zero UK (2020)* and *Net Zero Technical report (2019)*) has shown that deep emissions reductions in the agriculture and land sectors cannot be achieved without changes in how we use our land. The contribution to emissions reduction from these sectors requires actions to change farming practices and consumer behaviour to release agricultural land for uses that reduce emissions and sequester carbon. Our analysis assumes that land needed for food production, housing and other activity is met before climate mitigation objectives. Key actions are set out in the following sections:

- a) Low carbon farming practices and technology
- b) Options to release agricultural land for other uses
- c) Afforestation and forestry management
- d) Agroforestry and hedges
- e) Peatlands
- f) Bioenergy

a) Low carbon farming practices and technology

i) Low-carbon farming practices

It is not possible to reduce agricultural emissions to zero on current understanding of biological and chemical processes in food production.

Based on current understanding and knowledge, it is not possible to reduce agricultural non-CO₂ emissions to zero due to the biological and chemical processes inherent in crop and livestock production. Emissions can be reduced through the take-up of farming practices and the adoption of technological options that improve nitrogen use efficiency, livestock diets and breeding and the management of wastes and manures.

We commissioned the Scottish Rural College (SRUC) to assess the abatement potential of such measures.⁴ SRUC was able to draw upon updated evidence from Defra's on-going project, Delivering Clean Growth through Sustainable Intensification, which aims to deliver sustainable growth in agriculture (Box M.7.1).

Our scenarios include the deployment of 18 measures. A more detailed description of each measure is set out in the accompanying SRUC report:

Livestock measures

- **Breeding measures:** breeding aims to select animals with beneficial traits (e.g. to improve health and fertility), which can also lower emissions intensity of production as well as increase profitability. We include four measures:
 - Genomics. Genetic improvement can be enhanced by using genomic tools in current breeding goals (the specification of the traits to be improved). This requires farmers to collect performance information on the individual animals which is used to develop the breeding goal. This measure can be applied to 90% of dairy and 20% of beef cattle.

Low-carbon farming measures can reduce emissions from soils and livestock but would still leave agriculture as one of the largest emitting sectors.

- Current breeding. Using current breeding goals to improve genetic material. Current uptake is around 25% for the dairy herd and lower for beef cattle, but this measure is applicable to 90% of dairy.
- Low methane. This includes selecting lower-emitting animals for breeding which can reduce the methane emissions in subsequent generations.
- Genetic modification of cattle involves altering the genetic material to reduce enteric methane emissions. This measure is currently not legal within the UK and the EU, and yet to be proven. Deployment should only occur once current uncertainties relating to efficacy, animal welfare, and the unknown wider impacts on ecosystems are fully addressed. We therefore assume this measure is deployed from 2040 at the earliest.

- **Increasing the milking frequency** from the common practice of twice to three times a day can reduce N₂O emissions. More milking increases the nitrogen utilisation of the cow, which leads to a fall in nitrogen excretion. Milk yields are assumed to increase by 10%, which can partly offset the infrastructure costs (robotic milk parlour).
- **Livestock diets.** We include measures comprising animal feed and additives that can reduce enteric emissions in cattle and sheep, and one that improves the feed conversion efficiency (FCR):
 - Feeding high sugar content grasses (HSG), grown on grassland for grazing livestock, and a high starch diet for dairy cattle reduce methane emissions. A high starch diet will also reduce methane emissions from waste. Current uptake of HSG is 9% and 30% for high starch diet.
 - 3NOP (3-nitrooxypropanol) is a chemical that can inhibit the production of methane in livestock rumen. It is a novel option which we assume is available from 2025. Nitrate additives can partially replace non-protein nitrogen sources or high protein sources (e.g. soya).
 - Precision feeding involves monitoring and adjusting feed intake to better match each animal's nutritional requirements with the aim of improving the feed conversion ratio (FCR). It is suitable for housed livestock (dairy cattle, pigs and poultry). As well as lowering feed costs, increasing the FCR can reduce N₂O and methane by reducing the rate of nitrogen and volatile solid excretion in manure.
- **Livestock health:** Grazing livestock are particularly vulnerable to endemic disease. Improving health can reduce emissions intensity by improving the FCR and fertility and reduce mortality, all of which can increase growth rates and milk yields. Better health includes preventative measures e.g. changing housing and management to reduce stress and exposure to pathogens, vaccination, and improved screening, and curative treatments such as anti-parasitics and antibiotics.

Measures such as breeding, diets and health can help reduce emissions from livestock and improve productivity.

Soil measures

- **Grass and legumes** (e.g. clover) mix fix nitrogen into the soil thereby reducing the need for synthetic nitrogen fertiliser (e.g. by 200 kg per hectare), which reduces N₂O emissions. Current uptake is assumed to be 26%.
- **Cover crops** are non-cash crops that are incorporated into the main crop rotation to minimise soil erosion and maintain soil carbon. Depending on the type of cover crop used, they can also reduce N₂O emissions by reducing nitrogen leaching and when ploughed in as green manure can reduce nitrogen use. Current uptake is assumed to be zero.
- **Grass leys** are perennial non-woody biomass that are planted as part of an arable and temporary grassland rotation. It can improve the soil structure and increase soil organic matter. Current uptake is assumed to be zero.

Waste and manure management

- **Anaerobic digestion (AD)**. We include two types of AD plants, one fed with cattle manure (536 kW capacity) and the second using pig and poultry manure (984 kW capacity), both of which are co-digested with maize silage. Current uptake is 2.5% for both systems.
- **Covering slurry tanks** with a retrofitted impermeable cover. There is no current uptake of these on beef and dairy farms, while around a quarter of pig slurry tanks are fitted with a cover. The measure is applicable to all slurry tanks and lagoons.

Box M.7.1:

Modelling abatement from low-carbon farming practices

SRUC developed a long-list of 31 measures covering crop and soils management, livestock and management of wastes and manures, that could be deployed to reduce non-CO₂ emissions across farms in the UK. These were assessed according to their technical abatement potential and cost-effectiveness against our assumed carbon values (£181/tCO₂e in 2035).

This resulted in 18 measures which we deployed in our scenarios. Each of these was assigned a feasibility rating and categorised into type of measure, reflecting whether they mainly relied on behaviour change, or mainly on innovation which determined the level of ambition of our scenarios:

- A feasibility rating (hard, medium or easy) corresponding to the ease of implementing the measure on-farm. The ratings were derived based on farmer feedback undertaken as part of Defra's Sustainable Intensification project (Work Package 2: Improving the understanding of social factors).
- We used this rating to determine an uptake rate for each measure, with the 'easy' measure assigned a high uptake ranging 75-80% dependent on scenario, and the 'hard' measures a lower take-up rate of 50-60%.
- Measures were categorised as either 'behavioural' (e.g. planting cover crops) or 'innovative' (e.g. genomics breeding), and we assume that the Wider Engagement scenario has the highest uptake of behavioural measures, while the Wider Innovation has the highest uptake of innovative measures.
- A lead-in time to deployment to reflect technical and/or policy readiness. We assume that measures we categorised as being low-cost and low-regret could be deployed immediately (from 2022) achieving a higher-level of uptake earlier, while a lead-in time of between five, 10 and 20 years was assumed for the more innovative measures (e.g. GM cattle is deployed from 2040).

Source: SRUC (2020) and CCC analysis.

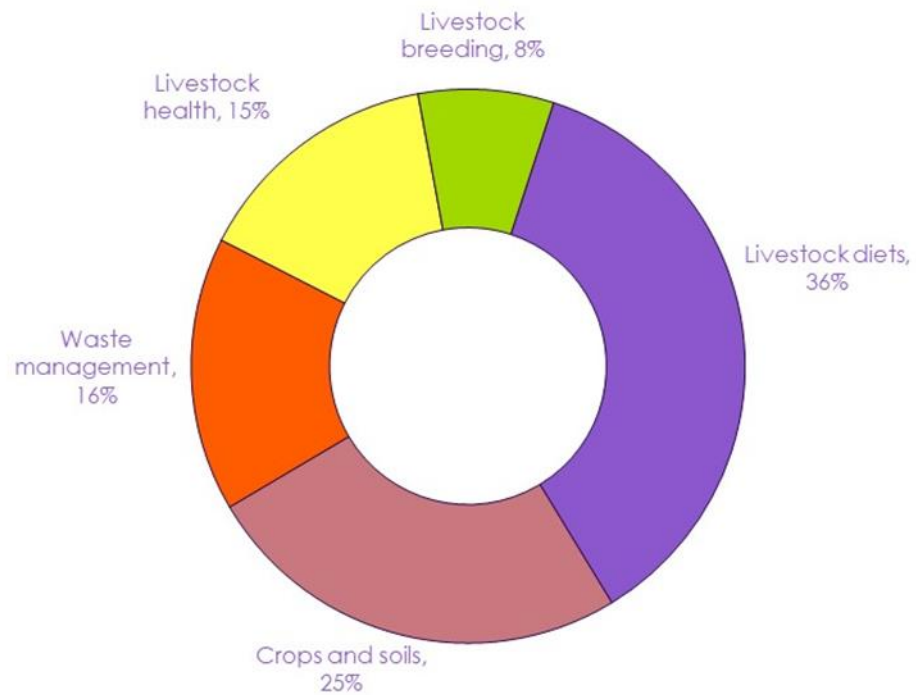
The abatement potential from these measures depends on the area of land used for agriculture and the structure of production. The measures set out in section (b) below already imply large changes in livestock numbers and land use in the UK:

- The number of cattle, sheep, pigs and poultry falls by between 6% and 24% by 2035.
- Grassland area decreases by 12–32% and land for crops by 10–23% by 2035. The land release from these measures is used productively for other uses.

This reduces the abatement potential from the take-up low-carbon farming practices relative to a baseline with no change in land use and livestock numbers:

- Where there is no change in land use and agricultural production remains as in 2018, the implementation of a high level of low-carbon farming practices could deliver around 6 MtCO₂e emissions savings by 2035 (Figure M.7.5).
- Abatement from the take-up of low-carbon farming practices falls to between 3–5 MtCO₂e after taking account of changes in the composition of agricultural production resulting from the measures in our scenarios.
- Our scenarios exclude the take-up of four crop and soil related measures assessed by SRUC; pH crops, crop health, bio-stimulants and precision crop farming. Our assumptions on crop yield improvements (section b), already imply a more efficient use of nitrogen and adding these to our scenarios would be double-counting. Although we have not included the abatement savings from these measures, it is important that farmers are encouraged to take these up to reduce emissions from crops and soils.

Figure M.7.5 Abatement potential of low carbon farming practices (2035)



Source: SRUC (2020), CCC analysis.

Notes: Cost-effective abatement up to our assumed carbon value of £181/tCO₂e in 2035.

i) Low carbon technology

Fossil fuels used in agricultural machinery and buildings are currently responsible for 4.6 MtCO₂e. There were around 40,000 sales of new agricultural equipment in 2019, covering a wide range of uses including tractors, loaders, ploughs, utility vehicles and combines. These can be decarbonised through take-up of zero carbon technologies with our assumptions on decarbonisation technologies aligned to those in the industry and the off-road machinery sectors. We assume that electrification of smaller machinery and equipment starts around 2023, with larger electric machinery entering the market after 2025. Hydrogen options start to be taken-up in the 2030s.

- **Stationary machinery.** Emissions are reduced to zero by 2050. Opportunities to switch to zero carbon options (e.g. renewables and low-carbon electricity) will reflect action undertaken in the wider-commercial sector.
- **Mobile machinery.** The bulk of agricultural vehicles switch away from diesel and biofuels by 2050. Options include hydrogen and electrification and the uptake of robotics. This sector can draw on advances made to commercialise low-carbon heavy goods vehicles (HGVs) e.g. reduction in battery costs and deployment of hydrogen in buses. Data on fleet size, composition and turnover was drawn from various sources.^{5 6}

b) Options to release land for other uses

Societal behavioural change and farm productivity improvements play a crucial role in shifting land use.

The use of the UK's land has evolved over time. Deep emissions reduction in agriculture and land cannot be met without further changes in the way UK land is used. The options we consider shift land use from traditional agricultural production towards alternative uses to reduce carbon and increase sequestration. These changes will present new challenges to farmers and landowners. Policy will need to be designed to ensure new opportunities and revenues are created to reflect the benefits these measures bring to society (see Policy Report).

In this section we consider the following measures to change the way land is used while maintaining a strong food production sector:

- i) Improving agricultural productivity
- ii) Moving horticulture indoors
- iii) Diet shift towards healthier eating guidelines
- iv) Food waste reduction
- v) Summary of impact of measures

i) Improving agricultural productivity

Crop yields

Cereal crop yields in the UK have risen modestly (e.g. 0.5% annual average increase for wheat, barley and oats) or fallen (e.g. for rye) over the past three decades. While these yields are higher than the EU average, they remain lower than key competitors such as France, Germany and the Netherlands.⁷ Within the UK there are also wide yield variation between the best and worst performing farms, irrespective of soils and climate.

Crop yield improvements can deliver productivity improvements on farm, enabling the same level of production with less land and other inputs. Our scenarios for future crop yields are based on the latest literature, discussion with experts and internal analysis.⁸ They take account of climate impacts, management practices and the role of technology and innovation:

- **Climate impacts.** The scenarios are designed to be compatible with limiting global average temperatures to 1.5°C. Climate impacts represent both risks and opportunities to crop yields:
 - Higher CO₂ concentrations leading to higher fertilisation rates and longer growing seasons.
 - Risks from reduced water availability, particularly in East Anglia and the south of England.
 - Increased risk of soil erosion (e.g. through increased incidents of high intensity rainfall).
 - Increased incidence of floods in winter may limit planting of winter crops.
 - Risk of increased incidence and severity of native and non-native pests and diseases.

We sought feedback on our crop yield assumptions from experts in Defra, AHDB, Rothamsted Research, ADAS and academia.

- **Management practices.** There is evidence of a large gap between the best and worst performing farms and wide distribution of yield rates, irrespective of soils and climate. Better management practices through measures such as good soil structure and fertility (e.g. through crop rotation); selecting the optimum planting period and tillage; ensuring good crop nutrition (both optimum fertiliser and trace elements) and protection from weeds, pests and diseases could support higher average yields and close the performance gap between the best and worst farms narrows.

There is also the opportunity to maximise the land resource through spatial planning and the protection of better-quality land, which could also address the inefficiencies in the use of land for crops.⁹

- **Technology and innovation.** Crop breeding and selection could lead to higher yields through development of new cultivars /traits that allow the next generation of wheat and other crops to be more sustainably productive and resilient to disease in a warmer climate. It is assumed that policy will enable technological developments to be transferred to farmers (e.g. through information, skills and other incentives) to ensure the take-up of climate-resilient varieties that are most suitable to local conditions.

It should be possible to sustainably increase crop yields in the future. If climate risks dominate then yields could fall – we demonstrate the impact of this.

Our scenarios assume average crop yields rise from 8.2 tonnes/hectare for wheat (the average over the past four years) to between 11 and 13 tonnes/hectare by 2050 (and equivalent increases for other crops). We also include a sensitivity to reflect a reduction in crop yields, where the adverse impacts of climate change dominate (Table M.7.1).

Table M.7.1 Crop yield assumptions	
Average crop yields (wheat), with equivalent increases for other crops	Description
Baseline 8.2 tonnes/hectare	Current farming practices and agronomy largely continue, with no focus on improvements in the sector. R&D leads to some new varieties but these do not deliver across the board increases in yields. Some areas are negatively impacted by climate impacts, which affect yields in some years. No improvement in soil fertility, and continued degradation in some areas. These impacts offset the CO ₂ fertilisation effect and longer growing season.
Medium 11 tonnes/hectares	Some positive impacts of climate change on yields through increased CO ₂ fertilisation rates and longer growing season. Risks of higher temperatures and flooding do not significantly impact on yields. No significant water scarcity constraints, but on-farm adaptive measures including increased water storage capacity help to overcome periods of water shortage. More widespread take-up of good agronomy practices leading to better soil fertility and structure which reduces the yield gap between the best and worst farms. R&D and innovation leads to improvements in crop varieties and policy supports a moderate level of take-up in the sector.
High 13 tonnes/hectare	Increased fertilisation rates from climate change lead to positive gains on yields. Risks of higher temperatures and flooding do not significantly impact on yields. On-farm reservoirs help to overcome periods of water shortage. High take-up of good agronomy practices across the sector leads to substantially improved soils. R&D and innovation in crop breeding results in new cultivars and traits. There is a concerted effort across the sector to improve yields, and a co-ordinated effort between industry and farmers to share learning and experience. Lower productivity farms are driven out of the sector/taken-over by higher productive farms, with some more innovative techniques such as vertical farming becoming more widespread for certain crop types.

Climate risk sensitivity 6 tonnes/hectare

Climate risks dominate future yields. Risks of higher temperatures significantly impact on yields e.g. heat stress affects yields during flowering time. Crops are affected by water related constraints, including reduced water availability from trends to drier summers and increased incidents of water-logged fields from increased flood events in winter. There is insufficient planning and take-up of measures to mitigate these impacts on crop production. Increased susceptibility of plants to diseases and genetic improvements and breeding lead to failure connected to unanticipated crop susceptibility to new pests and diseases. Farming practices continue as present, with no focus on improving soils and adapting to climate impacts.

Livestock stocking density

Grass, as grazed grass and cut for silage for the winter months, is an important feed for ruminant livestock. It can provide 85% -95% of the energy requirements of beef and sheep in England.¹⁰ But it is estimated that most of the grassland area is under-utilised by as much as half, such that grazing cattle and sheep eat just 50% of the grass that is produced.

Utilisation can be improved by grazing at the right time, to the right height and with the right amount of livestock. This presents an opportunity to increase stocking rates without impacting feed requirements (quantity and quality) to enable some grassland to be used for other uses.

There is considerable scope to improve grassland utilisation, improve productivity and enable land to be used for other uses.

Key to achieving this is good grassland management, which includes grazing management systems. The Agriculture and Horticulture Development Board (AHDB) estimate that switching away from set-stocking to alternative grazing management systems can increase grass yields and reduce costs:

- Increasing utilisation rates (i.e. the grass that is eaten) from the current 50% to 80% with paddock grazing can lead to a near-doubling in yields as measured by dry matter per hectare.
- These can deliver multiple benefits and offset additional costs to improve farm profitability:
 - Extending the grazing period reduces the costs of housing.
 - An increase in improved grass quality can lead to higher livestock yields, higher dry matter yields and more silage. This reduces the need to buy in more expensive feed for the winter.
 - There will be additional costs associated with infrastructure (e.g. fencing) and additional labour hours needed to move animals and fencing.

Our scenarios model the impact of increasing livestock stocking rates by:

- Moving livestock in upland grazing areas and redistributing to other grassland, resulting in an overall increase in the stocking rate on the remaining grassland by 5–10%.
- A higher level of ambition with stocking density on both uplands and other grasslands increasing by 10%.

ii) Moving horticulture indoors

Horticultural products such as fruit, vegetables and salad crops are grown on 163,000 hectares, or 3% of cropland in the UK.

Indoor horticulture can raise productivity while reducing nutrient, land and water footprints.

Indoor systems such as vertical farming, where crops are grown in stacks in a controlled environment, can raise productivity while reducing the nutrient, land and water footprint.

Indoor horticulture in the UK is mainly for high value salad crops and is currently small scale. Some systems are based on hydroponic and vertical production systems using LEDs. Our analysis assumes that this system could be applied to 10–50% of current horticultural production.

Given the small area of land currently used for horticulture, moving production indoors has a limited impact on land area and carbon impacts. More significant emissions savings would come from moving horticultural production from lowland peat, although we have not included this in our analysis.

Greater benefits could accrue from shifting arable crop production indoors. The controlled environment could allow for quicker and multiple harvests each year. Estimates suggest that combined with a ten-tier stacking system, yields could be 220 to 600 times higher than the current global average annual wheat yield of 3.2 tonnes/hectare.¹¹ However, this production method is still at the experimental stage, with trials on-going at Rothamsted Research, while the costs of energy (e.g. LED lighting) would also have to reduce to make this a cost-effective option. Indoor wheat production is not included in our scenarios.

iii) Diet shift towards healthier eating guidelines

There is good evidence that a shift in diets away from meat and dairy products to more plant-based options is good for both climate change mitigation and for human health. The National Food Strategy is committed to looking at sustainable diets (including GHG emissions) as part of its second report, due out in 2021.

Climate change mitigation

Protein can be sourced from a wide range of plant and animal products, some of which have high GHG and other environmental footprints. The most comprehensive and up-to-date life-cycle assessments (LCAs) identifies several robust conclusions regarding the GHG-intensities of different food types produced around the world (Figure M.7.6):

- Ruminant meat is the most GHG-intensive source of protein. In general, beef from dedicated beef herds has the highest level of total GHGs, beef from the dairy herd is generally less GHG-intensive, with a similar emissions intensity to lamb.
- Plant-based protein sources have significantly fewer GHG emissions than animal-sourced proteins when compared on a like-for-like basis. The most GHG-intensive production methods for plant-based proteins generally have lower emissions than even the most GHG-efficient sources of animal-based protein.
- Although pigs and poultry produce less emissions directly compared to ruminant livestock, there are concerns that imported animal feed, in particular soy, may have high embedded emissions and wider environmental costs (e.g. loss of natural habitats and biodiversity) associated with land use change. A 2019 study assessing the livestock supply chains of 11 European retailers including UK supermarkets found that only 25% of the 1.8 million tonnes of soy sourced was certified to a deforestation free standard.¹²

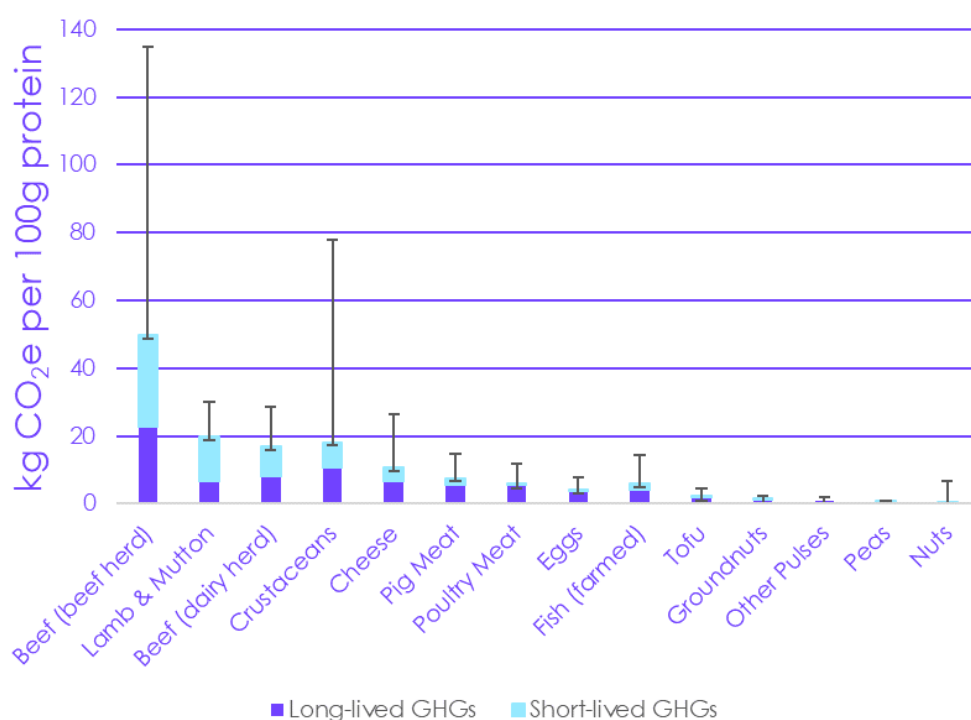
A shift in diets away from meat and dairy products is good for health and the climate.

As well as being the most carbon-intensive protein sources, meat products have a high land footprint.

In addition to the emissions impact, livestock require land for grazing and cropland to grow feed. A study published in 2017 illustrates the relative land inefficiency of producing livestock products:¹³

- In 2010 only 15% of UK agricultural land area was used to grow crops that are directly grown for human consumption with a further 22% to grow livestock feed crops. Grassland for livestock accounted for the remaining 63% of agricultural land.
- 85% of the land footprint used to produce animal products contributed about 32% of total calorie supply and 48% of total protein supply.
- However, cropland and grassland should not be treated equally. In some regions, crops and livestock farming do not compete for the same land as many grassland areas (e.g. the uplands) are not suitable for crop production.

Figure M.7.6 Lifecycle GHG emissions associated with different protein sources



Source: Poore, J. & Nemecek, T. (2018) Reducing food's environmental impacts through producers and consumers. *Science*, 360 (6392), 987-992.

Notes: Solid bars indicate the production weighted global mean GHG-intensity of different food categories from studies looking at production across the world. Lifecycle emissions are expressed on the basis of equal protein content. Error bars indicate the 5th and 95th percentile of studies within the database. GHG emissions are aggregated using the GWP100 metric. Long-lived GHGs refer to CO₂ and N₂O and short-lived GHGs to methane.

There has been a growing interest in 'alternative' meats that are not animal-based. Initial LCA studies suggest that these products can have significantly lower lifecycle emissions than animal-based protein (Box M.7.2).

Box M.7.2

Novel protein sources

There are a number of 'alternative' protein sources that have a less developed LCA literature than conventional animal and plant-based sources:

- **Lab-grown meat** is produced from animal cells cultured in a lab and is a possible replacement for animal-based meat in the longer-term, but it is currently far from large commercial scales. If it can be made economically competitive at scale and achieve customer acceptability, it could offer significant environmental benefits with no non-CO₂ emissions and very small land footprints. Electricity requirements (and its carbon intensity) are the biggest uncertainty in assessments of GHG-intensity. Estimates in the literature range from 1.1 - 3.7 kgCO₂e per 100 grams of protein.
- **Insects** are efficient converters of their feed into edible calories and protein and are consumed by humans in some parts of the world. If they could achieve widespread acceptability with consumers and lower production costs more insects may be eaten in western diets. Insects could also be used for animal feed. When fed on waste biomass, insects can be a low GHG protein source (around 0.2 kgCO₂e per 100 grams of protein) and have minimal land-use impacts, but scale may be limited by the available waste resource. If fed with dedicated crop feedstocks, emissions and land-use impacts are higher.

Source: SRUC and ADAS (2019) *Non-CO₂ abatement in the UK agricultural sector by 2050*.

Human health

Current UK average protein consumption is significantly higher than the recommended daily amount based on the Dietary Reference Values.

A healthy diet requires eating a sufficient amount of protein. The recommended daily protein consumption is 55.5 grams per person for adult men and 45 grams per person for adult women based on the Dietary Reference Values.¹⁴ Particular individuals or groups may need to consume more or less than this to remain healthy, depending on age, lifestyle and medical conditions. Current consumption of protein in the UK is on average significantly above these levels:

- Average daily protein intake was 76 grams per person per day in 2018/19.¹⁵ 60% of this protein is derived from animal sources, with 40% from plant-based sources.
- Modelling by Oxford University of Public Health's *Eatwell Guide*, the Government's official guide to achieving a healthy and balanced diet, estimate that meeting the Guide would require an average reduction in the consumption of meat by around 89% for beef, 66% for pork and 63% for lamb, and a 20% reduction in dairy products.
- The assumed levels of meat reduction in our scenarios (20–50%) are below the Oxford University estimates. Dairy reduction in our Balanced Pathway is in line with the Oxford modelling with further reductions post-2030 in some scenarios. In both cases we assume that the same amount of protein intake is delivered through plant-based options, but we also include lab-grown meat in the Widespread Innovation Scenario.

Consuming more of a plant-based diet can reduce non-communicable diseases like diabetes, heart disease and a range of dietary-related cancers, which in turn can lower the risk of developing severe complications from COVID-19. People with Type 2 diabetes (both controlled and uncontrolled) are 81% more likely to die from the virus.¹⁶ NHS England estimate that over 100,000 lives could be saved each year from healthier diets.¹⁷

Official data indicate that consumption of some meat and dairy products has fallen in the UK. Recent survey data suggests an increased willingness to adopt more of a plant-based diet, while the increased focus on healthier diets due to the impact of COVID-19 may be leading an acceleration in this trend amongst certain groups (Box M.7.3).

Box M.7.3

Trends in UK food consumption

Official government data shows that the consumption of some meat and dairy products have fallen between 2008 and 2018.* Recent survey data points to an increased willingness to adopt more of a plant-based diet than official estimates suggest with the impact of COVID-19 providing an added impetus:

- The average per person meat consumption decreased by 6%, with fresh meat (i.e. beef, lamb and pork carcass) down by 23%. However, processed meat, which accounts for around 80% of the meat consumed has remained broadly constant.
- The consumption of dairy products has decreased by 16%, largely due to cuts in milk and milk products, while cheese consumption increased by 14% over the period. The overall consumption of fruits and vegetables also decreased by 13%.
- Official data suggest that the proportion of the UK population that is vegetarian or vegan has increased from 1.6% in 2009/10 to 2.5% in 2015/6. However, more recent survey data suggests higher figures and a willingness to eat less meat in the future:
 - Around 9% of the 2,095 people that participated in a public attitude survey don't eat meat. The 2020 survey commissioned by the Eating Better Alliance also found that around 65% of those surveyed were willing to eat less meat in the future, citing that more knowledge on how to plan and cook less meat dishes would help them to cut back.
 - Research from Mintel reveal that due to COVID-19 a quarter or people between 21-30 years of age (and 12% of all people surveyed) would find a vegan diet more attractive. The same research found that consumption of fruit and vegetables had increased since the start of the pandemic.

Source: Public Health England (2019) *National Diet and Nutrition Survey*; Mintel (2020).

Our ambition on diet change are within range of the Climate Assembly's recommendations for a 20-40% change in diets by 2050

In our previous 'Further Ambition' scenario set out in our Net Zero advice, we assumed a 20% shift away from beef, dairy and lamb by 2050 towards plant-based alternatives. All but one of our Sixth Carbon Budget scenarios go further than this, with the Balanced Pathway towards the middle of the Climate Assembly's recommendations for a 20-40% change in diets by 2050.¹⁸

In this stylised analysis, our model assumes that farmers do not respond to the change in diets by increasing meat and dairy exports. This has three main impacts:

- It reduces emissions from livestock (e.g. methane from enteric fermentation) and from managing grassland and cropland used to grow animal feed (e.g. N₂O from fertiliser use).
- It increases the area of cropland used to grow crops for human consumption and reduces land required for livestock production – both grassland for grazed livestock and cropland for livestock feed.
- There is a corresponding fall in imports of meat, dairy and animal feed which reduces the carbon footprint of the UK's food imports.

There are uncertainties as to whether these could all be achieved in practice. This will require a strong policy framework in place to encourage a shift in diets and, incentives for farmers to improve productivity and to use their land for measures to sequester carbon (see our accompanying Policy Report: *Policies for the Sixth Carbon Budget & Net Zero*).

iv) Food waste reduction

UK households waste between one fifth and a quarter of food they buy.

The Waste Reduction Action Programme (WRAP) estimate that around 13.6 million tonnes of food and drink is wasted each year. Of this, around 3.6 million tonnes occurs on-farm, with the remainder post-farm gate.¹⁹ Householders account for the largest share of post-farm gate waste (70%), while the supply chain comprising manufacturing (17%), hospitality and food service (9%) and retail (2%) make up almost all of the remainder.

Reducing the level of food waste could reduce agricultural emissions by avoiding unnecessary food production and enabling land to be used differently. It would also reduce emissions downstream (e.g. from avoided emissions from landfill), which is covered in the Waste chapter of this report.

The private sector has signed up to various international commitments to reduce food waste and some devolved administrations have their own targets:

- The UN's Sustainable Development Goal 12.3 has the objective of cutting per capita global food waste at the retail and consumer level by half compared with 2007 levels and reducing food losses along production and supply chains (including post-harvest losses) by 2030.
- This UN target has been adopted by WRAP and the Institute of Grocery Distribution, in its UK Food Waste Reduction Roadmap (2018) but goes further by also including on-farm food waste. Around 260 organisations, including 16 retailers and 162 producers/manufacturers had signed up to the Road Map as of September 2020.²⁰
- The Welsh Government is aiming to meet the UN target five years earlier and are proposing to go further beyond 2025.²¹
- The Scottish Government are targeting a 33% reduction (against 2013 levels) by 2025.²²

WRAP announced this year that the UK is halfway to achieving UN SDG12.3.²³ All our Sixth Carbon Budget scenarios deliver a 50% reduction (pre-and post-farm) by 2030 as a minimum, with a higher level of 60-70% reduction by 2050 in all but one scenario.

v) Summary of impact of measures

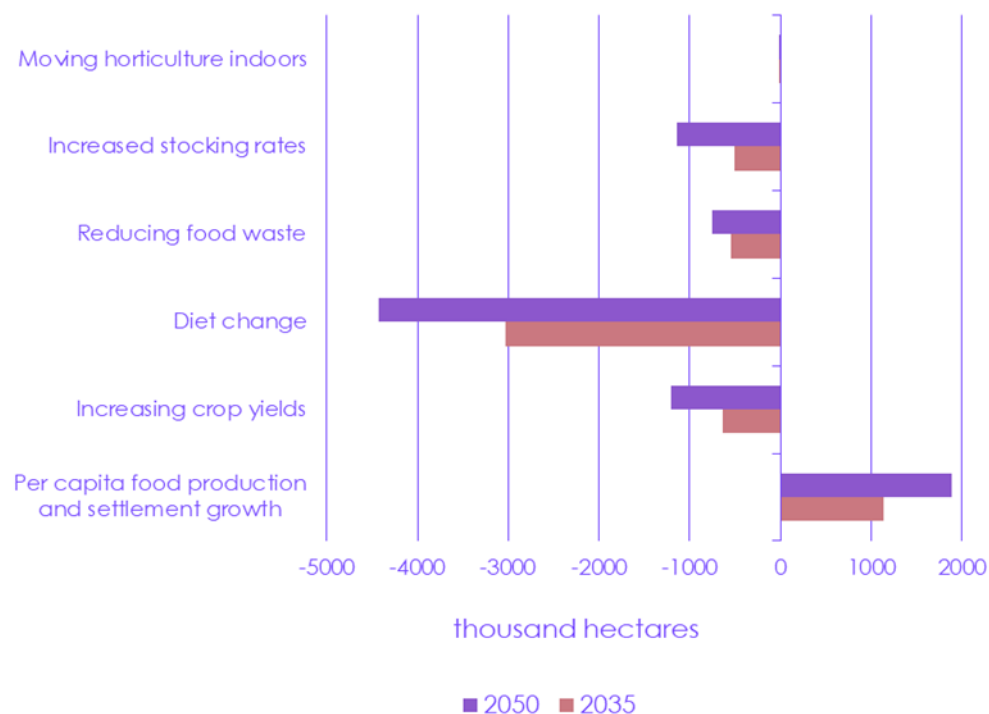
Diet change has the biggest potential to change how land is used.

Our analysis shows that 1.1 million hectares (7%) more land will be needed to maintain current levels of per capita food production and for settlement growth by 2035 if there is no change in productivity. The measures we identify above could free up between 3 and 6 million hectares (or (17–35%) of current agriculture land for other uses. Diet change has the largest impact followed by improvements in crop yields and increased stocking rates (Figure M.7.7).

- 1.1 million hectares of agricultural land is needed to maintain existing per capita levels of food production and settlement growth to 2035.
- In the Balanced Pathway, diet change alone accounts for almost two-thirds (3 million hectares) of land released in 2035.

- Improvements in crop yields, higher livestock stocking rates and food waste reduction release about the same area of land (0.5 to 0.6 million hectares each) in 2035.
- The impact of moving horticulture indoors is limited (7,000 hectares by 2035) due to the current low land footprint of these products.

Figure M.7.7 Agricultural land area released by different factors in the Balanced Pathway



Source: CCC Analysis.

Notes: A negative number indicates land is released; a positive number land is required.

c) Afforestation and forestry management

i) Afforestation

Planting new woodland on previously unforested land delivers carbon sequestration as well as a range of other benefits for health and well-being and the environment e.g. air quality and flood alleviation. The future profile of carbon and other impacts depend on assumptions on the planting and rates, planting density, tree type and productivity.

Planting rates

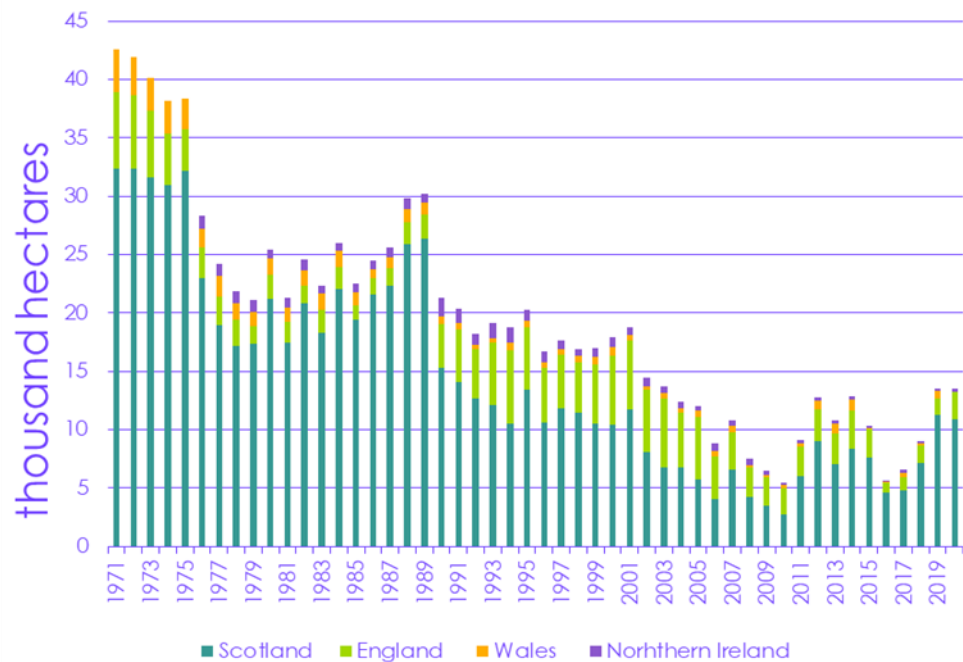
UK Woodland area could increase from 13% of land to 17-20% by 2050 in our scenarios.

Around 13% of UK land area is woodland currently, compared with 43% for the EU-28 area.²⁴ We assume annual planting rates range reach 30,000–70,000 hectares from 2035, recognising it will take time for the sector to scale up to reach these levels. This would increase woodland cover to between 17% and 20% by 2050.* The lower bound corresponds to the Government's commitment to plant 30,000 hectares in 2025 while the upper bound is within range of our assessment of what is feasible:

- A programme of afforestation after the Second World War increased UK woodland area from 6% in 1947 to around 8.7% over a 30-year period.²⁵ This corresponds to planting around 22,000 hectares each year.
- Annual afforestation rates averaged 40,000 hectares in the early 1970s and close to 30,000 hectares in the late 1980s in Great Britain. If we include the restocking of existing forested areas, planting rates reached over 50,000 hectares in the early 1970s and over 40,000 hectares in the late 1980s. This serves as a useful indicator of the supply chain's capability to meet higher levels of tree planting (Figure M.7.8).
- In France, woodland area expanded by almost 7% between 1990 and 2015 to 17 million hectares.²⁶ This is equivalent to an average annual afforestation rate of 46,000 hectares during the period. The UK has a similar ratio of population to land area as Germany, but Germany has over 30% of land that is forested compared to the UK's 13%.
- Studies by industry and the voluntary sector suggest higher levels of UK planting:
 - The Confederation of Forest Industries' (Confor) call for UK planting rates to reach 40,000 hectares a year by 2030 takes account of their assessment of the industry's capacity to scale-up (e.g. nurseries and foresters).²⁷
 - The Woodland Trust set out an ambition to deliver 19% of UK woodland cover by 2050, with preference given to the planting of native woods and trees.²⁸
 - Friends of the Earth cite an ambition to double woodland to 26% by 2045, both to support efforts to increase carbon removals and protect and restore nature.²⁹

* This excludes the area of small woodlands of less than 0.5 hectares in size, and less than 20 metres in width, which currently totals 355,000 hectares.

Figure M.7.8 Afforestation rates (1971-2019)



Source: Forestry Commission, Natural Resources Wales, Forest Service and Forestry Commission statistics.
Notes: Planting year ends end March. Data not available for Northern Ireland from 1971-1975.

Type of woodland created

The right trees need to be planted in the right place and take account of soil, climate and other land uses.

The UK Forestry Standard prohibits the planting of mono-cultures and limits the planting of any one species on one site. The ratio of broadleaf and conifer planting vary across our scenarios to reflect different objectives for woodland creation, and regional differences in climate and soils (e.g. conifers can withstand cold weather in the north of Scotland). Existing woodlands in England are predominantly broadleaved and conifers dominate in Scotland:

- We develop different scenarios in favour of broadleaved forestry and in favour of conifers:
 - A 67:33 planting ratio in favour of broadleaves is assumed for the UK where the focus is on biodiversity. Taking account of regional differences, the ratio increases to 80/20 in England, and is lower in Scotland at 50:50.
 - A 33:67 planting ratio in favour of conifers is assumed where the focus is on productive forestry. This increases to 75% for conifers in Scotland.
- In our modelling, Sitka spruce is used to represent conifer forestry and sycamore/ash/birch to represent broadleaf forestry.

We model different planting densities to better reflect differences between broadleaf and conifer woodland creation.

Planting density

Tree planting density is important for determining tree growth, carbon sequestration and wood density as well as wider impacts such as soil health and biodiversity.

Our scenarios reflect different planting densities (number of stems planted per hectare) to better reflect differences between broadleaf and conifer woodland creation, and to understand the trade-off between maximising carbon sequestration and other impacts such as biodiversity. We assume:

- A planting density of 3,000 stems/hectare for conifers to maximise carbon sequestration and timber output, and 2,000 stems/hectare for broadleaves, which is commonly seen as the upper end.
- Where society places a higher value on biodiversity, the planting density for broadleaves is reduced to between 1,200–1,800 stems/hectares. Lower density planting also allows for the retention of landscape features and open views, and glades. Our range is consistent with the planting regime supported by the Woodland Trust.

While the planting density we use are averages for the UK, we recognise that in practice there will be variation across the UK than we can capture in our analysis.

Forest productivity

There is scope to increase productivity of new forests.

Different trees have different growth rates and levels of productivity as measured by their Yield class (YC). This has a bearing on the time profile and rate of carbon sequestration, and the quantity of timber output. We have updated our yield class assumptions since our Net Zero advice based on data from the National Forest Inventory (NFI) and stakeholder engagement (Box M.7.4):

- The average yield class of existing conifer and broadleaf woodland is YC14 and YC6 respectively under the NFI.* We take this as the baseline yield class for new planting.
- Best practice in silviculture and innovation through breeding can increase productivity to an average of between YC16–18 for conifers and up to YC8 for broadleaves. We assume it takes 10 years before YC18 and YC8 are introduced in our scenarios.

Box M.7.4
Tree productivity

Improving yields enables trees to be more productive both in terms of the amount of CO₂ they can sequester and the volume of harvested products. In addition, breeding can improve the quality of the wood to be used as timber and increase resilience to the impact of climate change. Our assumptions on improvements in average yield class follow discussions with a wide range of stakeholders that include the Forestry Commission, Scottish Forestry, Future Trees Trust, the Woodland Trust, Confor and Pryor and Rickett Silviculture. We considered two factors that could deliver higher productivity rates:

- Silvicultural practices. The adoption of best silvicultural practice covers the nursery stage, choice of planting stock and area, establishment and on-going management as the tree grows.

* Weighted mean yield class based on stands aged 15-50 years.

Measures would include site preparation to ensure the successful establishment of saplings. Selecting the right trees for the right area means taking account of the level of moisture and nutrients in the soil. For example, Sitka spruce does not tolerate drought and requires moisture, while beech is no longer considered a good option due to susceptibility to drought. On-going management could entail protection of young trees from deer and squirrels, managing the surrounding vegetation to reduce competition and ensure successful establishment, and decisions on when to respace, thin and fell.

- **Breeding.** Research is being led by the commercial sector with organisations such as the Conifer Breeding Co-operative, and the broadleaved focused Future Trees Trust. Work of the latter is focused on six major broadleaf species of British origin (ash, oak, sycamore, chestnut, birch and cherry) that are genetically diverse and resilient. Due to its susceptibility to drought beech is no longer considered an appropriate species. Breeding requires selecting the best parents, whereby seeds are collected from the mother tree, and bringing them together to cross-fertilise. Their progeny breeding work to date is still based on theoretical gains (3-5% by 2030 and 10% by 2050 for the six broadleaf species) rather than real gains. More time is needed to test the real gains, with trees of at least 10 years old, when yield and height measurements can be assessed across a variety of UK situations and sites.

Open ground

We allow for an area of open ground in new woodland to improve biodiversity.

The UK Forestry Standard (UKFS) sets out a requirement that new woodland over 10 hectares in size should include a minimum 10% of open ground or ground managed for the conservation and enhancement of biodiversity as the primary objective.

Our scenarios are consistent with these standards, with the lower bound of open ground in line with the minimum 10% set out by the UKFS, and an upper bound of 20% is used where we place an increased value on biodiversity. This area of open ground increases the land area needed to meet our afforestation ambition by an additional 10-20%.

ii) Forestry management

Around 80% of broadleaf woodlands in England (74% of woodland area) are in an un-managed or under-managed state. Introducing sustainable management broadleaf woodlands that is compliant with the UK Forestry Standard has several benefits:

- It can improve woodland health and productivity and increase carbon sequestration by allowing young and better-quality trees to thrive.
- Improve habitat quality and biodiversity by allowing in more light.
- Increase the resilience of woodlands to wind, fire, pests and diseases, which could increase under a warming climate.
- Management can generate revenue from the sale of harvested material.

We assume that 67–80% of broadleaf woodlands are managed sustainably by 2030. The lower level is the ambition set by Defra, covering both broadleaf and conifer woodlands, to be achieved by 2018. The target was missed, with 59% of woodland currently managed. Management increases timber output and accounts for 75–90% of the material used for fuel across our scenarios by 2035. Our analysis assumes that all conifers are in some form of management, although not necessarily compliant with the UK Forestry Standard.

d) Bioenergy crops

Bioenergy crops are specifically grown for use in the energy sector, providing emissions savings from displacing fossil fuels (and/or engineered CO₂ removal if combined with carbon capture and storage – CCS) alongside any net carbon benefits that are derived while growing these crops. A sustainable UK supply of bioenergy is important in contributing to Net Zero. Issues around supply and best use of bioenergy are discussed in more detail in Chapter 6 of this report. Issues around sustainability are dealt with in our 2018 Report '*Biomass in a low-carbon economy*.'

The current area of miscanthus and short-rotation coppice (SRC) is only around 10,000 hectares (or 0.2% of UK arable area), and there is no short rotation forestry (SRF) planted for energy use. Our analysis includes these three types of energy crops and forestry:

- We assume an immediate scaling up of the industry would be required from the mid-2020s in order to deliver the rates in our scenarios: 10,000, 30,000 or 60,000 hectares being added annually by 2035. This results in a total planted area of 0.2 million, 0.7 million or 1.4 million hectares by 2050. The lower level corresponds to a scenario where there is low BECCs capacity, while the middle and upper levels correspond to work by the Energy Technology Institute (ETI):³⁰
- To maximise carbon sequestration, planting of energy crops (miscanthus and SRC) in our scenarios is limited to cropland and excluded from permanent grassland. Due to the higher soil carbon stocks planting energy crops on permanent grassland can increase net emissions with on-going soil carbon losses exceeding the carbon sequestered by the energy crop. SRF is grown on both cropland and grassland.
- We assume planting rates are staggered, with miscanthus and SRC starting in 2022 and SRF starting in 2025. The faster growing miscanthus and SRC can be harvested two to three years after planting. SRF poplar is conventional forestry and the slower growth rate means its rotation length is around 26 years.
- Our modelling includes the carbon benefits (e.g. carbon stock changes in the soil and biomass) of bioenergy crops but not the additional emissions savings from reduced nitrogen use by moving from annual to perennial crops.
- Productivity improvements through better agronomy and breeding can boost yields from the current average of 12 oven dried tonnes (odt)/hectare to between 15 and 20 odt/hectare by 2050 for both miscanthus and SRC. Current SRF yields of YC12 are assumed to remain unchanged.

The roll-out of CCS elsewhere in the economy could determine how land is used. Bioenergy crops used with CCS deliver higher GHG savings than standing forest alone. However, if the requirement for bioenergy with CCS is low, it would be preferable to grow standing forest than bioenergy crops (Box M.7.5).

Box M.7.5

GHG impact from bioenergy crops and forestry

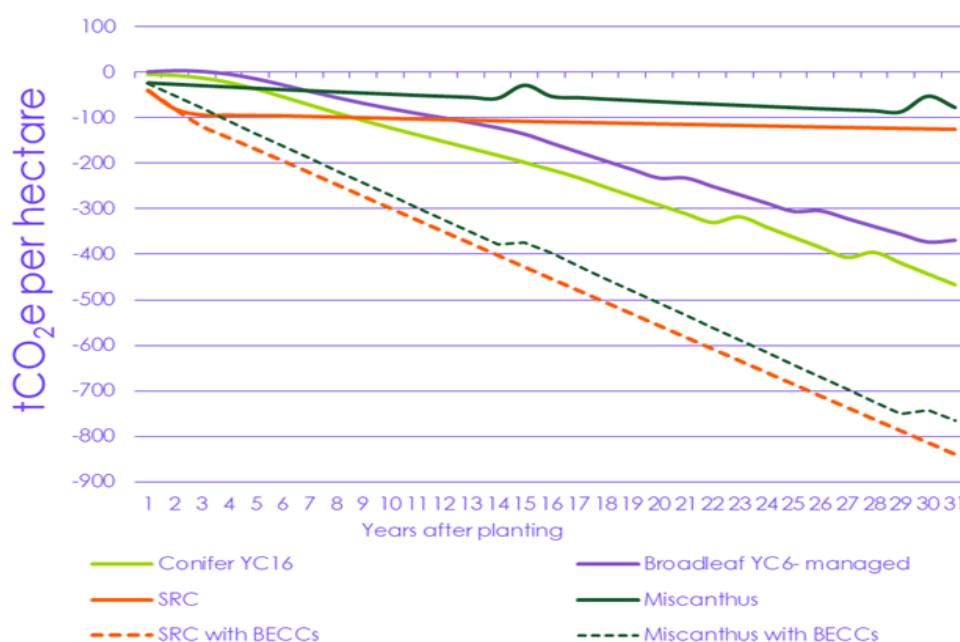
The optimum level of UK bioenergy crop production depends in part on the requirement for bioenergy with CCS (which is used for a range of activities in our scenarios, including electricity generation and production of low-carbon hydrogen, as set out in Chapters 2 and 3 of the accompanying *Advice report*).

To compare the emissions savings from planting trees versus energy crops for use with CCS we analysed how each can be expected to deliver emissions savings over time on a per hectare basis (Figure B.7.5):

- The land-based emissions savings from planting a hectare of perennial energy crops are lower than from planting conifer and broadleaf forest with typical yield classes.
- Including savings from BECCs reverses this and bioenergy crops with BECCs deliver higher GHG savings than afforestation over 30 years.
- Standing forests will produce thinnings and harvested material as they grow and reach maturity which would add to the savings beyond the period shown below.

Different assumptions could change this picture, for example a lower CO₂ capture rate in BECCS facilities would reduce the emissions saving from energy crops. The value of BECCS will also depend, for example, on how cheaply low-carbon hydrogen and electricity can be made from alternative sources. Perennial energy crops are only grown on cropland in our scenarios as the soil carbon impacts when grown on grassland can be negative. The availability of cropland for energy crops relies on delivering diet change and crop yield improvements.

Figure B7.5 GHG savings from planting different types of biomass from year of planting



Source: CEH (2020) and CCC analysis.

Notes: Bumps in lines represent periods of harvesting of biomass, and there-planting of miscanthus every 15 years.

e) Agroforestry and hedges

Trees on farm can sequester carbon, improve water quality, improve soil structure and fertility, enhance biodiversity and increase welfare of grazing livestock.

We use the term agroforestry to mean the integration of trees and/or shrubs on to cropland (silvoarable: trees and crops) and grassland (silvopastoral: trees and livestock). Agroforestry can sequester carbon in the biomass and soils, improve water quality from reduced nitrate leaching into water courses, improve soil structure and fertility from litter fall, increase livestock welfare and enhance biodiversity.

There is no official data on the amount of land currently used for agroforestry in the UK but a close proxy is the use of trees and hedges for buffer strips alongside water courses, fruit production in shrubs and shelter belts. It is estimated that these account for around 1% of UK agricultural land:³¹

Our modelling assumes that between 5-15% of agricultural land adopt silvoarable or silvopastoral systems by 2050. Our assumptions for planting densities are taken from Defra's Delivering Clean Growth through Sustainable Intensification project and CEH's CFlow model was used to estimate the carbon sequestration rates:

- The low planting densities of agroforestry systems results in 14% of the grassland area and 7% of cropland area dedicated to these systems.
- Silvoarable systems plant poplar YC 12 in two-metre-wide rows, a spacing of 30 metres between each row and seven metres between each tree. The spacing takes account of the need to minimise shading which can adversely impact crop yields.³²
- Silvopastoral systems are planted with broadleaf species (e.g. sycamore, ash and birch) with a YC6, and at a higher planting density of 400 trees per hectare.

For the purposes of our modelling we have adopted a particular set of assumptions, but we recognise that in practice agroforestry systems will vary considerably in terms of tree species and density, comprising both formal alley planting and alongside field margins.

Hedges

Historically, hedgerows were used to mark field boundaries. Hedgerows can provide a similar set of benefits to those derived from agroforestry in terms of carbon sequestration, improving farmland biodiversity and shelter for grazing livestock. The current length of hedgerows in the UK is around 120,000 hectares, of which around a half is under management.³³

We assume that hedgerow length increases by between 30% to 40% by 2050:

- The lower bound corresponds to the level recorded in the 1984 Countryside Survey.
- We assume that 10% of the lower bound and 30% of the upper bound is managed for biomass fuel.
- Hedges are planted on permanent and temporary grassland only, and carbon stock changes in the soils do not change. This is because of the lack of robust evidence in this area but is likely to be a conservative assumption.
- Hedges are assumed to be 1.5 m wide and with biomass stock densities derived in the BEIS Biomass Extension project.³⁴

f) Peatlands

Well-functioning peatlands can sequester carbon, regulate the quality and quantity of drinking water, and are important wildlife habitats.

Peatlands occupy around 12% of UK land area. Organic soils such as well functioning peatland (soils with more than 50% organic matter are defined as peats) can continuously accumulate carbon under water-logged conditions at a rate of around 1mm per year. Peatlands are therefore an important and potentially growing reservoir of carbon.

Well-functioning peatlands also provide a range of other vital services to society:

- They can regulate the quality of drinking water. It is estimated that up to 70% of UK drinking water is sourced from upland catchments that are peatland habitat.³⁵ Healthy peat in the uplands hold water, which can slow the flow of water, alleviating the risk of downstream flooding.
- Provide highly valued cultural services (e.g. recreation, archaeology) and are internationally important wildlife habitats supporting biodiversity.

Climate change strengthens the case for action to protect and restore peatlands. If functioning peatlands are to survive in a changing climate and continue to provide these key ecosystem services, they need to be in a good condition. Warmer and drier conditions in the future are likely to increase the rate of carbon losses from degraded peatlands and reduce the water-holding and filtering capacity of degraded peat. The longer the delay in reversing degradation, the more expensive it will become to deliver.

Under a quarter of the area is in a near-natural or re-wetted state and is a small net carbon sink. A wide range of uses over time have led to severe degradation of the remaining area. This includes grazing livestock with high stocking densities, drainage for forestry and agriculture, burning on moorlands for grouse shooting and peat extraction for horticultural use.

We assume that the area of UK peatland that is rewetted increases from the current 25% up to 60% by 2035.

Our scenarios assume the rewetting (raising the water table) of between 800,000 and 1 million hectares by 2035, which would increase the area of peat under restoration to between 53% and 60%. This would exceed current commitments by the UK government to restore 35,000 hectares in England by 2025, and 250,000 hectares over the next 10 years by the Scottish Government.³⁶ The water companies are also targeting to restore 20,000 hectares of their owned land by 2030.³⁷

Our assumptions consider both restoration and sustainable management options where land remains in agricultural production. These are drawn from stakeholder engagement and on-going work from Defra's lowland peat project.³⁸

i) Upland grassland

This represents the largest area of peatlands (40% or 1.2 million hectares) and has been mainly used for sheep grazing. We assume that all upland peat is restored by 2045 at the earliest and by 2050 at the latest. Where the level of degradation is so severe to prohibit the re-start of peat formation, we assume that action is taken to stabilise the peat to halt carbon losses. We also include an end to damaging practices (e.g. rotational burning of upland peat).

ii) Lowland restoration

Lowland fen peat comprises both extensive and intensive grassland and cropland. Although the lowland area accounts for 14% of UK peatland, it is responsible for around 56% of peatland emissions (Figure. M.7.9) This is due to the high level of degradation with historic and on-going drainage resulting in significant peat loss and shrinkage. For example, it is estimated that over 100 years of drainage has resulted in peat shrinkage of around 4 metres at Holme Fen in Cambridgeshire.³⁹

We consider the impacts of rewetting and sustainable management of lowland peat.

Our scenarios assume that between a quarter and 50% of grassland is rewetted by 2050. Although lowland cropland is highly productive agricultural land, it produces the most emissions per hectare of any peatland - of around 39.5 tCO₂e/hectare compared to 3 tCO₂e/hectare in the uplands.

Restoration and sustainable management can therefore deliver significant emissions savings and enable this area to be farmed productively for longer. At the current rate of degradation (observed to be between 10-30mm a year) most of the remaining peats will become wasted over the next 30 to 100 years, depending on current depths and usage.⁴⁰

Our analysis includes two different approaches for full restoration of cropland, and we have updated the costs of full restoration based on stakeholder engagement (Box M.7.6):

- **Full restoration to near-natural condition.** This takes land out of crop production and we estimate emissions would fall to around 2.5 tCO₂/hectare. Most rewetting has been done for nature conservation. Examples includes Wicken Fen, which has rewetted 350 hectares of land and the Great Fen Project, which is looking to create 3,700 hectares of fen landscape over a 50-year period. The project started in 2001 and to date has restored 1,200 hectares.
- **Paludiculture.** Switching crop production to 'wet-farming' covers both food and non-food crops that can be grown in water (e.g. blueberries, reeds, sphagnum). Emissions savings are slightly lower, falling to 3.6 tCO₂e/hectare. This represents a novel agricultural system and work has been on-going by Defra to evaluate its viability, while a pilot run by the Great Fen project is trialling different crops (Box M.7.7)

CO₂ emissions from rewetting upland and lowland peat is assumed to fall to zero in the year of restoration. This is a simplifying assumption as there is a lack of robust scientific data on the time profile of emission reduction after restoration.⁴¹ This is the currently accepted IPCC methodology, and is one of the many uncertainties associated with peatlands.

There are additional societal benefits from the avoided costs of maintaining road and rail infrastructure due to land subsidence from drainage (Box M.7.6).

'Given the limitations in the available scientific literature, the Tier 1 basic methodology assumes that there is no transient period and that rewetted organic soils immediately behave like undrained/natural organic soils in terms of CO₂ flux dynamics.'
(IPCC 2014)

Box M.7.6

Costs and benefits of restoring lowland peat

There has been less restoration of lowland fen peat compared to the uplands, with most centred on the creation of wildlife habitats and nature reserve. Consequently, there is less data available on the upfront costs of restoration.

The data we have used to estimate the average restoration cost is derived from costs provided by a wetland conservation centre in Norfolk and a water and land management company that carries out restoration work:

- The data shows a large range (£240/hectare to £4,900/hectare) based on the level of landscaping and revegetating:
 - The lower upper bound is indicative of light intervention such as the reseeded of arable land to allow for low levels of grazing at certain times of the year for conservation purposes.
 - A median level of costs (ranging £550-£950/hectare) could involve the use of machinery such as bulldozers to move soil and re-landscape, cleaning of ditches and planting of sphagnum.
 - The upper bound (£1,000-5,000/hectare) could include additional costs of woodland and scrub removal, and submersible electric pumps to keep the water table high.
- We use these costs to derive an indicative central cost estimate of £2,500 per hectare (ranging £800-5,500 per hectare).
- There are also on-going maintenance costs that can include water pumping, ecological surveys and the cutting of grass for silage if the land is not grazed

Lowland peat restoration can deliver wider societal benefits for nature and recreation, and scope to reduce road and rail infrastructure costs:

- WWT Welney Wetland Centre converted 38 hectares of arable peat to a wetland habitat in 2008. In addition to attracting wading birds, the reserve has recorded over 300 species of butterflies and moths, and rare wildflowers. It also offers recreational benefits for reserve visitors.
- Peat subsidence due to drainage has adversely impacted local road and rail infrastructure in East Anglia. Rewetting the land could potentially reduce deformation of roads and tracks, cracking and potholing of roads, resulting in reduced repair costs for the local authorities and Network Rail. Further work, including data collection and disaggregation of costs to directly attribute them to drained peatlands, is needed to be able to quantify the potential avoided costs of restoration.

Source: WWT Welney Wetland Centre; The Fen Group; Centre for Ecology and Hydrology and the Universities of Leeds, Leicester and York and (2020) *An assessment of the societal impacts of water level management on lowland peatlands in England and Wales*; CCC analysis.

Box M.7.7

Paludiculture ('wet-farming')

There is growing interest in paludiculture (or 'wet-farming') as an option to reduce GHG emissions while continuing with agricultural production. It is estimated that under this rewetted farming system, emissions could fall by as much as 90% to 3.6 tCO₂e per hectare compared to conventional crop production on drained land. There is also scope to extend this system of farming to restored extraction sites:

- Rice is the most widely known crop grown in water-logged conditions, but crops for food, fibre and energy identified as suitable for the UK include:
 - Food crops include celery, watercress, cranberries and bilberries. It is estimated that 14% of the berry crop in Finland is grown on peatlands.
 - Suitable species for energy use include reed grass, bulrush, cattail, sedge, aquatic herb and trees such as alder, poplar and willow. The reed crops can also be used as fodder for livestock and is also already used as a construction material (e.g. thatched roofs).
 - Sphagnum farming on rewetted extraction sites could be used as a substrate in the horticultural sector, potentially replacing peat obtained from the damaging practice of extraction.
- The Great Fen project has allocated five hectares of land to non-food crops such as bulrush, reeds and sphagnum. The 2019-2021 trial will be used to demonstrate to local farmers the viability of this type of agriculture, including the income potential, while measurements of CO₂ and methane will be recorded to quantify the emissions savings.

The Defra commissioned work on the viability of paludiculture concluded that while there was significant potential, practical and economic barriers would need to be addressed if large-scale adoption is to be achieved. Work to show-case to farmers as is being done by the Great Fen project is a clear example of the steps that will be needed to widen its appeal.

Source: Defra Project SP1218 (2020); Great Fen – Water Works project.

iii) Lowland sustainable management

In some lowland areas current water levels are lower than may be needed for agricultural production and flood storage capacity.

The overriding control on the rate of emissions from peatlands is mean water-table depth. It is estimated that for every 10cm increase in the water table, there is a corresponding reduction in emissions of 3 tCO₂e/hectare. There is evidence that in some areas, current levels are lower than may be needed for agricultural production and flood storage capacity.⁴² We consider two water-table management options for the area of lowland cropland peat that remains in conventional agriculture:

- **Dynamic water-table management** (seasonal re-wetting) involves raising the water-table up to 10cm below the peat surface during the winter months when there are no crops in the ground, which is then drained to between 40-100 cm below the surface during the growing season. Assuming an average water table depth of 50cm for the year, we estimate that emissions could fall by less than half to around 18 tCO₂e/hectare.
- **A permanent increase of the water-table** to an average of 40 cm below the peat surface all year round could deliver higher savings, with annual emissions falling further to 16 tCO₂e/hectare.

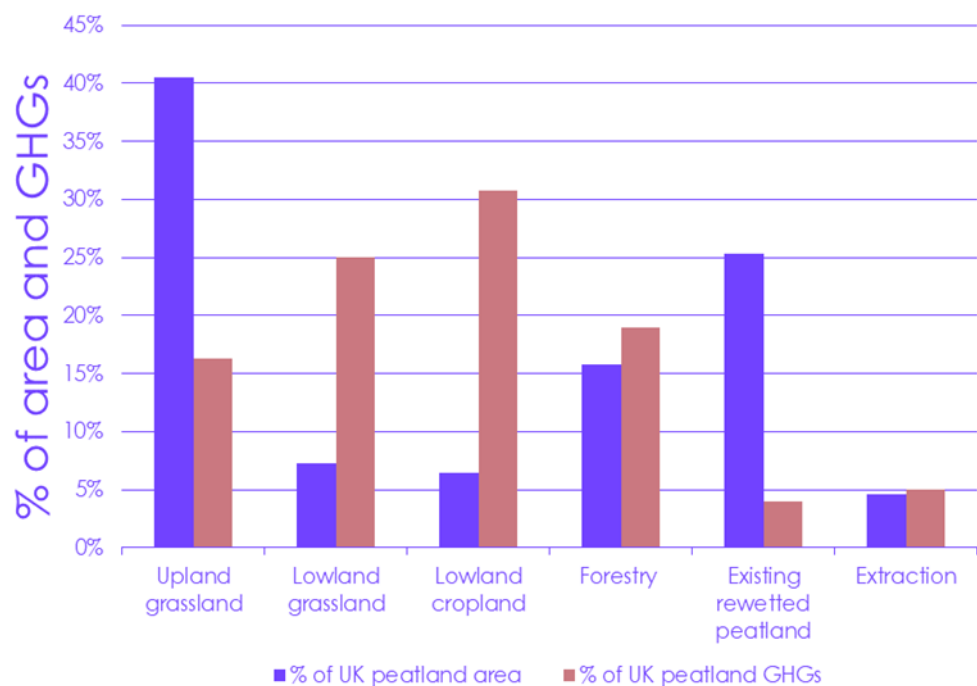
Both options represent new approaches that have not been trialled at scale, but on-going work to understand the practicalities and hydrology of the surrounding area is required to ensure that practices undertaken by one farmer do not impact a neighbouring farmer, and that flood storage capacity can still be maintained.

iv) Other peat

We include emissions savings from two further types of peatland that do not require the conversion of agricultural land. Ambition for these is the same across all our scenarios:

- **Removing low-productive trees off peat.** Around 13% of forestry is on peat mostly conifer woodland in Scotland. It is estimated that there are around 84,000 hectares of peat with low-productive trees of less than YC8. We assume removing these low-yielding trees improve the net carbon balance, with the peat emissions savings exceeding the carbon losses in the trees. Our ambition is to restore 84,000 hectares by 2035, of which over 80% would occur in Scotland.
- **Extraction sites.** Extraction of peat has largely occurred on lowland raised bog. Historically, it was mined for fuel and today its main use is in the horticultural sector, with smaller amounts for whiskey production. Our scenarios rewet around 144,000 hectares of peat extraction sites to semi-natural habitats by 2035. In our 2020 Land Use Policy report we recommended a ban on the sale of peat for use in horticulture and cessation of extraction by 2023, and this is assumed to be the case in our analysis.⁴³

Figure M.7.9 UK peatland area and GHGs by land use (2019)



Source: CEH (2020) and CCC analysis.

Natural regeneration and wildflower meadows could have a role to play for carbon mitigation and wider environmental benefits, though the GHG impacts are uncertain.

g) Other uses of land

Our analysis suggests that if all our land release measures are delivered on time, 1.8 million more hectares could be freed up than are required to deliver the land use change required in the Balanced Pathway by 2035. Choices on how to use this additional land include measures to increase emissions reduction further (e.g. more tree planting), conversion to other uses (e.g. wildflower meadows and rewilding/natural regeneration) to deliver wider environmental benefits and address biodiversity loss.⁴⁴ These options are not included in our scenarios due to the lack of robust evidence on the abatement potential. Land could also be used for less-intensive agricultural production (Box 7.8).

Box 7.8

Other uses of land to deliver environmental benefits

In addition to using land to actively plant trees and hedges and restore peatland, there are other uses of land that could deliver further environmental benefits to address biodiversity loss. This could also entail some form of low-intensive agriculture:

- **Rewilding** can be defined as the 'process of drawing back or de-intensifying agricultural or commercial forestry production in carefully selected areas using natural principles and processes' (Rewilding Britain). The most notable example is the Knepp Estate in West Sussex, which ceased intensive farming on its unproductive arable land for the benefit of nature 20 years ago. Fields soon gave way to scrub while free-roaming grazing animals including cattle and pigs are used to create a mosaic of habitats on the 1,400 hectare estate, which over time has seen a large increase in the diversity and numbers of species, including rarities such as the nightingale and turtle dove.
- **Wildflower meadows.** With intensification of agriculture, the expanse of wildflower meadows and species-rich grasslands have almost disappeared with the loss of 99% of 'unimproved grasslands' since the 1930s. Replacing high input (e.g. fertilisers and pesticides) grassland mono-cultures with low input species rich-grass and wildflowers can support a wider variety of wildlife including pollinators, reptiles, small mammals and birds.
- **Low-intensive farming.** Examples include mixed farming, combining arable and livestock production to close the nutrient loop (e.g. use of animal waste to fertilise the fields), and organic farming, which avoids the use of synthetic fertilisers and pesticides in preference for livestock and green manures, and natural pest control methods.

Beyond land, 'blue-carbon' is the carbon sequestered and stored in marine and coastal habitats. Carbon stocks are found in saltmarsh, maerl seaweed, kelp forest, and seagrass beds. There is concern that degradation (e.g. from anchoring and mooring of boats), which could worsen with climate change could release this carbon. However, considerable uncertainty on the dynamics of blue carbon exists and work is needed to calculate a baseline assessment of stocks. Blue carbon is not currently included in the UK GHG Inventory.⁴⁵

3. Analytical approach

We assume that key priorities for land, producing food for a growing population and for settlement growth, are met before allocating land for climate mitigation.

Our starting point for our analysis is the 2019 Net Zero report, which showed that the Net Zero target requires transformative changes in how land is used in the UK. We recognise other strategic priorities for land, including food production, housing and economic and social uses, a range of environmental services and biodiversity. Most of our measures have positive synergies with these but we highlight areas of potential risks. We quantify costs and benefits where good data exist and qualitatively assess other impacts where data is lacking.

We have used a bottom up analysis to produce a set of pathways to deliver land's contribution to Net Zero by 2050. We use the scenarios to explore a range of different futures, including ones with higher levels of innovation and behaviour change. Our scenarios aim to demonstrate what can be achieved with an ambitious and effective policy package that deals with various barriers to action in these sectors.

The following sections set out our scenarios, the approach to deriving the pathways for the devolved administrations and our approach to uncertainty.

a) Analytical methodology

i) Baseline

Our scenarios compare trajectories consistent with meeting the Net Zero target, with a projection of baseline emissions where measures to reduce emissions are largely absent. Baseline emissions for agriculture are based on the BEIS Updated Energy and Emissions Projections⁴⁶ and the LULUCF sector is based on a projection derived for this report by the Centre for Ecology and Hydrology (CEH), which includes all sources of peatland emissions:

- For agriculture these emissions decrease to 52 MtCO₂e by 2035. This includes an annual 0.6% efficiency improvement in the dairy herd, which leads to a decline in dairy cattle numbers.
- For land use we assume a continuation of past low rates of afforestation resulting in an increase in net emissions to 13 MtCO₂e by 2035. The baseline also includes projected savings from firm Scottish Government policy to fund the restoration of 250,000 hectares of peatland before 2030.⁴⁷ If achieved this would deliver annual emission savings of around 1 MtCO₂e by 2030.

We assume that key priorities for land, producing food for a growing population and for settlement growth to support housing and other economic activity, are met before allocating additional land for climate mitigation:

- The UK population is projected to increase from 66.4 million in 2018 to 70.9 million by 2035 and 73.6 million by 2050.⁴⁸
- Maintaining the current level of per capita food production in 2035 and constant food exports would require 0.9 million hectares of additional land, assuming no change in yields, other productivity improvements or structural changes in agriculture.

- Land for settlements account for 7% of UK land today. The expected increase in land for settlement growth takes account of the projected increase in the number of households, household density and economic activity. Meeting this growth requires the use of brownfield sites and 'non-previously developed' land. For 'non-previously developed', we had classified this previously to mean agricultural land. For this report, we make a distinction between 'non-developed land' that is already classified as settlement but not built-on (e.g. outdoor recreation areas) and non-settlement land (e.g. agricultural land). This reclassification reduces the need to convert as much agricultural land to meet these demands. Land for settlements now accounts for 9% of UK land area by 2050 compared with 12% in our Net Zero report.

ii) The Balanced Net Zero Pathway

The Balanced Net Zero Pathway results in net emissions for agriculture and land use falling to 40 MtCO₂e by 2035 and 16 MtCO₂e by 2050

The Balanced Net Zero Pathway represents our central scenario for how the agriculture and land sectors will need to evolve to deliver Net Zero across the economy by 2050. It results in net emissions in agriculture and land use of 40 MtCO₂e by 2035 and 16 MtCO₂e by 2050. Key elements are:

- **Low-carbon farming practices and energy use.** Take-up ranges between 50-75% for both behavioural (e.g. cover crops, high sugar grasses and livestock health) and innovation (e.g. 3NOP, breeding and anaerobic digestion) low-carbon measures depending on ease of implementation on-farm. Biofuels and electrification options are taken-up from the mid-2020s and hydrogen fuel cells for larger applications from 2030 for mobile machinery. Building heating and cooling systems switch to low-carbon alternatives including heat pumps and hydrogen, with use of biomass phased-out by 2035.
- **Options to release land from agriculture** result in 3.8 million hectares freed up by 2035.
 - **Agricultural productivity.** Average crop yields increase to 11 tonnes/hectare by 2050, driven by improvements in agronomy and technological innovation such as breeding. Livestock stocking rates on lowland grassland increase by 10%. 10% of current horticultural production is moved indoors by 2050.
 - **Consumer behaviour change.** There is a 20% shift away from all meat and dairy products by 2030 which is substituted by plant-based proteins. The reduction in meat consumption rises to 35% by 2050. WRAP's UK Food Waste Reduction Roadmap target of a 50% reduction on 2007 levels is met by 2030 across the supply chain, with a 60% reduction by 2050.
- **Afforestation and broadleaf management.** Woodland area increases to 18% of UK land area by 2050, most of which is under sustainable management. Forestry biomass output increases to 12 million oven dried tonnes (odt) by 2035 compared to under 5 million odt in 2019. The management of existing forests account for all the harvest, of which 60% is fuel-grade material.
 - Annual afforestation rates reach 30,000 hectares by 2025 and rise to 50,000 hectares between 2035 and 2050. An additional 15% of land is used as open ground for biodiversity.

Annual afforestation rates reach 30,000 hectares by 2025 and rise to 50,000 hectares between 2035 and 2050.

- Tree planting density is 2,000 stems per hectare for broadleaves and 3,000 for conifers, and a planting density of 66:34 in favour of conifers for the UK. This corresponds to planting 143 million trees in 2035.
- Productivity yields of new conifers are YC16, which is higher than the average for existing conifer woodlands of YC14. Yields for broadleaf trees remain at YC6.
- Active management of 80% of the existing broadleaf woodland area by 2030 (up from the current 20%).

- **Agroforestry and hedges.** The Balanced Pathway improves on-farm diversification with the integration of trees on 10% of farmland and extending the length of hedgerows by 40% by 2050, with 30% of this actively managed.

The area of restored peat increases from 25% currently to 58% in 2035 and 79% by 2050, and 35% of lowland cropland is sustainably managed

- **Peatland restoration** increases the area restored from 25% currently to 58% in 2035 and 79% by 2050, with a further 35% of lowland cropland sustainably managed:
 - All upland peat is restored by 2045 (or stabilised if degradation is too severe to restore to halt carbon losses). 25% of the area of lowland grassland is rewetted by 2035, rising to half by 2050.
 - 75% of lowland cropland is either rewetted or sustainably managed by 2050:
 - A quarter of the area is rewetted to near natural condition (and crop production ceases), and a further 15% is rewetted but conventional crop production switches to paludiculture crops.
 - Water-table management options are deployed to 35% of the area.
 - All low-productive trees of less than YC8 are removed off peatland; and all peat extraction sites are restored by 2035.
- **Bioenergy crop** planting reaches 30,000 hectares by 2035, equally split between miscanthus, SRC and SRF. The total area with bioenergy crops rises to 0.7 million hectares by 2050. Energy crop yields increase to 15 odt/hectare by 2050 driven by better agronomic practices and innovation. Harvested biomass products reach 1.8 million odt by 2035 and 6.4 million odt by 2050.

Most of these measures have lower abatement costs than our assumed carbon values (£181 in 2035) and some deliver wider benefits (Table M.7.2).

Table M.7.2Abatement costs in agriculture and land use in 2035 (£/tCO₂e)

	Measure	£/tCO ₂ e
Low carbon farming - crops	Cover crops	125
	Grass legumes mix	-1,040
Low carbon farming - livestock	Livestock breeding - current methods	-580
	Livestock breeding - low methane	-1,850
	Livestock breeding - genomics	-1,177
	Increased milking frequency	-850
	High sugar grasses	-415
	Precision livestock feeding	-15
	Adding nitrate to livestock diets	55
	3-NOP in livestock diets	85
	Improving sheep health	25
	Improving cattle health	-45
Waste and manure management	Cover slurry tanks	20
	Anaerobic digestion - pigs	-250
	Anaerobic digestion - cattle	-175
On-farm machinery	Stationary and mobile machinery	75
Land use measures	New conifer planting	65
	New broadleaved planting	105
	Miscanthus	180
	Short Rotation Forestry	240
	Silvoarable Agroforestry	155
	Silvopastoral Agroforestry	415
	Hedgerow Expansion	5
	Upland Peat Restoration	40
	Lowland Peat Restoration	5
	Woodland to Bog	30
	Short Rotation Coppice	-
	Broadleaf forestry management	150

Source: CCC analysis based on SRUC (2020) and Vivid Economics research.

iii) The exploratory pathways

These scenarios set out alternative pathways as to how agriculture and land could contribute to the UK's Net Zero commitment. They involve varying the deployment rate, timing and ambition of the measures outlined above. These result in different land use and residual emissions by 2050 than the Balanced Pathway (Figures M.7.10 and 7.11)

Headwinds is the least ambitious pathway, with remaining emissions in agriculture and land use of 48 MtCO₂e in 2035 and 26 MtCO₂e by 2050.

Headwinds is the least ambitious pathway, with remaining emissions in agriculture and land use of 48 MtCO₂e in 2035 and 26 MtCO₂e by 2050. The key differences are the lower level of diet change which releases 1.7 million hectares less land by 2035 compared to the Balanced Scenario and the rates of afforestation:

- Consumer behaviour change is limited to a 20% switch away from meat and dairy products to plant based alternatives by 2050. Food waste is halved by 2030 with no further reductions beyond that date.
- Other behaviour change assumptions and take-up of low-carbon farming practices are the same as in the Balanced Pathway.
- Emissions savings from take-up of low-carbon farming practices are higher in this scenario, as more land is in agricultural production, resulting in higher emissions and higher abatement potential. This measure delivers 0.5 MtCO₂e more emissions savings in 2035 than in the Balanced Pathway.

- Annual afforestation rates reach 30,000 hectares by 2025 and are maintained to 2050. Trees are integrated onto 5% of agricultural land, hedges increase by 30% and 67% of existing broadleaf woodlands are brought into active management by 2030.
- Peatland restoration extends to 52% of the peatland area by 2035, and 77% by 2050. There is lower ambition for lowland peat restoration, with only 25% of grassland and 20% of cropland area rewetted by 2050. A further 30% of the cropland area is under sustainable management. All upland peat is restored but five years later in 2050.
- Energy crop planting is aligned to the Balanced Pathway, and total biomass output from energy crops and forestry total 12.4 million odt in 2035.

Widespread Engagement reflects higher levels of engagement on climate and health issues by farmers and consumers, and emissions fall to 39 MtCO₂e in 2035 and to 8 MtCO₂e by 2050.

Widespread Engagement reflects higher levels of engagement by consumers and farmers, resulting in higher levels of diet change and land use change. This enables higher afforestation, peatland restoration and bioenergy crops. Residual emissions fall to 39 MtCO₂e in 2035 and to 8 MtCO₂e by 2050:

- Farmers adopt a high uptake of low-carbon behavioural practices of between 60-80%; and a lower uptake 50-75% for innovative measures. Decarbonising energy use focuses on electrification and the use of biomass and biodiesel as a transition fuel. There is no uptake of hydrogen.
- Crop yields are assumed to be the same as in the Balanced Pathway, but livestock stocking density is limited to 5% increase on grasslands.
- A larger shift towards healthier diets beyond 2030, results in a 50% switch away from meat and dairy products to all plant-based products by 2050. Food waste is halved by 2030 and continues to fall to 70% by 2050.
- Annual afforestation rates reach 50,000 hectares by 2030 and 70,000 from 2035 to 2050. There is an increased focus on creating woodlands for biodiversity rather than productive forestry: planting density is reduced for broadleaves to enhance conservation outcomes (1,200-1,800 stems per hectare); the mix of slower growing broadleaves is higher at 66:34, yields of conifers remain at the current level of YC14; and the area of open ground is increased to 20%.
- More grassland is allocated to trees with 15% of the area under a silvopastoral system, while trees on cropland area remains at 10%.
- Peatland restoration and the level of sustainable management of lowland cropland matches the ambition in the Balanced Pathway.
- Energy crop planting drops to a third (10,000 hectares by 2035) of the level in the Balanced Pathway with only miscanthus planted. This results in 1 million odt and 3.4 million odt of harvested output by 2035 and 2050 respectively.

Widespread Innovation is characterised by high levels of innovation, and emissions fall to 30 MtCO₂e in 2035 and by 2050, reaches negative emissions of 8 MtCO₂e.

Widespread Innovation is characterised by high levels of innovation with a focus on technology to deliver higher yielding food and energy crops and more productive trees. A lower tree planting rate (compared to the Wider Engagement scenario) is offset by a higher mix of conifers which delivers faster and higher carbon sequestration by 2035. Residual emissions fall to 30 MtCO₂e by 2035 and by 2050 agricultural emissions are offset by the land net carbon sink, with combined negative emissions of 8 MtCO₂e

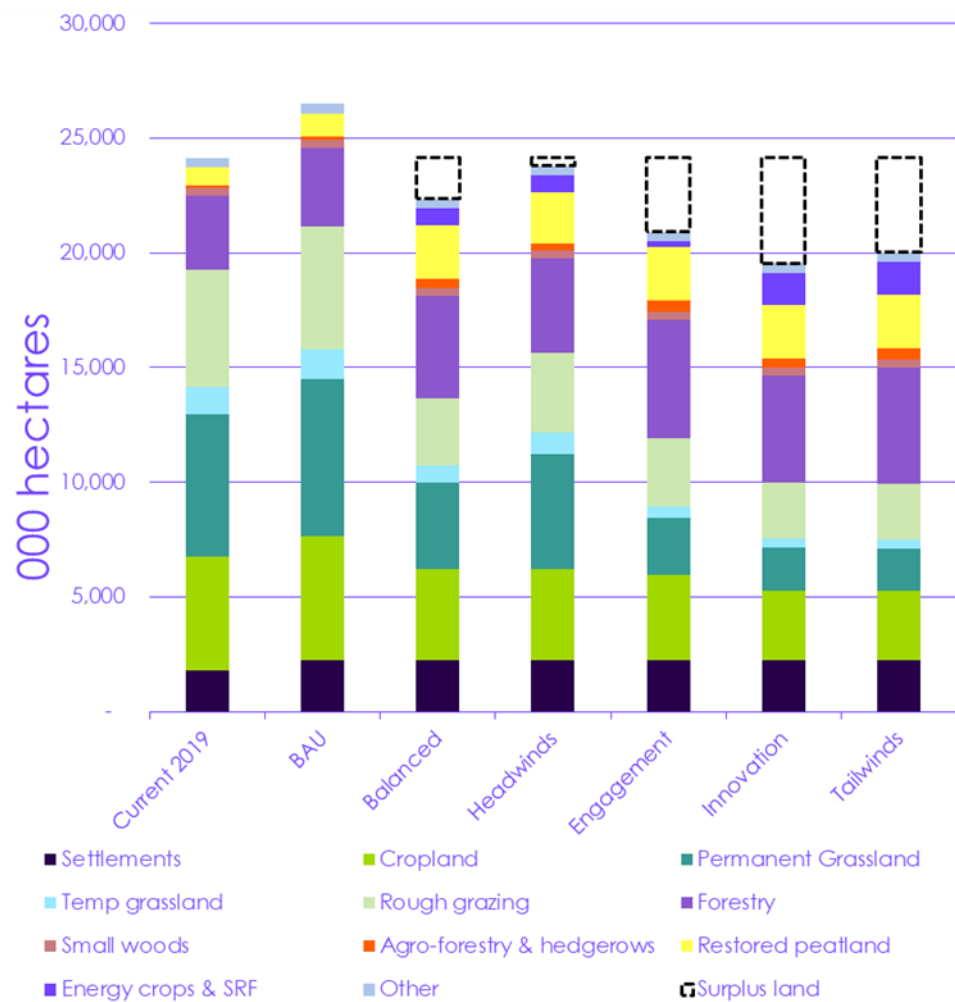
- Farmers adopt a high uptake of low-carbon innovation measures of between 60-80%; and a lower uptake of 50-75% for behavioural measures.

- Developments in crop breeding lead to wheat yields of 13 tonnes by 2050, and livestock stocking rates increase by 10% on rough grazing and permanent grassland.
- The same level of diet change as Widespread Engagement, except 30% of the meat is replaced with lab-grown meat and 20% by plant alternatives. Food waste is halved by 2030 and continues to fall, reaching 60% below 2007 levels by 2050.
- Afforestation rates reach 50,000 hectare five years earlier than in the Balanced Pathway in 2030. The focus is on more productive forestry with a higher mix of faster growing conifers (67:33) with higher yields.
- Breeding allows for the planting of conifers with an average YC18 and broadleaves with YC8 from 2030. This offsets the lower planting rates (50,000 hectares a year from 2030) and delivers quicker and higher savings by 2035 and 2050 compared to the Widespread Engagement Scenario.
- Agroforestry is applied to 10% of farmland, and hedges increase by 30% by 2050, with 10% managed.
- There is more reliance on sustainable management of lowland cropland peat driven by technological solutions that allow for better management of the water table. This is applied to 50% of lowland cropland. Only 25% of the area is rewetted for paludiculture and we assume no restoration to near-natural condition.
- Energy crop planting doubles by 2035 and reaches 1.4 million hectares by 2050. Developments in innovation allow for miscanthus and SRC yields to increase by 33% to 20 odt per hectare by 2050. This results in the highest level of harvested products (4 million odt) by 2035.

Tailwinds delivers the highest level of ambition, nearly 50% higher than in the Balanced Pathway by 2035.

Tailwinds represents the highest level of ambition. Measures are aligned to the Wider Innovation scenario, except for food waste where there is a higher level of ambition with a 70% reduction on 2007 levels reached by 2050. This scenario delivers the highest level of emissions savings which are 49% higher than in the Balanced Pathway by 2035. Residual emissions are 28 MtCO_{2e} by 2035, falling to below zero by 2046 and -14 MtCO_{2e} in 2050.

Figure M.7.10 Current land use and under our Sixth Carbon Budget scenarios by 2050



Source: CEH(2020) and CCC analysis.

Figure M.7.11 Residual GHG emissions in agriculture and land use in 2050



iv) Costs and Benefits

Our analysis covers private costs and benefits and wider social benefits of increased recreation, improved air quality, improved health and flood alleviation.

Our assessment of costs and benefits updates work we commissioned from Vivid Economics and new work from SRUC.⁴⁹ It covers all private costs and benefits and wider social benefits of increased recreation, improved air quality, improved health and flood alleviation.

There could be additional costs, both financial and non-financial, that has not been possible to include in our analysis:

- Costs of R&D and innovation to develop higher yielding crops that do not require additional inputs and are resilient to climate impacts. If these costs are passed onto farmers, they may lead to an increase in net costs.
- There are some costs to farmers from implementing low-carbon practices on their land. Where possible, costs have been considered e.g. capex of anaerobic digestion systems and changing livestock diets. There will be other non-financial barriers to overcome which could incur costs (e.g. providing information to farmers and re-education and re-skilling).
- Costs of moving horticulture indoors could involve costs of buildings and operational expenditure e.g. heating and lighting. This will be set against savings from using land, some lower input costs (e.g. fertiliser and pesticides) and higher yields.

- There could be some disruption costs associated with behaviour change e.g. for food producers to develop new plant-based foods and for consumers to change shopping and eating habits. Reducing food waste is cost saving to households and the food supply chain. WRAP estimate the value of food wasted by UK households and across the food supply chain has a value of £19 billion per year. There could be some added costs associated with trying to reduce food waste e.g. data driven approaches to optimise use by dates and technologies to monitor how much food is wasted, although these are expected to be much smaller than the cost savings made.
- The Widespread Innovation scenario assumes that meat products are partly substituted by lab-grown alternatives. These are currently at early stage of development and are more expensive than animal products. However, there is evidence that these costs are falling with Mosa Meats, a producer of lab-grown meat, reducing the costs of culturing the cells by 80% in 2020.

As set out in our accompanying Policy Report: *Policies for the Sixth Carbon Budget & Net Zero*, achieving these scenarios will require co-ordinated effort across sectors, covering farmers, the wider food supply industry and consumers, and a strong policy framework which addresses financial and non-financial barriers. There will need to be a strong Monitoring, Reporting and Verification (MRV) system to verify actions across the UK and trade policies that protect risks of carbon leakage from trade in agricultural products.

Wider benefits

Our scenarios capture some of the wider benefits from some measures – recreational benefits of woodland, air quality improvements, flood-risk alleviation and health improvements from increased physical activity. The approach was developed by Vivid Economics and we have updated this analysis to reflect the ambition in our revised Sixth Carbon Budget Pathways (Box M.7.9).

Box M.7.9

Valuation of non-market benefits of land uses

Recreational benefits

An Outdoor Recreation Valuation tool (ORVal) produced by the University of Exeter was used to model the number of additional visits to woodland that the planting of a new forest would generate. It was assumed that new visits do not occur until 10 years after planting, and annual visits increase as trees approach maturity. A £/visit willingness to pay for these visits was used from a large-scale cross European Union stated preference survey assessing how much people would be willing to pay to visit woodland.

Air quality

Ammonia is emitted during the storage and spreading of manures and slurries and from the application of inorganic fertilisers, and can contribute to particulate pollution in urban areas, leading to increased cardiovascular and respiratory disease.

A study commissioned by the ONS from the Centre for Ecology and Hydrology estimated the reduction in hospital admissions (from respiratory and cardiovascular conditions) from natural vegetation removing pollutants from the air. This model was adapted for use in this study. However, given that the forests in this study are predominantly located in peri-urban and rural areas, the population density is relatively low so the benefits are smaller than in studies which look at locating trees in urban areas.

Flood risk alleviation

Woodland in the upper catchments of rivers can help to alleviate flood risk by slowing down the flows of water, though the exact benefits depend on a number of factors including location and planting density. Furthermore, targeting woodland planting onto the most sensitive soils or in key locations can intercept and help absorb surface run-off generated from the adjacent ground. This is valued using a recent report by Forest Research that looked at the costs involved in holding the amount of water held in all UK woodlands in UK reservoirs (a replacement expenditure approach). This UK value is then scaled down to a per hectare basis.

Health improvements from increased physical activity

Natural environments are often used for walking, running and playing sports, leading to physical health benefits for the visitors. These benefits can lead to improved long-term health outcomes, which is measured in terms of a relative reduction in the risk of premature death. The value of this relative reduction in the risk of premature death has been calculated in many research papers, using surveys which elicit the value that individuals are willing to pay to improve their quality and length of life. In order to prevent an overestimate of physical health benefits, it is assumed some visitors to woodland would have engaged in a different form of exercise if they hadn't exercised in the woodland, so conservatively, only 10% of the exercise from recreation in the woodland is attributed to the creation of the woodland.

Source: Vivid Economics (2020); CCC analysis.

Due to lack of evidence, the quantitative benefits of biodiversity and water quality are not included in this analysis. While there is evidence that the creation of new woodland habitats support biodiversity broadly, there is no widely accepted way to value biodiversity⁵⁰. Other studies point to the benefits that land use change can have in improving water quality, increasing pollinator numbers, and reducing soil erosion. There was insufficient quantitative evidence to support their inclusion in our analysis, though these could be important:

- There is evidence of the high biodiversity value of restored peatlands from species such as sphagnum moss, invertebrate and bird species.⁵¹ Some studies indicate that drain or gully blocking can lead to an increase in indicator species like sphagnum moss and the recovery of aquatic macro-invertebrate fauna.
- Agroforestry and hedgerows are likely to provide biodiversity benefits (e.g. by providing habitats for insects, birds and small mammals), reduced water pollution, improved soil health and for grazing livestock shelter from wind and shade from the sun. Over 600 plants, 1,500 insects, 65 birds and 20 mammals species utilise UK hedgerow habitats.⁵² Numerous studies have shown the removal of hedgerows and the abandonment of hedge management on farmland is likely to have adversely affected different species groups, for instance yellowhammers (a declining species) in southern England.⁵³
- We have not included estimates of the health impacts of diet change in our analysis as these are uncertain. However, a study by Ricardo for the Committee in 2013 suggested the health impacts of reducing red meat consumption by 50% would represent 0.5% of GDP (around £1 billion), with other estimates suggesting reducing average meat consumption to two to three servings per person per week could reduce NHS costs by £1.2 billion per year.⁵⁴

There are also wider societal risks, particularly in relation to planting bioenergy crops that could have negative impacts on biodiversity, soil health, water quality and invasive species.

Half the low-carbon farming measures in our scenario have a major benefit for improving air and water quality.

These risks are higher when planting maize and on grasslands. Our scenarios look to mitigate these risks by planting only perennial energy crops and only on cropland, while SRF is grown on grasslands.

Our scenarios also include a high take-up of low-carbon farming practices. These could deliver benefits to biodiversity and soil quality, while there could also be some risks. Based on a review of evidence from Defra's on-going 'Delivering Clean Growth through Sustainable Intensification' project, we assessed the wider environmental considerations of the 18 low-carbon measures in the Balanced Pathway (Table M.7.3):

- The biggest benefits are for air and water quality, with nine of the 18 measures delivering major impacts. These include increasing milk frequency of dairy cattle, improving livestock health and covering slurry tanks with impermeable covers.
- There is less significant benefit to biodiversity and soil quality, with only two measures deemed to have a major impact (grass leys and cover crops).
- We also identified negative trade-offs from three of the measures, which could potentially worsen air quality (anaerobic digestion pigs and cattle), and water quality (from the adoption of high-starch diets).

Table M.7.3

Qualitative assessment of wider environmental benefits from low-carbon farming practices

Low-carbon farming practices	Water quality	Air quality	Biodiversity	Soil
Breeding measures Genomics Current breeding Low methane GM cattle	Minor Major Minor Major	Minor Major Minor Major	- - - -	- - - -
Increase milk frequency	Major	Major	-	-
Livestock diets High sugar grasses Nitrate additives Precision feeding High starch diet 3NOP	Major Minor - Negative Minor	- Minor Major - Minor	- - - - -	- - - Negative -
Livestock health Cattle Sheep	Major Major	Major Major	Minor Minor	- -
Soil measures Grass legume mix Grass leys Cover crops	Major - Major	- - Major	Major - -	- Major Major
Waste management AD pigs Ad cattle Cover slurry tanks	- - Major	Negative Negative Major	Negative Negative -	- - -

Source: CCC analysis based on Defra Sustainable Intensification Project.

b) Delivering the pathways for the Devolved Administrations

We have also quantified the emissions savings in each scenario for each of the devolved administrations.

The pathways for the devolved administrations (DAs) have been derived by applying the analytical approach outlined above to more detailed data in each DA for some key metrics:

- Agricultural baseline emissions projection is developed for each DA based on their share of UK 2018 outturn emissions from the 2020 GHG inventory. This is disaggregated into the main source of emissions (e.g. enteric fermentation and soils) by individual administration. Baseline projections in the LULUCF sector are derived from the CEH work for this report, which reflect net emissions in each DA under the current GHG inventory, and the inclusion of all peat emissions. The baseline projects forward the average level of afforestation achieved in each DA between 2014 and 2018, while for Scotland we include the firm Scottish Government commitment to restore 250,000 hectares of peat by 2030.
- In the agriculture sector, our modelling of low-carbon farming measures takes account of the abatement potential based on the current use of land for growing crops and rearing livestock in each DA. DA specific abatement costs for each measure were derived.
- Abatement savings from energy use in agriculture was derived from the UK level of abatement, which was split according to each DA's share of emissions in 2018 under the 2020 GHG inventory. The abatement options and costs are assumed to be the same as for the UK.
- The outputs of our modelling of land released through productivity and behaviour changes are based on DA specific data for current use of agricultural land, including grassland and cropland. Outputs of agriculture in terms of types of crops produced, yields, and livestock numbers are also split by DA based on latest data. The UK ambition on yields, livestock intensification and consumer behaviour change are assumed to apply equally across each DA.
- The level of ambition on how to use land for measures to sequester carbon – afforestation, peatland restoration and energy crops – are based on how much land is available for these activities and in some cases on levels of ambition that have been announced by the relevant governing bodies. This can result in significant differences in the level of each measure across the DAs. For example, afforestation rates are higher in Scotland due to the availability of land.

Estimates of costs and benefits are partly split by DA and partly use UK data. Our modelling distinguishes the level of take-up of different technologies and options by DA, with some costs associated with these are DA-specific (e.g. land acquisition/opportunity costs), while others are drawn from UK averages (e.g. costs of decarbonising tractors and costs of peatland restoration for different types of peat).

c) Approach to uncertainty

In developing our advice, we have sought to consider the key uncertainties which could influence the path for emissions reduction in agriculture and land use in the UK. We explore these uncertainties primarily through our use of scenario analysis:

- The exploratory pathways achieve emissions reduction in different ways, illustrating the range for how they can be achieved. We use these scenarios to guide judgements on the achievable and sensible pace of decarbonisation in the face of uncertainty, and to understand how less success in one area can be compensated for elsewhere.
- The Tailwinds Scenario assumes considerable success on both innovation and societal/behavioural change and represents the most ambitious scenario and assumptions on scaling up sequestration measures and evidence on consumer behaviour change.
- Our Balanced Net Zero Pathway is designed to drive progress through the 2020s, creating options that keep the three 'exploratory' scenarios open.

Other specific risks that we highlight are around climate impacts on agriculture and the level of peatland emissions:

Climate risks. In its 2017 Climate Change Risk Assessment (CCRA), the Adaptation Committee highlighted the risks that climate change poses to the natural world:

- Changes in climate are already impacting on natural systems in the UK and there is a substantial risk to vital goods and services provided by the natural environment and society.
- These risks are heightened because the nature environment is already stressed.
- There are potential opportunities from modest climate change through extended growing seasons and improved productivity.

If climate risks dominate and crops yields decrease, the Balanced Pathway can still be met but would require a larger shift in diets.

In our assessment of future UK crops yields, we took account of these risks and opportunities to improve yields through innovation and good agronomy (Table M.7.1). We also constructed a sensitivity under which climate risks dominate future yields, so that yields decrease to around 6 tonnes/hectare for wheat (and equivalent change for other crops) by 2050 compared with 8 tonnes/hectare currently.

- In the Balanced Pathway maintaining constant per capita food production with higher crop yields releases 1.2 million hectares by 2050. In the crop sensitivity scenario, this requires 1.8 million hectares more land due to lower yields – increasing cropland area by 37%, compared with today.
- Lower crop yields imply that to have enough land to deliver both the food production objective and the mitigation measures in our Balanced Pathway, more land would need to be released through other measures. If this was achieved through diets alone, it would require a 45% switch away from meat and 20% from dairy by 2050.
- The emissions reduction pathway we set out could still be achieved in a situation where climate risks dominate. But it is important that higher levels of diet change remain in scope in 2030 and are reviewed with evidence on how agriculture responds to climate impacts.

Better evidence is needed to improve our understanding of peat condition, depth and location under the different land uses.

Peatland emissions. Our estimate of emissions from peatland under different land uses is based on current understanding. UK emissions range between 18.5 and 24.5 MtCO₂e, depending on the method used to estimate forestry peat. Our analysis uses the higher figure, which is based on Tier 2 emissions factor for forestry peat. However, the confidence interval ranging from less than 10 MtCO₂e to more than 40 MtCO₂e (using AR4 for methane) highlights the large uncertainties of peatland emissions.⁵⁵ (Box M.7.10).

Box M.7.10

Uncertainties in peatland emissions estimates

The uncertainties in peatland emissions reflect the lack of robust activity data regarding the condition, location and extent of peatland under different land use types. For example:

- Wasted peat is soil that is no longer deep peat (i.e. organic soil of more than 40 cm in depth) due to intensive use, mainly for crop production. Due to insufficient data however, wasted peat is assumed to emit the same level of emissions as deep peat.
- The evidence on upland peat is incomplete with the peat condition and depth in some areas not properly mapped.

Other uncertainties relate to measuring abatement savings over time and the impact of climate change:

- Under the current IPCC methodology, CO₂ emissions from restoration is assumed to fall to zero in the year of restoration. This does not reflect real-life conditions, where emissions would decline over time as the peat recovers following restoration.
- The impact of projected changes in climate on emissions from degraded peatlands is unknown. There is more confidence that near-natural peatlands will be more resilient to climate change and are likely to emit less CO₂ than degraded peatlands under all climate scenarios.⁵⁶

A programme of work will look to improve the evidence base for these uncertainties, which will be used to update emissions estimates and abatement savings in the GHG Inventory. These include:

- On-going work to better quantify the area of wasted peat in England, while field measurements will be used to develop new emission factors. Preliminary findings from the BEIS commissioned project is expected next year.
- Nature Scotland is funding the establishment of a measurement site to measure emissions over an afforested area of peat, which will help to reduce uncertainties regarding the impacts of forestry on peat.
- Defra's sustainable lowland peat project is developing evidence on the abatement savings from a range of options that will allow for on-going crop production (see section 2 (e) above).
- Defra plan to commission work to develop an updated peatland map, which will determine peat location, depth and condition. It will enable improved spatial prioritisation of restoration work and more accurate estimation of GHG emissions. The project is expected to start in 2021.

We will provide an update on the work in next year's Progress Report.

Source: CCC analysis.

Other areas of uncertainty that we have not quantified, but are important to consider in designing policy to meet the pathway:

- The framework we have developed in our analysis of emissions pathways is necessarily stylised and relies on delivering a complex set of behavioural changes and interactions among consumers, the food supply sector and farmers. This transition is complex and reaches across the diverse farming sector, geographies and other actors. There are risks around how the timing and co-ordination of these actions are implemented in practice and in a way that delivers a fair transition across all players.
- In order to deliver emissions reduction in the UK, farmers need to respond to changes in UK diets by changing the type of food produced. This means reducing livestock production and increasing crops, if they can be grown. There is a risk that farmers respond to a change in UK demand by increasing exports of meat products rather than switching production to crops. If this happens UK emissions will not fall along the pathway we set out (although there may be reductions in emissions in other countries, depending how overseas demand and production responds).
- UK farmers are largely dependent on global commodity prices, which affect decisions on what to grow. These are historically volatile, with prices dependant on climate and global supply and demand. Our scenarios do not take account of future impact on prices, as they are difficult to predict with any certainty, but are likely to impact on decision making in practice.
- The COVID-19 crisis has impacted farmers through a fall in beef and lamb prices, driven by social distancing rules impacting on food demand from cafes and restaurants. Milk demand also reduced at a time when milk production was at a peak with cows grazing outside in the spring, which had a disproportionate effect on farmers. The sector was also affected by the travel restrictions impacting on the supply of seasonal workers. It is unclear how lasting these impacts could be. Going forward there will be uncertainties relating to the transition to the Environmental Land Management System (ELMs) of payment for public good. This and other policies put in place need to recognise the essential role of farmers as stewards of the UK's land while encouraging real change.
- The impact of COVID-19 has also focussed people's attention on essential needs, including food and the security of food supplies as well as the importance of green spaces and nature and access for people's physical and mental health. Research in 20 European countries found that the COVID-19 pandemic has led to a positive shift in public awareness of nature-related topics.⁵⁷ The Citizen's Assembly on Climate Change highlighted the role for a managed diversity of land that included peatland and forests. This, together with new research highlighting the biodiversity loss across the world and the importance of biodiversity in underpinning the many services that land and nature provides,⁵⁸ may strengthen public support for a recovery programme aimed at nature recovery and sustainability.

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Chapter 2

Emissions pathways for the agriculture and land use, land use change and forestry sectors

The following sections are taken directly from Chapter 3 of the CCC's Advice report: The Sixth Carbon Budget – The UK's path to Net Zero.

Introduction and key messages

Combined agriculture and land greenhouse gas (GHG) emissions were 67 MtCO₂e in 2018, which could fall to 40 MtCO₂e by 2035 in our Balanced Net Zero Pathway. Annual savings total 25 MtCO₂e when compared to emissions in the Business as Usual scenario in 2035 (Figure A.3.6.a). By 2050 residual emissions reach 16 MtCO₂e under the Balanced Pathway but fall to Net Zero by 2047 in the Wider Innovation and Tailwinds scenarios.

Delivering this transition requires a transformation in the use of land. Around 9% of agricultural land will be needed for actions to reduce emissions and sequester carbon by 2035 with 21% needed by 2050.* Improvements in agricultural productivity and a trend towards healthier diets are key to releasing land for afforestation, peatland restoration and bioenergy crops.

Investment of £1.5 billion per year by 2035 will be required to implement the necessary changes, but there will be co-benefits for health and recreation, air quality, flood alleviation and biodiversity.

Land is a critical natural asset providing a range of essential goods and services as well as carbon storage.

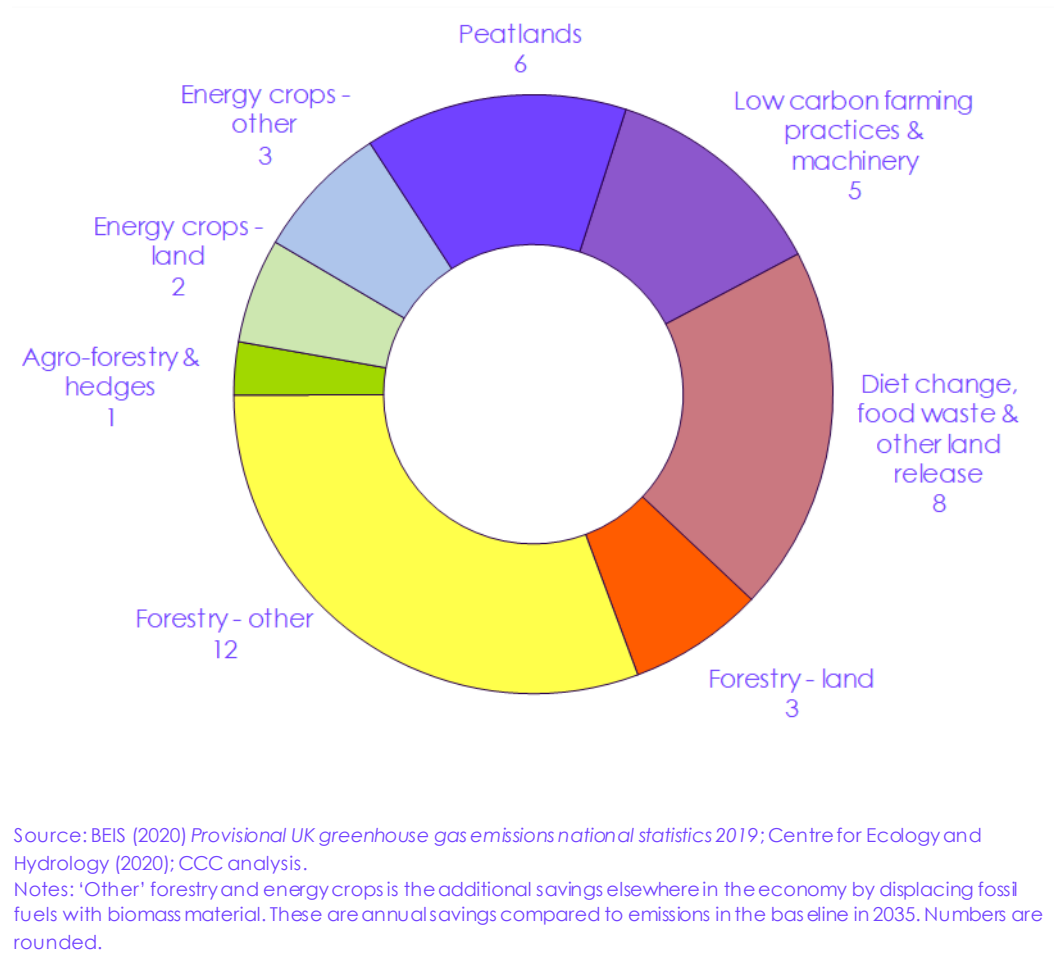
Our analysis balances the need to reduce emissions from land with other essential functions of land including maintaining food production and adapting to climate impacts. We draw on our previous reports,¹ new modelling work by the Centre for Ecology and Hydrology (CEH) on land-based pathways,² and Scotland's Rural College (SRUC)³ on options to reduce agricultural emissions as well as extensive literature reviews and stakeholder engagement.

The rest of this section is set out in five parts:

- a) The Balanced Net Zero Pathway for agriculture
- b) Alternative routes to reducing agriculture emissions
- c) The Balanced Net Zero Pathway for the land use sector
- d) Alternative routes to reducing land use emissions
- e) Scenario impacts: costs, benefits and co-impacts on society

* Rises to 11% and 23% when including land for settlement growth.

Figure A.3.6.a GHG savings from measures to Reduce agriculture and land use emissions, 2035 (MtCO₂e)



a) The Balanced Net Zero Pathway for agriculture

Our scenarios assume land for food and housing objectives are met first.

Agricultural emissions were 54.6 MtCO₂e in 2018, 10% of UK greenhouse gas emissions (GHGs). Completely decarbonising the agricultural sector is not possible (on current understanding) due to the inherent biological and chemical processes in crop and livestock production. However, there are options to reduce these emissions covering behaviour change, productivity improvements and the take-up of low-carbon farming practices. Our analysis starts with the assumption that land is prioritised for housing and other economic activity and food production before climate objectives. We estimate that sectoral emissions could fall to 39 MtCO₂e in 2035, and to 35 MtCO₂e by 2050 in the Balanced Pathway (Figure A.3.6.b.).*

- Low-carbon farming practices.** We commissioned SRUC to assess the abatement potential from measures to reduce emissions from soils (e.g. grass leys and cover crops), livestock (e.g. diets and breeding) and waste and manure management (e.g. anaerobic digestion). These reduce agricultural emissions by 4 MtCO₂e in 2035. This takes account of the interaction with other actions, notably diet change, which reduces the abatement potential of these measures over time (Table 3.6.a).

* All abatement savings are in reference to GHG emissions under the Business as Usual (BAU) scenario in that year.

Deep emissions reduction in agriculture and land cannot be achieved without changes in the way land is used in the UK

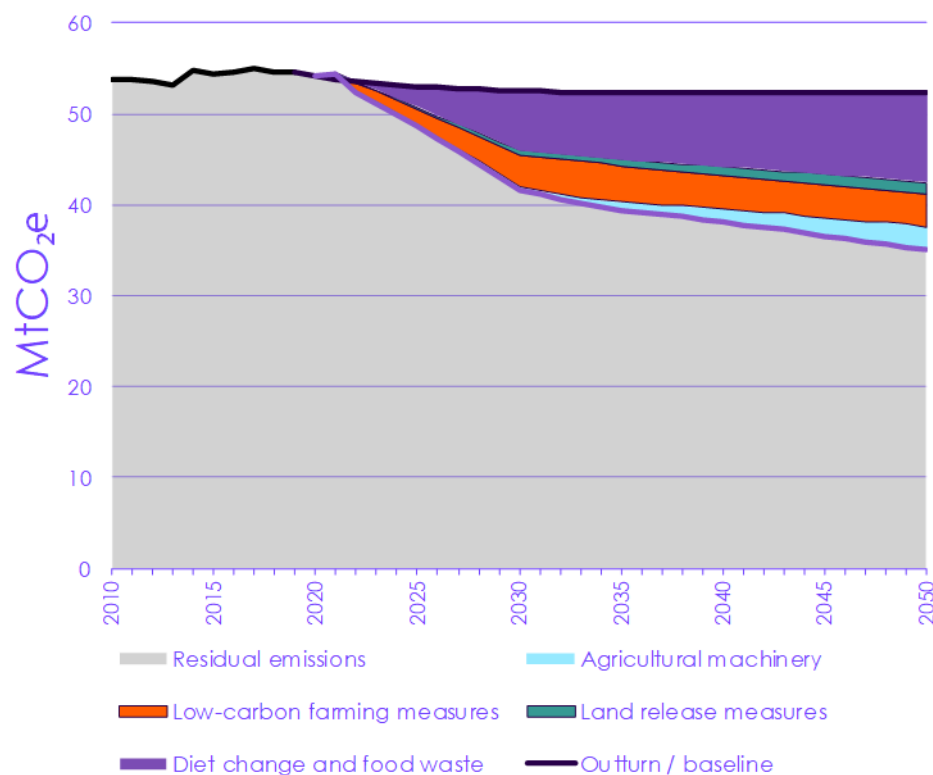
Productivity improvement in agriculture through innovation and better agronomy are vital.

- **Fossil fuel use in agriculture.** Currently 18 TWh of fossil fuels are used in agricultural vehicles, buildings and machinery, resulting in emissions of 4.6 MtCO₂e. Options to decarbonise fossil fuel use are similar to those in surface transport, off-road machinery in industry and commercial buildings. These cover electrification, biofuels, hydrogen and hybrid vehicles. Our Balanced Pathway assumes biofuels and electrification options are taken-up from the mid-2020s and hydrogen from 2030, reducing emissions to 2 MtCO₂e in 2035.
- **Measures to release land.** Changes in consumer and farmer behaviour can release land from agriculture while maintaining a strong food production sector. We considered five measures that could release land covering societal changes and improvements in agricultural productivity. Our analysis implies that these five measures could reduce annual agricultural GHG emissions by 8 MtCO₂e by 2035, rising to just over 11 MtCO₂e by 2050, with diet change the most significant:
- *Diet change.* Our Balanced Pathway involves a 20% shift away from meat and dairy products by 2030, with a further 15% reduction of meat products by 2050. These are substituted with plant-based options. This is within range of the Climate Assembly's recommendations for a 20-40% reduction in meat and dairy consumption by 2050.⁴ Our pathway results in a reduction in livestock numbers and grassland area, delivering annual abatement of 7 MtCO₂e by 2035, rising to nearly 10 MtCO₂e by 2050.
- *Food waste.* We assume food waste is halved across the supply chain by 2030 in line with the Waste and Resources Action Programme's (WRAP) *UK Food Waste Reduction Roadmap*. This would reduce UK emissions by almost 1 MtCO₂e in 2035.
- *Productivity improvements.* There is scope for further abatement from measures to increase agricultural productivity, which in our Balanced Pathway could reduce emissions by 1 MtCO₂e in 2035 and 2050. These cover crops and livestock:
 - *Improving crop yields without the need for additional inputs such as fertiliser and pesticides can be achieved through improved agronomic practices, technology and innovation while taking account of climate impacts. Our Balanced Pathway assumes that wheat yields increase from an average of 8 tonnes/hectare currently to 11 tonnes/hectare by 2050 (with equivalent increases for other crops).*
 - *Stocking rates for livestock can be increased through improving productivity of grasslands and management practices such as rotational grazing. Evidence suggests there is scope to sustainably increase stocking rates in the UK.⁵*
 - *Moving horticulture indoors.* Shifting 10% of horticulture production indoors under a controlled environment reduces the carbon, nutrient, land and water footprint.

Delivering emissions reduction should not be at the expense of increasing food imports that risk 'carbon leakage'. Therefore, both production and consumption of the highest carbon foods need to fall.

Our analysis assumes that the same proportion of UK food demand is met by UK food production in 2050 as is the case currently.* The carbon footprint of the UK's imported food would also fall, with the change in diets reflected in reduced imports of meat and dairy products. Policy will need to be carefully designed to ensure that risks of carbon leakage are avoided (see the accompanying Policy Report: *Policies for the Sixth Carbon Budget & Net Zero*).

Figure A.3.6.b Sources of abatement in the Balanced Net Zero Pathway for the agriculture sector



Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; SRUC (2020); CCC analysis.

b) Alternative routes to reducing agriculture emissions

We explore alternative pathways for transitioning to Net Zero by varying the deployment rate, timing and ambition of the measures outlined above. We also consider other options that could emerge over time, given investment in R&D and innovation as well as wider public acceptability for options that require behaviour change (Table A.3.6.a).

The alternative pathways deliver annual emissions savings ranging between 9–19 MtCO₂e by 2035 relative to the baseline. Apart from the Headwinds scenario, these deliver higher GHG savings than the 13 MtCO₂e in the Balanced Pathway (Figure A.3.6.c).

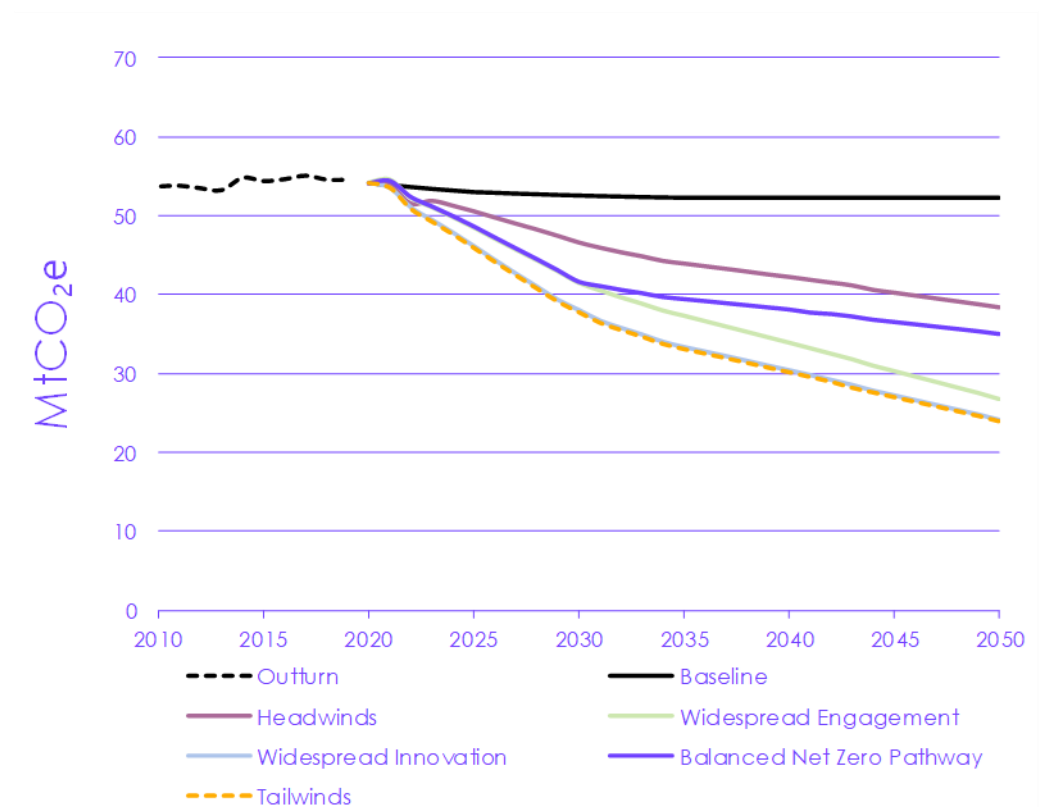
* Taking account of the nutritional composition of different food after diet change.

Implementing low-carbon practices offers some emissions reduction but is not enough for Net Zero.

- **Low-carbon farming measures.** We assume the take-up of measures associated with changing farming practices (e.g. planting cover crops, livestock health measures and feeding cattle a high starch diet) is highest in the Widespread Engagement scenario, and take-up of more innovative options (e.g. 3NOP additives, GM cattle, and breeding) is highest in Widespread Innovation. However, there is relatively little difference in emissions savings across these scenarios, which vary from 4 MtCO₂e in Widespread Engagement to 5 MtCO₂e under Headwinds by 2035.
- **Agricultural machinery.** While the mix of technologies differ across the pathways, they all achieve the same level of abatement by 2050. Which technologies emerge will depend on technology development and costs.
- **Measures to release land.** Among the measures to release land, moving diets away from the most carbon-intensive foods delivers the highest emissions savings. A higher or lower willingness to act on changing diets, reducing food waste and productivity improvements could change emissions relative to the Balanced Pathway:
 - Under the Widespread Engagement scenario, a greater shift away from meat and dairy (e.g. a 50% switch by 2050) and a greater willingness to act on food waste results in additional GHG savings of 2 MtCO₂e in 2035.
 - In the Widespread Innovation scenario, we assume that technology develops lab-grown meat for the market, such that 30% of the higher level of diet shift is towards lab-grown meat rather than plant-based alternatives. This results in 5 MtCO₂e additional GHG savings by 2035.
 - In the Headwinds scenario we assume a 20% shift away from meat and dairy products is achieved by 2050 instead of 2035. There is no further reduction in food waste beyond the 50% target reached in 2030. This results in 6 MtCO₂e lower GHGs savings in 2035 than the Balanced Pathway.
 - Crop breeding (e.g. development of new cultivars /traits) could lead to higher yields (e.g. to 13 tonnes/hectare for wheat by 2050). Higher livestock stocking densities on permanent grassland releases around 0.8 million more hectares of land out of agricultural production under the Widespread Innovation and Tailwinds scenarios compared with the Balanced Pathway. These result in 1 MtCO₂e additional GHG savings in 2035.

Diet change away from meat and dairy offers the biggest potential to release agricultural land for other uses.

Figure A.3.6.c Emissions pathways for the agriculture sector



Source: BEIS (2020) Provisional UK greenhouse gas emissions national statistics 2019; SRUC (2020); CCC analysis.

Table A.3.6.a

Summary of key differences in the agriculture sector scenarios

	Balanced Net Zero	Headwinds	Widespread Engagement	Widespread Innovation	Tailwinds
Behaviour change and demand reduction	<p>Medium level: 20% cut in meat and dairy by 2030, rising to 35% by 2050 for meat only. All replaced with plant-based; and</p> <p>Medium level: 50% cut in food waste by 2030, 60% by 2050.</p>	<p>Low level: 20% shift away from all meat types and dairy products to all plant-based by 2050; and</p> <p>Low level: 50% fall in food waste by 2030, with no further reduction.</p>	<p>High level: 50% less meat and dairy by 2050. All replaced with plant-based; and</p> <p>High level: 50% fall in food waste by 2030, 70% by 2050.</p>	<p>High level: 50% less meat and dairy by 2050 with 30% of meat replaced with lab-grown meat.</p> <p>Medium level: 50% cut in food waste by 2030, 60% by 2050.</p>	<p>Diet change aligned to Wider Innovation.</p> <p>Food waste reduction aligned to Widespread Engagement.</p>
Other land release measures	Aligned to Headwinds.	<p>Medium level for increasing average crop yields, livestock stocking rates on grassland and shifting horticulture indoors.</p> <p>Low level for increasing livestock stocking rates on grassland.</p>	<p>Medium level for increasing average crop yields and shifting horticulture indoors.</p> <p>Low level for increasing livestock stocking rates on grassland.</p>	<p>High level for increasing average crop yields, livestock stocking rates on grassland and shifting horticulture indoors.</p>	Aligned to Widespread Innovation.
Low-carbon farming practices	Aligned to Headwinds.	Lower uptake: 50-75% for both behavioural and innovation measures.	High uptake of behavioural measures 60-80%; and lower uptake 50-75% for innovative measures.	High uptake of innovation measures 60-80%; and lower uptake 50-75% for behavioural measures.	Aligned to Widespread Innovation.
Agricultural machinery	Aligned to Headwinds.	Mix of electrification, hydrogen and later phase-out of biofuels.	Focus on electrification and biofuels.	Hydrogen, electrification and biofuels.	Aligned to Widespread Innovation.

c) The Balanced Net Zero Pathway for the land use sector

Land sector emissions were 12.8 MtCO₂e in 2018, equivalent to 2% of UK GHG emissions. The land-based measures in the Balanced Pathway could deliver annual savings (against a baseline) of 12 MtCO₂e in 2035, and 30 MtCO₂e by 2050, moving the sector to a net sink of 19 MtCO₂e by 2050 (Figure A.3.6.d). Further emissions reduction could be delivered in other sectors from the use of biomass material e.g. in displacing fossil fuels or when used with Carbon Capture and Storage (CCS). Key measures to achieve this are:

Planting 50,000 hectares a year would increase woodland cover from 13% to 18% of UK land area by 2050.

As well as carbon sequestration peatlands provide other vital services such as water regulation, flood protection and habitats for wildlife.

- **Afforestation.** Scaling up afforestation rates to 30,000 hectares a year by 2025 in line with the UK Government's commitment, rising to 50,000 hectares annually by 2035. This would increase woodland cover from 13% of UK land area to around 18% by 2050*, with a mix of tree types that focus on broadleaves. This could deliver annual savings of over 2 MtCO₂e in 2035 and 12 MtCO₂e in 2050. It is important that the right tree is planted in the right place. Decisions on tree planting should take account of biophysical suitability of different species, projected climate impacts and other constraints and uses of land.
- **Peatlands.** Full restoration of upland peat by 2045 (or stabilisation if degradation is too severe to restore) and re-wetting and sustainable management of 60% of lowland peat by 2050. These would deliver annual saving of nearly 6 MtCO₂e by 2035 and around 10 MtCO₂e by 2050.
- **Energy crops.** Planting perennial energy crops (e.g. miscanthus and short-rotation coppice) alongside short rotation forestry needs to accelerate quickly to at least 30,000 hectares a year by 2035, so that 700,000 hectares are planted by 2050. This could sequester 2 MtCO₂e by 2035 and over 6 MtCO₂e by 2050. When used with Carbon Capture and Storage (CCS) technologies this could displace a further 3 MtCO₂e of GHG emissions elsewhere in the economy by 2035, increasing to 10 MtCO₂e by 2050.
- **Other land measures.** Increasing on-farm diversification with the integration of trees on 10% of farmland and extending the length of hedgerows by 40% by 2050. Together with better woodland and hedge management, these could increase annual carbon removals by over 1 MtCO₂e by 2035 and by nearly 3 MtCO₂e in 2050.

Our analysis balances the need to reduce land-based emissions with other essential functions of land. The Balanced Pathway sets out a desirable and achievable level of ambition across all options. Together, our measures result in more land released out of agriculture than is required and choices will need to be made on how to use this land:

- The Balanced Pathway requires 9% of land to be released from agriculture for measures that reduce emissions and sequester carbon by 2035, rising to a fifth by 2050.† This rises to 11% and almost a quarter when taking account of land needed for settlement growth by 2035 and 2050 respectively.
- The measures we identify to release land result in around 2 million more hectares than is required by our scenarios by 2035.

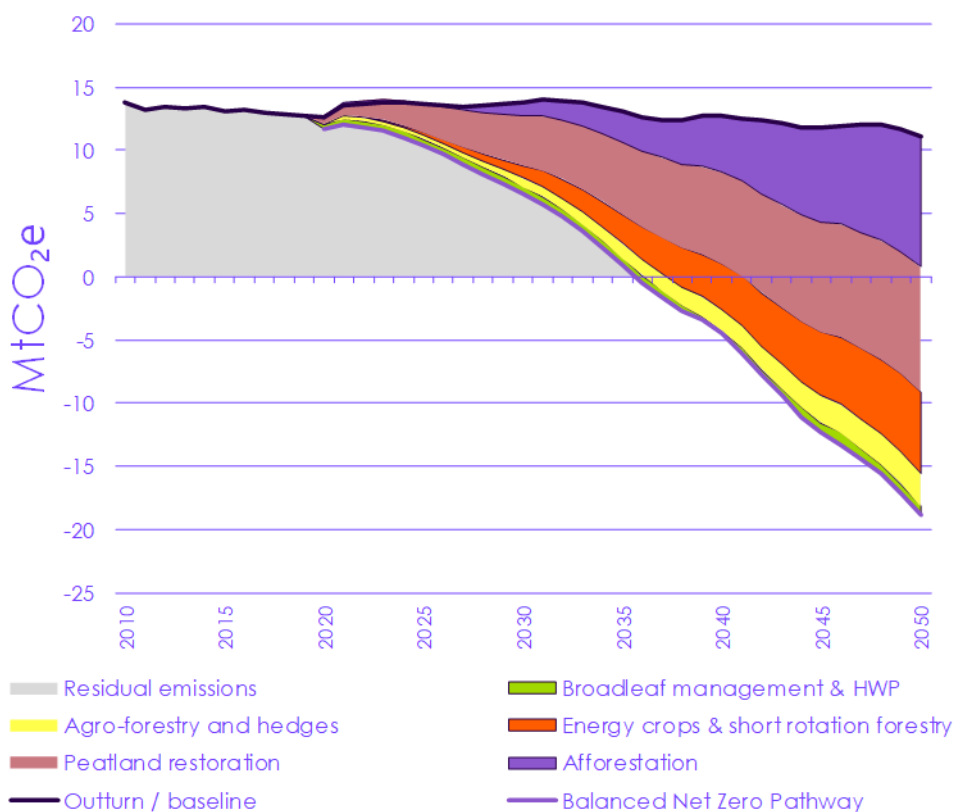
* Total woodland area increases to 18.6% if we include the 15% open ground area assumed in the afforestation target.

† A further 1% of non-agricultural land that is forested peat and peat extraction sites is also restored by 2035.

Natural regeneration and biodiverse habitat creation can be part of the picture, but work is needed to understand the carbon impacts.

- Choices on how this additional land could be used include less-intensive farming (e.g. agroecology farming), measures to deliver deeper emissions reduction (e.g. more tree planting) and conversion to other uses (e.g. wildflower meadows and natural regeneration) to deliver wider environmental benefits. The GHG impacts of these options are not included in our scenarios due to the lack of robust evidence on the abatement potential (see Chapter 7 of the Methodology Report).

Figure A.3.6.d Sources of abatement in the Balanced Net Zero Pathway for the LULUCF sector



Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; Centre for Ecology and Hydrology (2020); CCC analysis.

d) Alternative routes to reducing land use emissions

We explore different pathways for emissions by varying key factors such as roll-out rates of land-based measures, timings of behavioural measures and technological progress impacting productivity (Table A.3.6.b). These exploratory scenarios lead to both lower and higher ambition compared to the Balanced Pathway (Figure A.3.6.e):

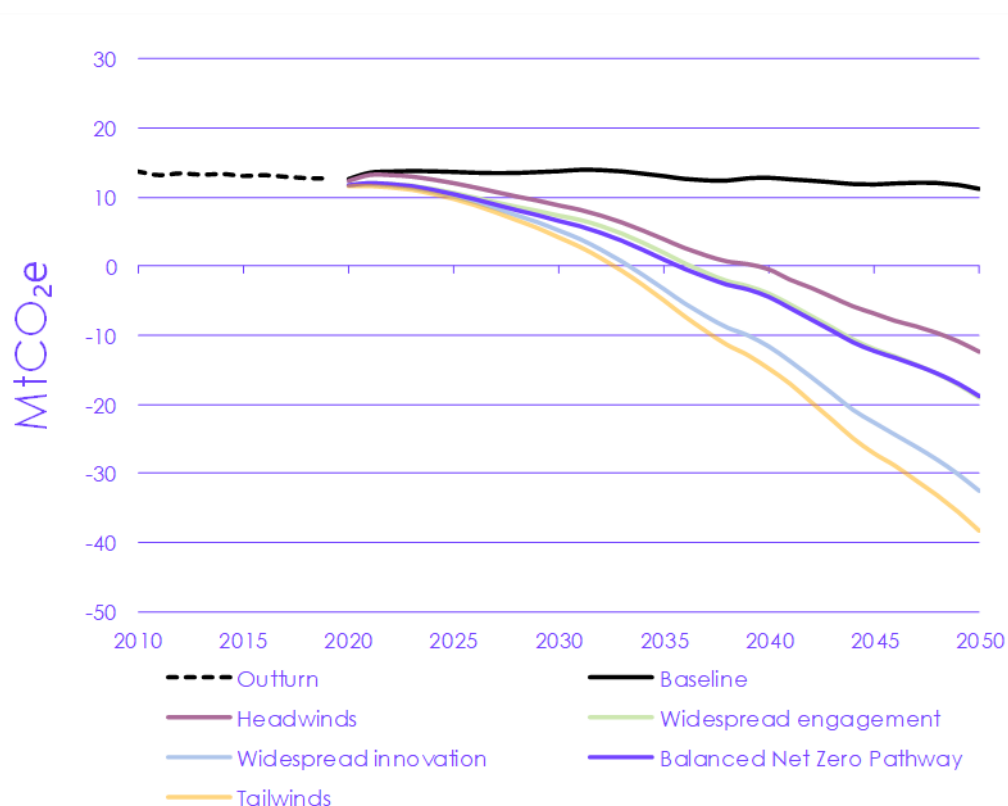
- The **Widespread Engagement** scenario assumes that higher ambition on diet change and food waste reduction can be achieved with greater societal engagement. This allows for a higher level of woodland creation of 70,000 hectares by 2035. In this scenario we also assume that tree planting is focused on more biodiverse woodlands (e.g. higher broadleaf mix) over productive forestry and planting of energy crops is reduced to a third.

There are choices in the type of woodland planted but these need to take account of local topography and other objectives for land.

This results in 1 MtCO₂e more GHG emissions in 2035 compared to the Balanced Pathway.

- The **Widespread Innovation** scenario is characterised by technological solutions, increasing yields of food crops, trees and energy crops and a doubling in the planting rate of energy crops. Compared with the Balanced Pathway, this results in 4 MtCO₂e additional emissions savings in 2035.
- The **Headwinds** scenario assumes less progress on behavioural change to release land and the same ambition on technological progress on yields and productivity measures. There is lower ambition on afforestation, with 30,000 hectares per year in the 2030s, and peatland, with 50% less lowland peat rewetted by 2035. This results in residual emissions that are 3 MtCO₂e higher in 2035.
- **Tailwinds** delivers faster progress on behaviour change, technological improvement and more ambition on converting agricultural land to the planting of all types of biomass. Emissions are 6 MtCO₂e lower by 2035 compared with the Balanced Pathway.

Figure A.3.6.e Emissions pathways for the LULUCF sector



Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; Centre for Ecology and Hydrology (2020); CCC analysis.

These scenarios draw out potential choices that society could make on how far to change current consumption patterns, the types of trees planted and use of innovation and technology:

If bioenergy with CCS is not needed it is better to plant trees than bioenergy crops.

- **Diet change.** A higher ambition on switching away from meat (e.g. 28% by 2035) would release around a fifth more land out of agricultural production than in the Balanced Pathway. This allows for increased afforestation, trees on-farm, and the planting of energy crops. The differing levels of ambition for each are explored in the Widespread Engagement and Widespread Innovation scenarios.
- **CCS.** The roll-out of CCS elsewhere in the economy could determine how land could be used. Bioenergy crops used with CCS deliver more GHG savings than standing forest alone (see Methodology report). If widespread CCS is needed more land will be required for energy crops (e.g. 60,000 hectares per year by 2035) with a focus on improving energy crop yields (Widespread Innovation). Where the ambition for CCS is low (the Widespread Engagement scenario), energy crop planting is just 10,000 hectares by 2035, with a greater emphasis on afforestation.
- **Afforestation** in the Widespread Engagement and Widespread Innovation scenarios achieves similar levels of annual sequestration by 2050 (around 15 MtCO₂e) but differences in afforestation rates and planting regimes drive different cumulative sequestration rates to 2050:
 - The Widespread Engagement scenario has the highest level of afforestation (70,000 hectares a year from 2035), and societal preference for more biodiverse woodlands results in lower planting density and a higher mix of broadleaves. This pathway sequesters 149 MtCO₂e cumulative GHGs by 2050. This rises to 155 MtCO₂e when including use of harvested material elsewhere in the economy.*
 - The Wider Innovation scenario is focused on delivering more productive forestry, resulting in higher planting density and a higher proportion of conifers with higher yields. These factors offset the lower planting rates (50,000 hectares a year from 2030), sequestering 178 MtCO₂e to 2050. This rises to 182 MtCO₂e when including emissions abated by using harvested material in other sectors.

* Based on the harvest material from the planting of new broadleaves only.

Table A.3.6.b

Summary of key differences in the LULUCF sector scenarios

	Balanced Net Zero Pathway	Widespread Engagement	Widespread Innovation	Tailwinds	Headwinds
Afforestation	30,000 hectares/year by 2025 then rising to 50,000 hectares by 2035.	70,000 hectares/year by 2035, low yields, greater mix towards broadleaf	50,000 hectares/year by 2030. High yields, high mix of conifers	70,000 hectares/year by 2035, high yields.	30,000 hectares/year by 2035.
Peatlands	Aligned to Widespread Engagement.	All upland peat restored by 2045. 40% lowland cropland rewetted & 35% sustainably managed.	All upland peat restored by 2045. 25% lowland cropland rewetted & 50% sustainably managed.	Aligned to Widespread Engagement.	All upland peat restored by 2050. 20% lowland cropland rewetted & 30% sustainably managed.
Energy crops	Aligned to Headwinds.	Low energy crop planting (0.23 million hectares by 2050) and yields.	High energy crop planting (1.4 million hectares by 2050) and yields.	Aligned to Widespread Innovation.	Medium energy crop planting (0.7 million hectares by 2050) and yields.

Notes: Land release measures are the same as in Table 3.6.a

e) Scenario impacts

In this section we set out estimates of the costs and benefits of delivering the Balanced Pathway in agriculture and land use. Our assessment is that private costs exceed private benefits by £1.7 billion in 2035. Wider societal benefits of £0.1 billion in 2035 could be delivered from improved air filtration, flood alleviation, health and recreation. There are likely to be further environmental benefits (e.g. biodiversity and water quality) but we have been unable to quantify these.

Costs and benefits

Our assessment of costs and benefits updates work we commissioned from Vivid Economics⁶ and SRUC. It covers all private costs and benefits and wider social benefits of increased recreation, improved air quality, improved health and flood alleviation. Wider environmental impacts on biodiversity and water quality are assessed qualitatively.

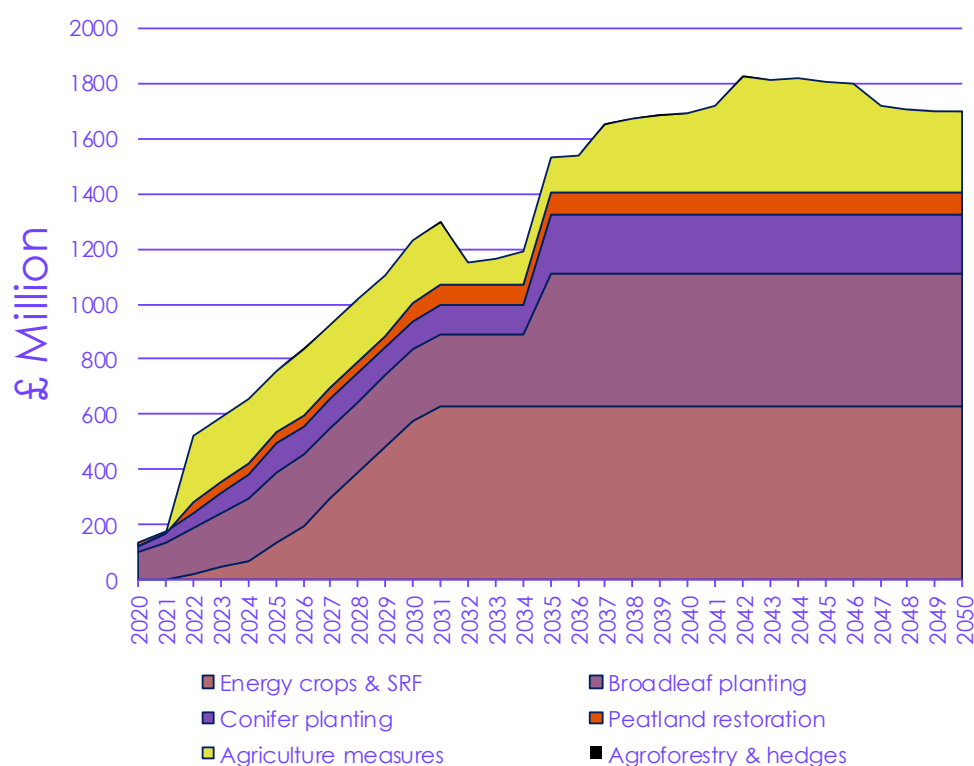
Delivering the Balanced Pathway will require significant up-front investment in trees, bioenergy crops, peatland restoration and peat management and for some agricultural measures such as AD plants, zero-carbon machinery and livestock breeding. Some of this will be offset by revenues from harvested materials. It will require a scaling up of supply chains and investment in training, skills and R&D to overcome non-financial barriers.

- The Balanced Pathway requires net investment of £1.5 billion in 2035, with £1.4 billion in the land sector and £0.1 billion for agricultural measures. Woodland creation and energy crops are the most significant (Figure A.3.6.f).

Significant investment and scaling up forestry and bioenergy sectors are needed to meet Net Zero.

- On-going operating costs are associated with managing woodlands and hedges, harvesting biomass from trees and energy crops, maintenance of peatlands and on-going costs for zero-carbon fuels and farming practices. These are estimated at £0.3 billion in 2035.
- These are partly offset by revenues from the sale of harvested products from energy crops, existing broadleaf woodlands and thinnings from the planting of new trees, estimated at £0.1 billion in 2035.
- Addressing non-financial barriers for many of these options include widespread information around new practices, re-skilling, and tenancy issues for tenant farmers. More innovative options (e.g. improved crop varieties and use of hydrogen) will require R&D and market commercialisation to bring these to market.

Figure A.3.6.f Net investment costs in the Balanced Net Zero Pathway



Source: CCC analysis.

Wider social and environmental impacts

Societal benefits take time to scale up but can deliver £0.6 billion by 2050 in benefits to people and the environment.

We estimate that the social benefits of land-based measures will contribute around £0.1 billion per year to the UK economy by 2035, rising to £0.6 billion per year by 2050 in the Balanced Pathway. The largest of these is recreation benefits from increased use of woodlands (74%), physical health benefits from exercising in the natural environments (14%), air filtration from increased natural vegetation, primarily trees near urban areas and flood risk alleviation from woodland creation in the upper catchments of rivers. There are also impacts on biodiversity and water quality which have not been possible to quantify. These are detailed in the Methodology Report.

Endnotes

- 1 CCC (2020) *Land Use – Policies for a Net Zero UK*; CCC (2019) *Net Zero – Technical Report*.
- 2 Centre for Ecology and Hydrology (2020) *Updated quantification of the impact of future land use scenarios to 2050 and beyond*.
- 3 Scottish Rural College (2020) *Non-CO₂ abatement in the UK agricultural sector by 2035 and 2050*.
- 4 Climate Assembly UK (2020) *The path to net zero*.
- 5 ADAS (2016) *Refining estimates of land for bioenergy*.
- 6 Vivid (2020) *Economic impacts of Net Zero land use scenarios*.

Policy recommendations for the agriculture and land use, land use change and forestry sectors

The following sections are taken directly from Chapter 7 of the CCC's Policy Report for the Sixth Carbon Budget.

Table 7.1 Summary of policy recommendations in agriculture and land use	
A strong post-CAP regulatory baseline	<p>Regulations are needed to cover low-cost, low-regret options, including standards for emission reduction through the use of existing legislation (e.g. the Nitrates Directive to extend the coverage of Nitrate Vulnerable Zones to all of the UK) and new legislation (e.g. the Clean Air Strategy) to reduce methane emissions. The extraction of peat and rotational burning as well as the sale of peat for use in the horticulture sector should end.</p>
Comprehensive delivery mechanisms for land-scape scale changes and low-carbon farming practices	<p>A comprehensive delivery mechanism to deliver land-scape scale changes is needed. This should include:</p> <ul style="list-style-type: none"> • An increase in afforestation rates to at least 30,000 hectares per year across the UK by 2025 (in line with the Government's commitment) and an average of 40,000 hectares per year in the 2030s. • Restore 60% upland peat (and where this is not possible, stabilise the peat) by 2035; and restore or stabilise the remaining the area by 2045. • Rewet 20% of lowland cropland area and sustainably manage a further 18% by 2035. • Plant trees on 10% of farmland while maintaining their primary use, extend hedgerows by 20% and better manage hedgerows by 2035. • Plant energy crops on 30,000 hectares per year across the UK by 2035. • High take-up of low-carbon agricultural measures covering livestock (diets, breeding and health), soils (cover crops and grass-legume mix) & waste management (anaerobic digestion and slurry covers). • Government should set out a clear path to incentivise the take-up of zero or near-zero emission options for agricultural machinery and to develop options where these are currently not available. <p>The strategy should cover mechanisms for private and public financing, such as a trading scheme or auctioned contracts. These measures will deliver a range of co-benefits including flood alleviation, improved health, recreation and improved air quality as well as biodiversity gains.</p>
Measures and funding to avoid a hiatus in delivery	<p>Delivery of measures needs to start immediately given time to scale up the sector. It is important that a hiatus in the take-up of measures required for delivering Net Zero is avoided during the transition to a post-CAP framework (e.g. the Environmental Land Management Scheme in 2024):</p> <ul style="list-style-type: none"> • On-going public funding should continue, and where necessary be increased. • Terms of funding available under existing programmes (e.g. Countryside Stewardship) should be amended to incorporate measures that directly reduce emissions.
Measures to address non-financial barriers to change	<p>Introduce measures to address non-financial barriers including:</p> <ul style="list-style-type: none"> • Knowledge exchange of low-carbon farming practices, contractual issues for tenant farmers, support upskilling and scale-up of supply chains. • Barriers to invest in R&D to improve productivity and resilience (e.g. crop and tree yields) and develop low-carbon machinery (e.g. tractors).
Policies to encourage a shift in diets and food waste reduction	<p>Implement policies to encourage consumers to shift towards healthier diets and reduce food waste, including:</p> <ul style="list-style-type: none"> • Low-cost, low-regret actions to encourage a 20% shift away from all meat by 2030 rising to 35% by 2050, and 20% shift from dairy products by 2030. An evidence-based strategy to establish options to successfully change behaviour and demonstrate public sector leadership. • Measures are needed to reduce food waste by 50% by 2030 and 60% by 2050 with the public sector taking a lead through measures such as target setting and effective product labelling.

Reducing emissions and increasing carbon sequestration in agriculture and land-use has been slow, with emissions broadly unchanged over the past decade.

There are some EU regulations and funding that impact Greenhouse Gas (GHG) emissions by incentivising actions on land use and management to deliver environmental benefits. However, there are no national or UK-wide policies that directly target the reduction of GHG emissions beyond voluntary action. Policies are also fully devolved.

Government is currently working on its Environmental Land Management (ELM) scheme, the key policy to pay farmers and land-owners in England for the delivery of environmental benefits, including climate mitigation and adaptation. Similar action is needed in the devolved administrations.

Our recommendations are based on an assessment of existing policies, stakeholder engagement, review of evidence and previously commissioned research which we set out in detail in our '*Land use: Policies for a Net Zero UK*' report earlier this year. We set out a comprehensive new approach which takes account of other strategic priorities for land such as food production and wider environmental objectives, which must be delivered alongside emissions reduction. We also set out new opportunities and revenue streams that reward farmers for measures to reduce emissions and sequester carbon and reflect the benefits this brings to society. Policy should also help deliver a fair transition which recognises the important role farmers play as stewards of the land.

This section covers:

1. Challenges in decarbonising agriculture and land use
2. Current Government policy commitments
3. Key changes needed

1. Challenges in decarbonising agriculture and land use

Meeting the ambition for emissions reductions set out in our Sixth Carbon Budget advice requires overcoming a range of financial, social and behavioural barriers across key sectors.

a) Low-carbon farming practices and agricultural machinery

Reducing emissions in agriculture to meet our Balanced Net Zero Pathway requires farmers to adopt a range of farming practices and technological options to reduce non-CO₂ emissions, and to switch away from fossil fuel use in agricultural machinery to low-carbon alternatives. The main challenges include:

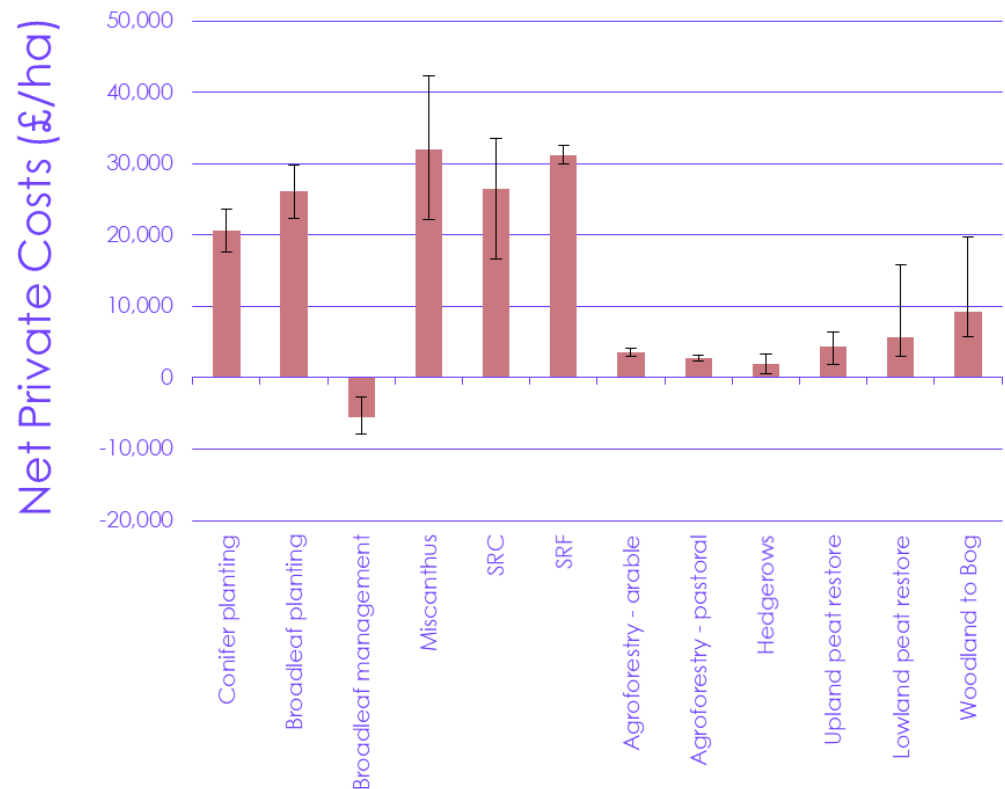
- Some of the measures we identify are cost-saving to farmers (e.g. cover crops and cattle health), while others have high up-front costs (e.g. anaerobic digestion and low-carbon machinery). Lack of financial support to target emissions reduction on-farm has led to limited take-up of these measures. Public subsidy payments under the Common Agricultural Policy (CAP) have been largely based on the area of land farmed rather than the delivery of environmental goods.
- For those options that represent technological solutions (e.g. livestock breeding measures) there is often a disconnect in translating R&D into market commercialisation that would allow for wide-scale adoption. Use of biofuels is the only low-carbon option currently available for agricultural vehicles with electrification of large machinery (e.g. tractors) still at the proto-type stage.
- Action may be constrained by a lack of knowledge, experience and skills in applying farming techniques and practices. The ageing profile of farmers and the lack of new entrants with the right skills and training may make it more difficult to transition to low-carbon farming.

b) Land-based measures

The measures aimed at reducing land-based emissions in our Balanced Pathway (e.g. afforestation, peatland restoration, bioenergy crops, agroforestry and hedges) are largely not cost-effective from the perspective of farmers or land-managers. Private costs tend to be higher than private benefits and/or have high-up front costs which will need to be funded (Figure P.7.1).

Measures aimed at increasing sequestration and reducing emissions in land use need to be funded as private costs exceed private revenues.

Figure P.7.1 Lifetime net private costs of land-based measures



Source: CCC Analysis based on CEH (2020) and Vivid Economics (2020) *Economic Impacts of Net Zero land use scenarios*.
Notes: Error bars show range of upper bound and lower bound costs estimated in the above report.

Non-financial barriers that need to be addressed include:

- **Application process.** Applying for funding from existing schemes can be time-consuming. Despite the availability of grant funding for woodland creation and broadleaf management, take-up has been modest reflecting an overly burdensome application process. The lack of local markets for the sale of the harvested material has also hindered the management of broadleaf woodlands.
- **High up-front costs and price uncertainty.** Measures such as afforestation, peatland restoration and growing bioenergy crops have high upfront costs and long lead in times for revenues, which may need to be bridged through loans or other finance mechanisms. Price uncertainty in existing schemes e.g. the Woodland Carbon Guarantee auctions may be a barrier to widespread adoption.
- **Contractual issues.** Issues around tenancy and common land could be acting as a barrier to action.
 - Around 28% of the land area in England, 22% in Wales, and 24% in Scotland is tenanted. The length (an average of 2.9 years in England and Wales in 2018) and the terms of the tenancy contract may prohibit switching land to alternative uses. Resolving tenancy constraints (e.g. lease renewal arrangements and aligning incentives between landowners and tenants) is important to allow and encourage tenanted farmers to undertake long-term investment decisions.

Awareness raising, information provision and demonstration trials are needed to break down cultural barriers to change.

Bringing innovation on-farm is essential to improving productivity and competitiveness of UK farming.

- Common land, which is mainly used for grazing, has special status under law. Under this type of tenure, the commoners rather than the landowner control the use and management of land, which could prohibit a willing landowner from making sustainable changes.
- **Lack of awareness.** Lack of information on the range of low-carbon options available to farmers, cultural resistance and risk aversion can act as a barrier to change. Sustainable farming is knowledge-intensive and in order to make the right decision, farmers need trusted advisors and networks (e.g. agricultural colleges and universities) to make informed choices and demonstration projects e.g. for bioenergy and agroforestry to illustrate benefits.
- **Bringing R&D on-farm.** Many low-carbon measures in our scenarios are innovative and will need commercialisation to bring to market (e.g. higher crop yields and breeding of lower-methane emitting livestock). Ensuring widespread deployment of innovative options across a diverse range of farms in the UK will require overcoming existing barriers such as awareness and uncertainty over outcomes.

c) Consumer behaviour change

Meeting emissions reduction in the Balanced Pathway also requires consumers to overcome barriers to shifting towards healthier diets and reduce food waste.

- **Lack of understanding and awareness** on the climate impact of diets may impede change, and where these are known, people may not have the skills to cook plant-based recipes. This extends to both householders and those employed in the catering industry (e.g. kitchen staff in canteens).
- **Common metrics and standards** to measure the carbon footprint of food products are needed to enable consumers to make informed decisions on their purchases. This is crucial if food labelling is to be widely introduced in the retail sector.
- **Date labelling and guidance** on cooking, planning and storing food could help reduce consumer waste. Challenging existing consumer preferences and supermarket standards on the appearance of fruit and vegetables could reduce pre-farm waste.

2. Current Government policy commitments

Land use in the UK has been highly influenced by a complex set of sub-national, national, EU and international policies. These have, to date, rewarded food production over other services that land can provide including climate change mitigation and adaptation and wider environmental benefits.

There are no national or UK-wide policies that directly target the reduction of greenhouse gas (GHG) emissions in the agriculture sector. EU regulations, a voluntary approach to reducing on-farm emissions, and grant funding are key existing mechanisms:

- EU environment legislation to address non-GHG pollutants has indirectly reduced agriculture GHGs through changes in farming practices. For example, the Nitrates Directive restricts fertiliser use in Nitrate Vulnerable Zones (NVZs) and under the Water Framework Directive, farmers are required to meet basic standards to reduce diffuse water pollution.
- Under Pillar II of the CAP, England's £3 billion Rural Development Programme (RDP) was available for environmentally friendly practices, woodland creation and the restoration of priority habitats (e.g. including peatland) for the 2014-2020 period. Similar RDP schemes exist in Scotland, Wales and Northern Ireland. The last round of agreements signed before the end of 2020 will continue as RDP schemes despite the UK exit from the EU.
- The provision of information and advice to farmers is the main mechanism to incentivise emissions reductions in agriculture. These voluntary approaches include the industry-led Greenhouse Gas Action Plan in England and the Farming for a Better Climate initiative in Scotland.
- England's Woodland Carbon Fund launched in 2016 is providing £19 million for woodland planting and on-going maintenance. A £10 million Peatland Grant is funding the restoration of around 6,000 hectares of lowland and upland peat in England. The Peatland ACTION project funded by the Scottish Government has awarded £8 million to restoration projects since 2012.

Provision of information and advice to farmers is the only policy directly targeted at reducing agricultural emissions.

More recent announcements have looked to increase commitments in some areas. However, the planned publications to increase afforestation and peat restoration (the Tree and Peatland Strategies) have both been delayed, while design of the ELM scheme is still on-going:

- The passage of the Agriculture Bill into law allows for the replacement of the CAP with a new domestic policy, including subsidy support for farmers. The ELM scheme will be the key mechanism to pay farmers and land-owners for the delivery of environmental benefits in England, including climate mitigation and adaptation. Defra has set out initial proposals on the high-level design of the ELM scheme and a national pilot will be rolled-out in 2021. Action in the devolved administrations includes:
 - Wales are considering responses to its consultation to replace CAP with a similar type of payment scheme for delivering environmental benefits ('Sustainable Farming Payment'). A second mechanism is being developed to help farm businesses (Business Support Payment).

New post-CAP frameworks for paying farmers are being developed by each devolved administration.

- Scotland has yet to set out the future direction of its rural support policy.
- Northern Ireland is expected to launch its Future Agricultural Policy Framework in 2021. Increased productivity, environmental sustainability, improved resilience and an integrated effective and efficient supply chain are to be the four main pillars of the framework.

- Some of the £640 million Nature for Climate Fund announced in the 2020 budget will be used to deliver the Government's manifesto commitment to plant 30,000 hectares per year of new woodland by 2025 across the UK and to restore 35,000 hectares of peatland in England over the next five years. This will be delivered in part through the creation of ten Landscape Recovery projects, which aim to establish 30,000 football pitches (~22,000 hectares) of wildlife rich habitat in England over the next four years.
- The first and second reverse auction of Defra's Woodland Carbon Guarantee were held earlier this year. Designed to stimulate private sector investment in woodland creation in England, the two auctions generated 108 bids, of which 45 were successful, covering 1,700 hectares. Auctions will be held each year between 2020 and 2025 with £50m committed to the scheme.
- The Scottish Government has committed to funding the restoration of 250,000 hectares of peat by 2030 with funding of £100 million to Scottish Forestry as well as £30 million to Forestry and Land Scotland to expand Scotland's national forests by 18,000 hectares per year until 2024.
- In Northern Ireland, the administration will start a pilot payment for the growing of protein crops (peas, beans and sweet lupins) to demonstrate schemes that can increase farm profitability and sustainability.

Early auctions for woodland creation were successful but small scale.

The existing policy framework and recent announcement are insufficient to meet the emissions reduction set out in our Sixth Carbon Budget advice. A new set of policies is urgently required to deliver this on the path to Net Zero.

3. Key changes needed

Measures to reduce emissions should also be designed to deliver wider environmental objectives e.g. climate adaptation and biodiversity.

In our report '*Land use: Policies for a Net Zero UK*' earlier this year we set out a comprehensive framework to deliver deep emissions reduction in agriculture and land. These should be designed to deliver other environmental objectives as set out in the Environment Bill, including climate change adaptation and biodiversity, where synergies exist. Key elements of our framework, including paying farmers to store and sequester carbon, information and skills training and low-carbon farming regulations were endorsed by the UK citizens' assembly on climate change.

The recommendations in our report remain valid and cover a mix of regulations and incentives for land managers to overcome financial and non-financial barriers to change and policy levers to shift consumer behaviour:

- **Strengthening the regulatory baseline to ensure low-regret measures are taken up.**
 - Extend existing regulation to reduce on-farm emissions (e.g. Nitrogen Vulnerable Zones) and use new legislation to regulate additional sources of emissions not currently regulated such as enteric fermentation from livestock (e.g. the Clean Air Strategy could require feed additives that reduce methane emissions from livestock).
 - Ban damaging practices such as rotational burning on peatland and peat extraction and end the sale of peat for horticultural use.
 - Set an obligation for water companies to restore peatland on land they own, and on owners of peatland within a site of special scientific interest (SSSI).
- **Funding for actions above the baseline to support more costly measures.**
 - The key mechanism for afforestation and some agroforestry schemes should be auctioned contracts (e.g. similar to those offered for renewable electricity) or a carbon trading scheme. These need to be carefully designed to avoid potential negative impacts and ensure carbon credits from land-based solutions are not available to offset emissions reductions that are needed to meet Net Zero in other parts of the economy.
 - Public funding should be used to encourage the non-carbon benefits of afforestation (e.g. alleviating flood risk, recreation); planting trees on farms where it would not occur through the main mechanism above; the take-up of low-carbon farming practices (e.g. robotic milking parlours and cattle breeding) that go beyond the requirements of new regulatory baseline and where they impose costs to farmers.
 - Peatland restoration should also receive public funding, alongside sustainable management practices on lowland peat that remains in agricultural production. In the longer term, this could move to a trading or auctioning system, once emissions reductions can be verified effectively.
 - Bioenergy crops should be supported through existing instruments in the short term.

Auctioned contracts or a carbon trading scheme are needed for afforestation and could be privately funded.

- Government should set out a clear path to incentivise the take-up of zero or near-zero emission options for agricultural machinery and to develop options where these are currently not available. We recommend that, failing its inclusion in either the Industrial Decarbonisation Strategy, Heat and Buildings Strategy or Transport Decarbonisation Strategy, it should be covered by the Net Zero Strategy.

- **Enabling measures to address non-financial barriers**

- Support schemes to strengthen skills, training and market commercialisation of innovative low-carbon farming options (e.g. livestock breeding and diets). Raise awareness and provide training in energy crop and peatland management.
- Additional measures to support the UK bioenergy market e.g. agreements to source a minimum proportion of biomass feedstock from the UK and concessionary finance for growing energy crops.
- Address contractual arrangements that may constrain uptake amongst farms that are tenanted or designated as common land.
- The tax treatment of woodlands should be reviewed and, if necessary, amended to ensure there is no disadvantage to farmers from changing their use of land to forestry.

- **Policies are needed to encourage consumers to shift diets and reduce food waste.**

- **Diets:** Government should implement low-cost, low-regret actions to encourage a shift away from meat and dairy (e.g. the public sector taking a lead in providing plant-based options with all meals). An evidence-based strategy is required to establish which measures will successfully change behaviour, encompassing information provision, skills support, and encouraging greater accountability of business through clear and robust metrics and mandatory reporting. These were also highlighted by the UK citizens' assembly on climate change. If these measures are not enough to change consumption patterns, a second stage will need to look at stronger options, whether regulatory or pricing.
- **Food waste:** Implement steps to reduce food waste from the farm to the householder. This should include immediate low-cost measures (e.g. target setting in the public and private sectors); measures to 'nudge' consumers towards best practice and mandatory separate food waste collection.

- **A strong monitoring, reporting and verification system (MRV)** is needed to create a robust framework to monitor and pay for actions across the UK.

- **Interim policies to avoid a hiatus in action.** Early action is essential to enable the transition to lower carbon uses of land given the time required for some measures to deliver emissions reduction and removals. Interim policies should be implemented to avoid a hiatus in action while awaiting the implementation of the new framework (e.g. the roll-out of the ELM scheme starts in 2024):

An effective strategy to tackle awareness of the climate impacts of what we eat is an essential part of our pathway.

Interim policies and funding should be implemented to avoid a hiatus in action.

- On-going public funding should continue, and where necessary be increased. This includes Treasury matching the level of funding that had been previously been allocated under CAP's Pillar II. As of 2021, all agreements signed for the Countryside Stewardship scheme will be funded by the Treasury under domestic legislation.
- In addition, the terms of funding available under existing programmes (e.g. Countryside Stewardship) should be amended to incorporate measures that directly reduce emissions.



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